MILITARY MEDICAL MANUALS

GENERAL EDITOR:
RGEON-GEN. SIR ALFRED KEOGH
G.C.B., M.D., F.R.C.P.



# LOCALISATION & EXTRACTION OF PROJECTILES

OMBRÉDANNE & LEDOUX-LEBARD

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WITH A PREFACE ON

## EXTRACTION OF PROJECTILES IN THE GLOBE OF THE EYE

BY

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Ophthalmic Surgeon Middlesex Hospital

WITH 225 FIGURES IN THE TEXT AND 8 PLATES



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# GENERAL INTRODUCTION

THE infinite variety of injuries which any war presents to the surgeon gives to military surgery a special interest and importance. The special interest and importance, in a surgical sense, of the great European War lies not so much in the fact that examples of every form of gross lesion of organs and limbs have been seen, for if we read the older writers we find little in the moderns that is new in this respect, but is to be found in the enormous mass of clinical material which has been presented to us and in the production of evidence sufficient to eliminate sources of error in determining important conclusions. For the first time also in any campaign the labours of the surgeon and the physician have had the aid of the bacteriologist, the pathologist, the physiologist, and indeed of every form of scientific assistance, in the solution of their respective problems. The clinician entered upon the great war armed with all the resources which the advances of fifty years had made available. If the surgical problems of modern war can be said not to differ sensibly from the campaigns of the past, the form in which they have been presented is certainly as different as are the methods of their solution. The achievements in the field of discovery of the chemist, the physicist, and the biologist have given the military surgeon an advantage in diagnosis and treatment which was denied to his predecessors, and we are able to measure the effects of these advantages when we come to appraise the results which have been attained.

But although we may admit the general truth of these statements, it would be wrong to assume that modern scientific knowledge was, on the outbreak of the war, immediately useful to those to whom the wounded were to be confided. Fixed principles existed in all the sciences auxiliary to the work of the surgeon, but our scientific resources were not immediately available at the outset of the great campaign; scientific work bearing on wound problems had not been arranged in a manner adapted to the requirements—indeed, the requirements were not fully foreseen; the workers in the various fields were isolated, or isolated themselves, pursuing new researches rather than concentrating their powerful forces upon the one great quest.

However brilliant the triumphs of surgery may be—and that they have been of surpassing splendour no one will be found to deny—experiences of the war have already produced a mass of facts sufficient to suggest the complete remodelling of our methods of education and research.

The series of manuals, which it is my pleasant duty to introduce to English readers, consists of translations of the principal volumes of the "Horizon" Collection, which has been appropriately named after the uniform of the French soldier.

The authors, who are all well-known specialists in the subjects which they represent, have given a concise but eminently readable account of the recent acquisitions to the medicine and surgery of war which had hitherto been disseminated in periodical literature.

No higher praise can be given to the Editors than to say that the clearness of exposition characteristic of the French original has not been lost in the rendering into English.

## MEDICAL SERIES

The medical volumes which have been translated for this series may be divided into two main groups, the first dealing with certain epidemic diseases, including syphilis, which are most liable to attack soldiers, and the second with various aspects of the neurology of war. The last word on *Typhoid Fever*, hitherto "the greatest scourge of armies in time of war," as it has been truly called, will be found in the monograph by MM. Vincent and Muratet, which contains a full account of recent progress in bacteriology and epidemiology as well as the clinical features of typhoid and paratyphoid fevers. The writers combat a belief in the comparatively harmless nature of paratyphoid and state that in the present war hæmorrhage and perforation have been as frequent in paratyphoid, as in typhoid fever. In their chapter on diagnosis they show that the serum test is of no value in the case of those who have undergone anti-typhoid or anti-paratyphoid vaccination, and that precise information can be gained by blood cultures only. The relative advantages of a restricted and liberal diet are discussed in the chapter on treatment, which also contains a description of serum-therapy and vaccine-therapy and the general management of the patient.

Considerable space is devoted to the important question of the carrier of infection. A special chapter is devoted to the prophylaxis of typhoid fever in the army. The work concludes with a chapter on preventive inoculation, in which its value is conclusively proved by the statistics of all countries in which it has been employed.

MM. Vincent and Muratet have also contributed to the series a work on *Dysentery, Cholera, and Typhus* which will be of special interest to those whose duties take them to the Eastern Mediterranean or Mesopotamia. The carrier problem in relation to dysentery and cholera is fully discussed, and special stress is laid on the epidemiological importance of mild or abortive cases of these two diseases.

In their monograph on *The Abnormal Forms of Tetanus*, MM. Courtois-Suffit and Giroux treat of those varieties of the disease in which the spasm is confined to a limited group of muscles, *e.g.* those of the head, or one or more limbs, or of the abdomino-thoracic muscles. The constitutional symptoms are less severe than in the generalised form of the disease, and the prognosis is more favourable.

The volume by Dr. G. Thibierge on *Syphilis and the Army* is intended as a *vade mecum* for medical officers in the army.

Turning now to the works of neurological interest, we have two volumes dealing with lesions of the peripheral nerves by Mme. Athanassio-Benisty, who has been for several years assistant to Professor Pierre Marie at La Salpêtrière. The first volume contains an account of the anatomy and physiology of the peripheral nerves, together with the symptomatology of their lesions. The second volume is devoted to the prognosis and treatment of nerve lesions.

The monograph of MM. Babinski and Froment on *Hysteria or Pithiatism and Nervous Disorders of a Reflex Character* next claims attention. In the first part the old conception of hysteria, especially as it was built up by Charcot, is set forth, and is followed by a description of the modern conception of hysteria due to Babinski, who has suggested the substitution of the term "Pithiatism," *i.e.* a state curable by persuasion, for the old name hysteria. The second part deals with nervous disorders of a reflex character, consisting of contractures or paralysis following traumatism, which are frequently found in the neurology of war, and a variety of minor symptoms, such as muscular atrophy, exaggeration of the tendon reflexes, vasomotor, thermal and secretory changes, etc. An important section discusses the future of such men, especially as regards their disposal by medical boards.

An instructive companion volume to the above is to be found in the monograph of MM. Roussy and Lhermitte, which embodies a description of the psychoneuroses met with in war, starting with elementary motor disorders and concluding with the most complex represented by pure psychoses.

## SURGICAL SERIES

When the present war began, surgeons, under the influence of the immortal work of Lister, had for more than a quarter of a century concerned themselves almost exclusively with elaborations of technique designed to shorten the time occupied in or to improve the results obtained by the many complex operations that the genius of Lister had rendered possible. The good behaviour of the wound was taken for granted whenever it was made, as it nearly always was, through unbroken skin, and hence the study of the treatment of wounds had become largely restricted to the study of the aseptic variety. Septic wounds were rarely seen, and antiseptic surgery had been almost forgotten. Very few of those who were called upon to treat the wounded in the early autumn of 1914 were familiar with the treatment of grossly septic compound fractures and wounded joints, and none had any wide experience. To these men the conditions of the wounds came as a sinister and disheartening revelation. They were suddenly confronted with a state of affairs, as far as the physical conditions in the wounds were concerned, for which it was necessary to go back a hundred years or more to find a parallel.

Hence the early period of the war was one of earnest search after the correct principles that should be applied to the removal of the unusual difficulties with which surgeons and physicians were faced. It was necessary to discover where and why the treatment that sufficed for affections among the civil population failed when it was applied to military casualties, and then to originate adequate measures for the relief of the latter. For many reasons this was a slow and laborious process, in spite of the multitude of workers and the wealth of scientific resources at their disposal. The ruthlessness of war must necessarily hamper the work of the medical scientist in almost every direction except in that of providing him with an abundance of material upon which to work. It limits the opportunity for deliberate critical observation and comparison that is so essential to the formation of an accurate estimation of values ; it often compels work to be done under such high pressure and such unfavourable conditions that it becomes of little value for educative purposes. In all the armies, and on all the fronts, the pressure caused by the unprecedented number of casualties has necessitated rapid evacuation from the front along lines of communication, often of enormous length, and this means the transfer of cases through many hands, with its consequent division of responsibility, loss of continuity of treatment, and absence of prolonged observation by any one individual.

In addition to all this, it must be remembered that in this war the early conditions at the front were so uncertain that it was impossible to establish there the completely equipped scientific institutions for the treatment of the wounded that are now available under more assured circumstances, and that progress was thereby much hampered until definitive treatment could be undertaken at the early stage that is now possible.

But order has been steadily evolved out of chaos, and many things are now being done at the front that would have been deemed impossible not many months ago. As general principles of treatment are established it is found practicable to give effect to them to their full logical extent, and though there are still many obscure points to be elucidated and many methods in use that still call for improvements, it is now safe to say that the position of the art of military medicine and surgery stands upon a sound foundation, and that its future may be regarded with confidence and sanguine expectation.

The views of great authorities who derive their knowledge from extensive first-hand practical experience gained in the field cannot fail to serve as a most valuable asset to the less experienced, and must do much to enable them to derive the utmost value from the experience which will, in time, be theirs. The series covers the whole field of war surgery and medicine, and its predominating note is the exhaustive, practical, and up-to-date manner in which it is handled. It is marked throughout not only by a wealth of detail, but by clearness of view and logical sequence of thought. Its study will convince the reader that, great as have been the advances in all departments in the services during this war, the progress made in the medical branch may fairly challenge comparison with that in any other, and that not the least among the services rendered by our great ally, France, to the common cause is this brilliant contribution to our professional knowledge.

A glance at the list of surgical works in the series will show how completely the ground has been covered. Appropriately enough, the series opens with the volume on *The Treatment of Infected Wounds*, by A. Carrel and G. Dehelly. This is a direct product of the war which, in the opinion of many, bids fair to become epoch-making in the treatment of septic wounds. It is peculiar to the war and derived directly from it, and the work upon which it is based is as fine an example of correlated work on the part of the chemist, the bacteriologist, and the clinician as could well be wished for. This volume will show many for the first time what a precise and scientific method the "Carrel treatment" really is.

The two volumes by Professor Leriche on *Fractures* contain the practical application of the views of the great Lyons school of surgeons with regard to the treatment of injuries of bones and joints. Supported as they are by an appeal to an abundant clinical experience, they cannot fail to interest English surgeons, and to prove of the greatest value. It is only necessary to say that *Wounds of the Abdomen* are dealt with by Dr. Abadie, *Wounds of the Vessels* by Professor Sencert, *Wounds of the Skull and Brain* by MM. Chatelin and De Martel, and *Localisation and Extraction of Projectiles* by Professor Ombrédanne and R. Ledoux-Lebard, to prove that the subjects have been allotted to very able and experienced exponents.

ALFRED KEOGH.

# PREFACE

Although written mainly for those who have had little or no experience of X-ray work this book can be read with great advantage by those who have made a special study of the subject. In the Introduction the scope of the work is clearly set forth, and the practical experience of the authors during the war both at the front and at the base enable them to discuss the special problems involved with great authority.

It deals thoroughly with the theory and practice of the different methods of localisation both from the radioscopic and radiographic standpoint, and discusses their comparative utility. Distinction is drawn between the so-called (1) haphazard methods, (2) methods of precision (use of compasses, etc., which have been very sparingly used in this country), and (3) methods of certainty (which include the procedure that the authors have perfected, namely the aid of intermittent control of the screen after a preliminary localisation).

This latter procedure is described at length and in the authors' experience has proved to be extremely successful. It solves the problem which has militated against the use of the screen for extractions—namely the difficulty which is experienced by a surgeon in keeping his eyes sufficiently receptive to be able to see the image on the screen while the lighting arrangements are sufficiently good for the operation. By their method the whole of the observation is done by the radiologist, who wears an eclipse fluoroscope which keeps his eyes receptive during the whole operation, which can then be carried out with full illumination of the theatre, the surgeon never coming into contact with the rays at all. Whenever requested by the surgeon he gives him the point on the skin or in the wound through which the path of the normal ray passes through the projectile.

It involves, of course, close collaboration between the surgeon and the radiologist always and compels the presence of both at every operation. This is an ideal method where time is of no particular moment, but it is not feasible when a large number of casualties have to be dealt with rapidly, as for example at the Casualty Clearing Stations where five or six surgeons may be operating at the same time and there is only one X-ray outfit.

Of its successful application in expert hands, the figures of results quoted give the proof. In a series of 1,300 cases, only 3 were unsuccessfully operated upon.

The description makes the process appear fascinatingly simple, so much so that there is a risk that non-experts might be tempted after reading it to undertake extractions which would be unjustifiable or at least better left alone.

The well-known hypersensibility of those who have suffered from X-ray dermatitis to even a small amount of irradiation should certainly preclude their adopting this procedure.

The authors have not apparently had any casualties as regards burning of patients, but this contingency is certainly possible in the hands of non-experts.

The procedure adopted in the British Army is localisation by triangulation methods, the depth of projectile being determined and the exit of normal ray marked on skin.

The patient is replaced before operation in the position in which the X-ray examination was made. Stereoscopic plates are generally taken as well. This method gives very satisfactory results. Screen extraction is only resorted to in special cases.

The authors are to be congratulated on having produced this opportune work, the compilation of which in these times of stress reflects great credit on them for its carefully-thought-out reasoning and its valuable attention to detail.

It can be heartily recommended to the attention of all surgeons and radiologists.

ARCHIBALD D. REID.

# SECOND PREFACE: ON LOCALISATION AND EXTRACTION OF FOREIGN BODIES IN THE EYE

HAVING been asked by the Editor to write a short prefatory note on the localisation and removal of foreign bodies in the eye, the following summary is given of our experience on this subject during the war.

## LOCALISATION OF FOREIGN BODIES IN THE EYE

In dealing with penetrating injuries of the eye in war time, when time and numbers have to be taken into account, localisation of foreign bodies in the globe has, in the majority of cases, become of secondary importance to the early application of the big magnet.

For by far the greater number of penetrating particles are very minute, and these, as mentioned below, should be removed through the anterior chamber, and the sooner the better. To localise before the application of the magnet is only a waste of time and material. If we obtain a positive result, no localisation is required, and the eye has had the important advantage of having the foreign body removed at the earliest possible date.

When however we suspect from the size of the opening that the foreign body is dangerously large for removal through the anterior chamber, or in the case of a small foreign body the magnet has failed, an accurate localisation is of great importance to inform us whether the fragment is in the eye, and if so its exact location, or in the coats of the eye, or in the orbital tissues, and thus guide our future action.

If it be in the orbital tissues, an operation is rarely necessary, unless orbital cellulitis supervenes. More harm results from hunting for an aseptic foreign body in the orbit than in leaving it alone, if there are no special indications for its removal, such as its large size or its pressure on the globe or optic nerve.

If it be in the eye, an accurate localisation is a material aid should it be thought desirable to attempt removal with forceps through an incision in the sclera; while if it be in the coats of the eye and of a size to make it advisable to try to extract it, the sector to be explored will be indicated.

The stereoscopic method devised by Sir James MacKenzie Davidson, using either his special head support for a sitting patient, or Major Higham Cooper's head rest for a patient in the recumbent posture, gives us accurate information, and it may be stated that nothing but an exact localisation is of any real value.

The most likely cause of error is the faulty ocular fixation of the patient, and it is hoped that some method may be devised for an objective confirmation that the patient is keeping his eye riveted on the fixation point during the exposure of the two plates.

The method of Dr. Cleveland published in *The Archives of the Röntgen Ray*, January 1915, and applied to ophthalmic work by Capt. M. H. Watney, R.A.M.C., by which the position of the foreign body in relation to the centre of the cornea is determined by a carefully made diagram, does away with the necessity for special apparatus, also the difficulty of measuring the exact spot at which the threads cross, and is preferred by many.

Sweet's larger localiser is spoken highly of by some, but we have had no experience of it.

Capt. Herbert Fisher has drawn attention in his paper in *The Ophthalmic Review*, to a common inaccuracy in plotting out the position of the foreign body on the usual frontal and lateral diagrams of the eye.

The distance of the foreign body must first be measured in the frontal diagram, from the central corneal axis in a plane tangential to the centre of the anterior surface of the cornea, and from this point its depth must be plotted out in the lateral diagram placed in the plane, passing through the central corneal axis and the foreign body. It is only when the diagram is placed in this plane that it gives an approximately true indication as to the relative position of the foreign body to the eyeball. (We have no knowledge in any given case how accurate this indication is, as we cannot tell how closely the shape of the eye in question corresponds with the diagram.) The distance of the foreign body from the central corneal axis can be found by taking the square root of the sum of the squares of the respective distances of the foreign body from the vertical and horizontal axes of the eye, or more readily by reading off the distance, on one of the charts I have recently devised (War Office pattern).

### Removal of Foreign Bodies from the Eye

The removal of foreign bodies from the eye is one of the most dramatic and fascinating branches of Ophthalmic Surgery, and has been practically revolutionised since the introduction of the giant magnets.

The bulk of penetrating particles are deeply situated and out of sight, and unless they are magnetic they can seldom be removed leaving a useful organ; blindly groping is seldom successful, and it is therefore generally wiser to leave the non-magnetic invisible foreign bodies alone.

If the foreign body is visible in the anterior chamber it can be removed with forceps if it be non-magnetic, or with a small magnet if it be magnetic. In the cases in which the foreign body is near the angle of the anterior chamber a peripheral incision with a Graefe's knife is preferable to one with a keratome, as the posterior lip of the keratome incision is liable to prevent the operator from getting hold of the fragment.

When removing magnetic foreign bodies from the vitreous chamber we can choose one of two routes. (1) We may draw the foreign body into the anterior chamber by the big magnet, and subsequently remove it with the small magnet through an incision in the cornea; or (2) we may make a fresh incision through the sclera opposite the foreign body, or use the original opening if it is in the sclera, and remove the fragment by applying the large magnet to the lips of the incision or introducing the end of the large or small magnet into the eye. If a fresh incision be made, it is obvious that a preliminary localisation is advisable.

When a large foreign body has been proved to be present by X-rays, and shown to be magnetic by the eliciting of pain on applying the large magnet to the outside of the eye opposite the site of the fragment, the scleral route is probably the safest, for additional serious damage may be done by dragging a large piece of metal through the anterior chamber.

But in war practice, where some 50 per cent. of the foreign bodies in the globe are non-magnetic, it would be unjustifiable to incise every eye before applying the magnet as has been suggested by some, for in 50 per cent. a useless and dangerous incision would have been made.

Indeed, there is a great deal to be said for making an incision through an avascular structure such as the cornea rather than through the sclerotic and vascular choroid. In the latter case the incision may cause a vitreous hæmorrhage which may give rise to retinitis proliferans and subsequent detachment of the retina. From the pathological examination of eyes which have had foreign bodies in them it is quite evident that a vitreous hæmorrhage is a decided menace.

There are several important advantages of the corneal route, and Capt. Whiting and Capt. Goulden have written an excellent paper full of practical and original advice in the first number of *The British Journal of Ophthalmology*, 1917, in which they give a detailed account of the technique in using the Haab and small magnets.

The Mellinger magnet has an advantage over the Haab in that it can more easily be used for patients in the recumbent position, also the line of magnetic force can be very nicely adjusted with the soft iron pencils. The pull however with these is not as great as with the Haab. It remains to be proved whether in war work, where some of the penetrating particles are only partially magnetic or when gripped tightly in the coats of the eye or bound down by exudate, the greater power of the Haab is of more value than the ease of manipulation.

A mobile magnet car has recently been devised, fitted with a Haab's magnet and dynamo, and has proved of great value by enabling one to give a patient who is otherwise too ill to be brought to a Base Hospital where there is a magnet installation the advantage of early treatment with the magnet.

W. Tindall Lister.

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# INTRODUCTION

During the two and a half years' duration of the Great War the extraction of projectiles, an exceptional occurrence in ordinary practice, has now become an everyday operation.

All of us, whether operators by necessity or professional surgeons, have developed our experience and perfected our technical knowledge as far as possible and according to the resources of the environment in which we have been placed by the mobilisation.

Progress has, therefore, been rapid, and the extraction of projectiles may now be conducted with almost mathematical precision.

Having been stationed during the first part of the campaign at the front, and attached since then to specialised centres in the interior, we are acquainted with the very dissimilar conditions to which front- and rear-rank surgeons are subjected.

It seemed to us that, with very rare exceptions, all the surgical units (whether at the front or at the rear) would now be able to use those simple and precise methods which have been perfected by experience.

These methods are based on the use of physical means, the two most important of which are magnets and X-rays.

Magnets can only be used for the extraction of certain projectiles such as those which are generally responsive to magnetic attraction. Hence, although able to render considerable service, their use is consequently restricted to *special cases*.

X-rays, on the contrary, reveal the presence of *all* projectiles, and are thus a means of *general utility*. This work has, therefore, been especially devoted to their utilisation. From radiological methods we gain, first of all, assistance in diagnosing the *existence of a projectile* assumed to have lodged in the tissues. Once this first point has been ascertained, they also enable us to *determine the depth* at which it lies from any fixed point. Hence they enable us to decide upon the nearest and most favourable point of access to the projectile *thus indicated.*

In a very large number of cases they suffice to indicate whether the projectile be lodged in a bone, in a muscle (and if so in which), or in one of the viscera; whilst their movements (set up by deglutition, respiration, pulsation of the heart, or the movements produced by changes in the patient's attitude) enable us to obtain this diagnosis, as these movements can be analysed and interpreted according as they are thrown on the screen. The anatomical localisation of the projectile, so useful in preparing the plan of operation, is thus determined by radioscopy. But still more was expected from radiological methods, and they have now been made to lead the surgeon to the foreign body itself, even *during his preliminary examination.* We shall speak of *haphazard processes* which have been used occasionally, and of *very precise processes* necessitating the use of ingenious instruments called *compasses.* We shall show, however, that they admit of errors from which the standard processes are free; these latter are *extraction under the screen*, a sure but dangerous process, and *extraction assisted by intermittent control*, equally certain as regards results but free from all risk.

We have set ourselves to show that the radiological examination should not be confined to a mere measurement of the depth of a projectile, but that, on the contrary, it should form a complete radiological study of a given case, and should enable the radiologist to observe all the multiple indications which he must be in a position to supply to the operator, and also enable him to acquaint the surgeon with all those data which he may *expect and demand* from the radiologist. But here as everywhere else constant success depends essentially on a good understanding between the specialists, and perfect radio-surgical collaboration.

This is only possible if the radiologist has, in addition to a perfect technical knowledge, a sound anatomical and medico-surgical education; but to make it completely successful the surgeon himself should also possess some idea of radiology.

We have therefore preceded the two parts of this volume—one of which is devoted to the research and localisation, (Chapters V to XI), and the other to the extraction (Chapters XII to XV) of projectiles—by a few chapters (Chapters I to IV) the purpose of which is to give a brief summary of such physico-radiological ideas as are really indispensable to surgeons who wish to utilise X-rays to the greatest advantage.

As this book can be read by every medical man without difficulty, even if he has had hitherto nothing to do with radiology, we have endeavoured to explain these physical facts as clearly as possible, whilst presenting them in the light of the most recent theories and in a somewhat novel form.*

We hope, however, that specialists will be able to find some interest in this work in spite of its imperfections, of which we are aware; but should some of the parts appear to them to be rather elementary, we would like to point out to them that we have an excuse: viz. it was not our aim to write a learned book, but to show that all the operative units, however small, could now utilise advantageously the best radio-surgical technique to the greatest possible advantage of the wounded.

* Should any reader wish for more complete radiological evidence he could refer to the excellent handbooks by Jangeas, *Précis de Radiodiagnostic* (Paris, Masson; a new edition is being printed), and by Albert Weil (Paris, Alean); and, in the *Journal de Radiologie* (Paris, Masson), he would find an up-to-date and sure source of information. But we would strongly advise him to devote himself first for some time to the acquisition of some elementary knowledge of electricity (unless he already possesses this), which is so admirably set forth in the popular volume by George Claude: *Electricity for Everybody* (Paris, Dunod), and in the fine volume by M. Lermoyez: *Practical Ideas of Electricity* (Paris, Masson).

# THE
# LOCALISATION AND EXTRACTION OF PROJECTILES

## CHAPTER I

### PRODUCTION OF X-RAYS

§ 1. **Tubes.**—Let us consider a glass tube similar to that shown in Fig. 1, into the walls of which metallic electrodes are sealed: one, the *positive*, called *anode*; the other, or

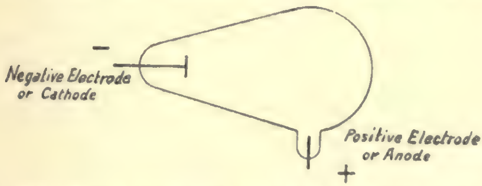



FIG. 1.—The X-ray producing tube in its original form, called the bulb or Crookes' tube. This is a simple glass tube of pyriform shape in which a very high vacuum has been produced, and in the walls of which are mounted two electrodes; one positive electrode or *anode*, and one negative electrode or *cathode*, terminating in a plate.

*negative*, being the *cathode*. Let us also presume that a very high vacuum has been produced therein.

By connecting (Fig. 2) the electrodes of this tube to the corresponding poles of some source of electric energy, we shall, if we have a source of high tension (of considerable voltage) at our disposal, *but only upon this condition*, succeed in causing it to be traversed by a current, whereas the so-called low- or mean-tension currents are incapable of overcoming the resistance which it offers to their passage.

As long as the passage of this high-voltage current lasts, the cathode (negative pole) of our tube will throw off *electrons*—that is to say, what it is now agreed to regard as elementary masses of negative electricity (something similar to atoms of simple bodies but in miniature)—because the electron corpuscule (supposed to be real) is about 2,000 times smaller than the smallest atom; viz. the hydrogen atom.

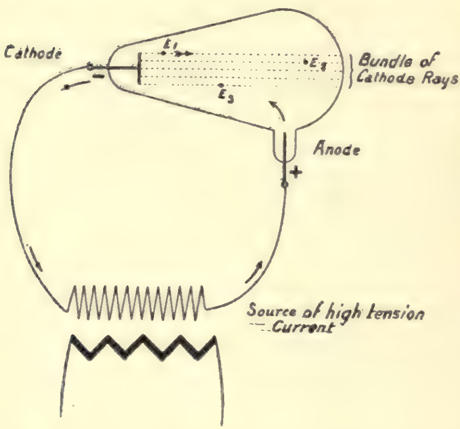



FIG. 2.—The anode of Crookes' tube is connected to the positive, and the cathode to the negative, pole of a high-voltage supply, the current of which circulates in the conductors and traverses the tube in the direction indicated by the four plain arrows. Its passage determines the emission at the level of the cathode, perpendicularly to its surface in the direction indicated by the barbed arrow, of elementary particles of negative electricity called electrons. They should be imagined as infinitely small spherules charged with negative electricity. $E_1$, $E_2$, $E_3$ are electrons shown at various points of their trajectory, which is designated as the *cathode ray*, the whole complex of these *virtual* rays forming the so-called cathode pencil.

These electrons (which we may represent to ourselves, in order to materialise our ideas, as very minute—punctiform—spheres charged with negative electricity) are projected on leaving the cathode, at right angles to it, from their point of emission at a speed which increases with the difference of potential at the terminals of the bulb, or rather with the voltage at our disposal, and which may attain a speed of 100,000 kilometres per second or one-third the speed of light.

If we have, as in Figs. 2 and 3, a cathode formed of a flat aluminium disc, a multitude of successive electrons will be continually emitted from it during the passage of the current through the tube, and the trajectory of each electron could be compared to a radiation termed the *cathode radiation*, the total forming a regular cone or sheaf of rays, viz. *the cathode pencil.*

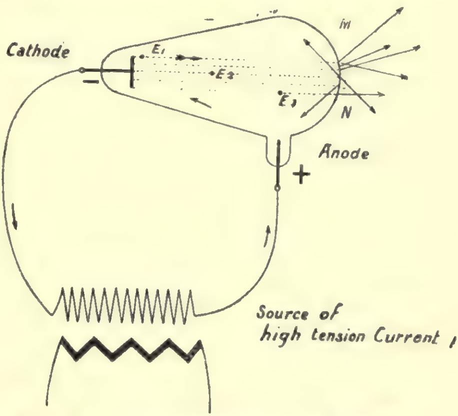



FIG. 3.—The electrons emitted perpendicularly to the cathode are arrested by the glass surface of the tube in the zone *MN*, which becomes the emission zone of the X-rays, as whenever an electron is suddenly arrested an X-ray wave is produced. These X-rays are thus emitted on the interior surface *MN*, and are diffused in a straight line in every direction starting from that surface.

*Whenever the moving electrons are suddenly arrested in their course, X-rays will be produced at the stopping-point.* This may also be expressed as follows: X-rays are produced whenever cathode rays come into contact with an obstacle.

The bulb or tube of the type shown in Figs. 1 to 3 was invented by the great English physicist Crookes (whence the name of Crookes' tube by which it is often known), to whom we have been indebted, since 1878, for his studies of cathode rays. In this type of tube the cathode pencil is arrested by the glass wall on which the X-rays are produced, the zone *MN* (Fig. 3) forming the source of emission.

But we have seen that the electrons might be likened to projectiles which, although very minute, are yet endowed with a formidable rate of speed. This velocity is such that, assuming it to actuate a projectile with a mass of one milligramme, its sudden arrest would have the same effect as a collision with a fast thousand-ton train running at full speed.

It is, therefore, not surprising that the electrons or cathode rays (the two expressions may now be considered as synonymous) produce a considerable effect, and possess particular qualities. Thus every surface upon which they impinge is rapidly heated, namely, to such an extent that the glass wall of the bulb or tube receiving them is quickly melted. Owing to this important reason the construction of Crookes' tubes for the production of X-rays was soon altered, and another form adopted which was introduced in 1898 by the English chemist Jackson; since then it has remained the same with the exception of a few points of mere detail.

This new tube has been provided with a platinum sheet

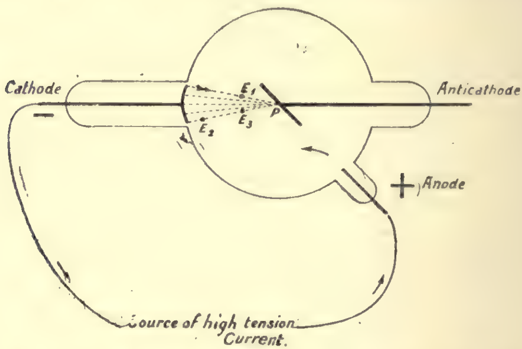



FIG. 4.—Crookes' tube modified by Jackson, similar to the modern form of X-ray tube. The cathode is concave and all the electrons $E_1$, $E_2$, $E_3$ converge towards its focus on a level with which there is placed—opposite the cathode—a plate of platinum called for that reason the "anticathode." Hence it is on this that all the electrons are arrested and the X-rays are produced at the point $P$, called *focus* or *source*; from this point the rays radiate in a straight line in all directions as shown in the following figure.

in front of the cathode, this metal not being very fusible; hence the name of *anticathode*, and it is consequently adapted to receive the shock of the electrons (Fig. 4).

In this connection we must remember that there are two forms of electricity, viz. positive and negative electricity. By general agreement, fortunate owing to its simplicity, these are indicated by the corresponding algebraic signs + and −. It is, moreover, well known that electrical currents of the same name or sign repel, whilst of the opposite name or sign attract, each other. Thus two electrons which are two quantities of negative electricity —consequently of the same name or sign—repel each other. Numerous experiments have enabled the rather simple laws which govern the distribution of electricity over the surface of bodies to be determined. They constitute the principal domain of static electricity, and are applied to the distribution of charges of electricity over the surface and over the various parts of X-ray tubes.

Without having to quote these laws here it will be apparent from what has just been said that the anticathode must necessarily be considered as charged with positive electricity if it is desired that it should be able to receive and to attract the electrons which represent charges of negative electricity. The anticathode which receives positive electricity may therefore be considered as a positive electrode or anode.

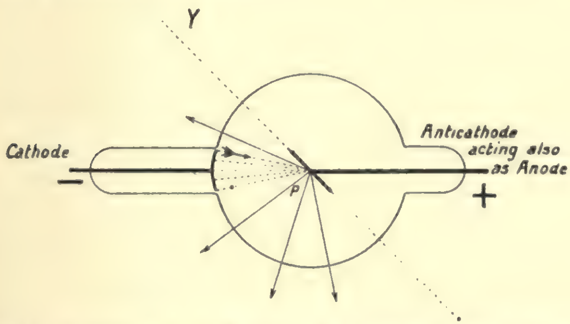



FIG. 5.—Production of X-rays. The cathode pencil converges on the anticathode at *P*. Starting from that point, X-rays pass in a straight line in all directions towards the plane *YX*, determined by the surface of the anticathode.

Tubes are in fact being constructed to comply with the scheme of Fig. 5, and in which the anticathode serves at the same time as anode. Fig. 6 represents a type of the same tube of French construction. If in several other models manufacturers have preferred to retain one separate anode at the side of the anticathode, as shown in the tube in Fig. 7, this is mainly due to simplicity of construction, and care is taken to connect the two parts by means of a conductor when in operation.

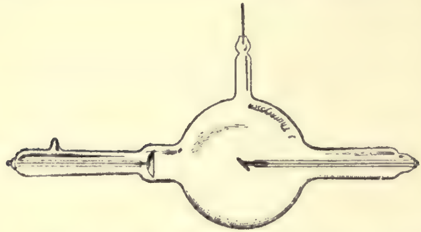


FIG. 6.—Chabaud tube in which the anticathode serves at the same time as an anode. This tube is provided with an osmo-regulator (p. 17).

But as the X-rays are to be utilised for radiodiagnostic purposes, as we shall see later on, in order to produce images by projecting shadows on to a fluorescent screen or photographic plate, the surface

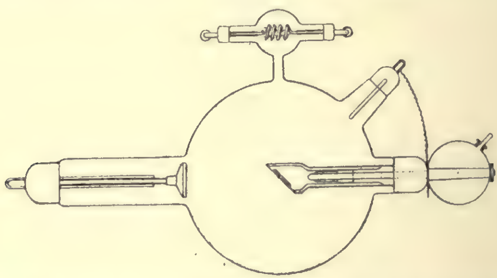


FIG. 7.—A Pilon tube presenting a distinctive anode and anticathode in which the cooling thereof is effected by a mass of water contained in a spherical reservoir, shown at the end of the neck of the anticathode. This reservoir is in direct contact with the metal extension of the anticathode, the surplus heat of which it thus absorbs by conduction. Should the water get warm it can safely be replaced by cold water, as the receptacle is of metal and consequently not exposed to breakage owing to the sudden change of temperature.

which produces them may be compared, as regards what follows, to a source of light. It is necessary therefore, if we wish to obtain clear images without penumbræ, that this source should be punctiform, or at least greatly reduced in size as far as is practicable. It is therefore necessary that the surface which receives the pencil of cathode rays should be as limited as possible. By giving the cathode the form of a concave mirror, the cathode rays converge theoretically to form one focus.

If the metal plate intended to receive them (the anticathode) is adjusted to this focus we shall obtain a punctiform source of X-rays at this point of contact, or point of impact of electrons (Fig. 4 *et seq.*).

In practice this result is, however, never strictly realised.

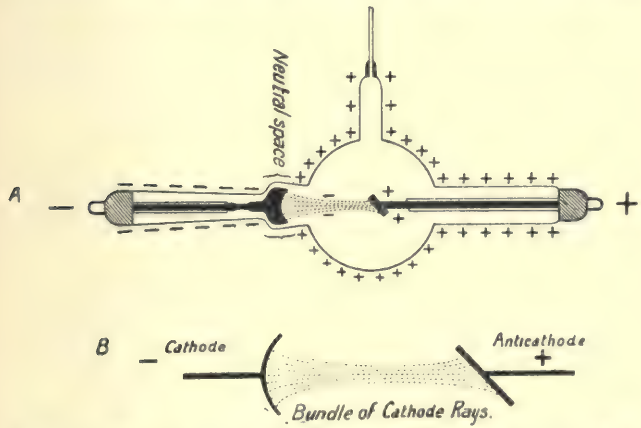



FIG. 8.—The purpose of this is to give a diagrammatic idea of the distribution of electricity over the surface of the tube *A* and of the approximate form *B* actually adopted by the cathode pencil. It will, however, be understood that this form can be modified according to the forces which act on the electrons, and especially if the voltage applied to the tube is varied.

The electrons are subjected, in consequence of the law which we have mentioned above (the attraction of electricity of a contrary sign, and the repulsion of that of the same sign), to the influence of multiple forces which induce them to deviate from their rectilinear path. The cathode pencil then assumes the aspect shown in Fig. 8, which corresponds more or less to the image of two curvilinear cones much drawn out with their apices in contact, one of the bases corresponding to the cathode and the other and very much smaller one to the anticathode. The elliptical surface whereby the second cone is cut off upon the anticathode is still sufficiently small in well-constructed tubes to satisfy all requirements as to the clearness of the images.

Furthermore, if the zone of impact of the electrons were reduced too much, then the heating, which at this point is limited, would cause there the melting of the anticathode very quickly, however resistant to fusion the metal of which it is formed might be.

Finally, the glass tube has during this transformation become spherical as illustrated, and its term "bulb" or "tube" has remained only as a matter of habit. It is provided at the opposite ends of one of its diameters with elongated necks into which the electrodes are sealed. In order to avoid still further heating of the anticathode due to its being incessantly "bombarded," so to speak, by the electrons it is often made hollow, and is placed in communication with a water reservoir (Fig. 9) into which it is even possible to establish a water circulation; whereas in other types the cooling is ensured by a current of air. Since the time when it became possible to work tungsten, the platinum plate on which the focus emitting the rays is produced has been replaced by a disc of tungsten.

§ 2. **High-voltage Sources.**—We are provided with an X-ray tube which has a punctiform or at least a sufficiently small focus to satisfy our legitimate requirements with regard to the clearness of our radioscopic or radiographic images. As we have seen, in order to make it work and produce X-rays we must have a source of electric energy of high voltage.

Now, in practice we have only at our disposal currents of low or medium voltage (few volts), but of high intensity (many ampères), which the electric mains, generating sets (similar to those installed on several of the radiological cars belonging to the Sanitary Service), or at the worst accumulators provide. But if, in order to work our tube, we require a high tension (number of volts), that is to say a high voltage, then the intensity (number of ampères, or ampérage in the language of electricians) required will be very weak, because it will not exceed 1 to 5 thousandths of ampères (called milliampères or even, for brevity's sake, *millis*—a term which we shall hereinafter adopt) for most of the ordinary small installations. The larger installations, on the other hand, will need from 10 to 15 millis, and the most powerful plants will, in practice, hardly utilise for rapid radiography more than 20 to 40 millis, and quite exceptionally as much as 100 millis,* and then merely for periods amounting to fractions of a second.

We know that the product of the voltage is estimated by the intensity of a current; that is to say, the *product of volts by ampères*, which is expressed by a new unit

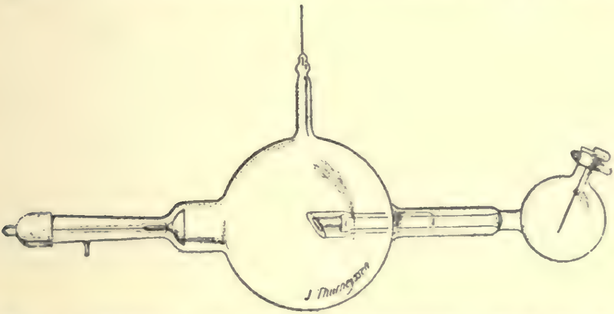


FIG. 9.—Chabaud tube with an anticathode cooled by direct contact with water.

called the *watt* representing *the power* of this current and *the electric energy* which it places at our disposal. This quantity of energy presents a maximum which it is not in our power to modify for any given installation.

On the contrary, it will be understood that we are at liberty to utilise it at our will in the form of low-tension current (low voltage), but of high intensity (high ampérage, or, *à fortiori*, milliampérage); or, on the contrary, in the form of current of higher tension (stronger voltage) and of weaker intensity (lower ampérage), or even in the shape of current of *high tension* (high voltage) of very weak intensity (*weak milliampérage*) on condition that the product of the volts by the ampères does not change.

* A meter device with direct reading, the milliampèremeter, measures momentarily this intensity in the high-voltage circuit.

We shall therefore have means of transforming the low-tension (up to 250 volts) and high-intensity current (up to 100 ampères) which is at our disposal into a current of very high tension (up to 100,000 volts and over) and very weak intensity (1 to 100 millis); the product of volts × ampères, that is to say the number of watts (the power) remaining of course invariable, subject to such losses as are caused by every transformation of energy.

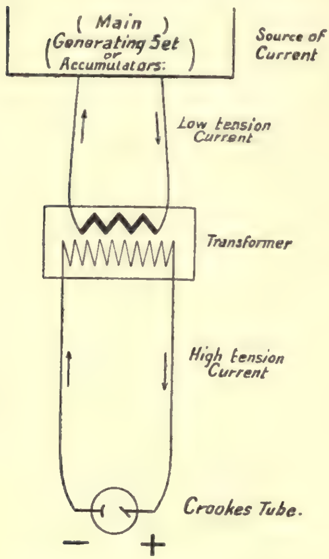



FIG. 10.—Complete plan of a radiological installation. An electric power station, a generating set or a battery of accumulators, is the source of electricity which gives us current of low voltage and high intensity to a transformer which passes a current of high voltage and weak intensity into the tube.

We are thus able to use at will either the electric energy placed at our disposal by employing 20 ampères at 110 volts or 0·020 ampère (20 milliampères) at 100,000 volts—not taking any waste into account in this *simplified* calculation.

The electrical industry to-day supplies us with a series of instruments for effecting this transformation, all of which are based on the principles of electro-magnetic induction. These are either induction coils or transformers properly so-called. But our task is not to deal here with their theory, nor with the details of their construction.

Those interested in these matters should consult the works previously mentioned.

It is sufficient for our purposes to know that every radiological installation includes a source of high-voltage current—generally obtained by transforming the low tension, continuous or alternating current, supplied by the mains—intended to excite the Crookes' tube which produces the X-rays.

But, as we have seen, this tube has well-defined poles. The current must, therefore, always traverse it in the same direction, or otherwise it will deteriorate very quickly.

Now these coils and transformers produce a "wave" or undulatory and alternating current. It is therefore necessary to use appliances which prevent the inverse wave from passing into the tube.

To achieve this it may be arrested and suppressed by mounting "cut-outs" in the circuit of the "Villard" valve type, which is an ovoid, elongated tube in which a suitable vacuum has been produced; hence owing to the special form of its electrodes it presents a very unequal resistance to the passage of the following current which has to traverse it in one direction or the other.

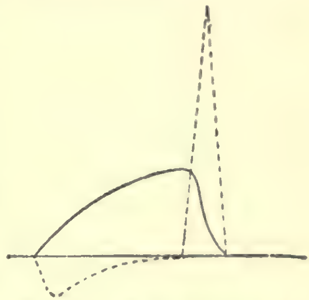


FIG. 11.—Diagrammatic curve of induced waves, the dotted lines representing the secondary voltage. The waves of high-voltage current, supplied by the coil or transformer, are projected into the tube circuit. The inverse wave is that which is shown below the horizontal line, and it is this wave which must be arrested or rectified as it would pass into the tube in an inverse direction; that is to say the cathode would serve as an anode and the anti-cathode as an anode. The electrons would then impinge upon the cathode. The full line represents the primary intensity.

It is mounted in the high-voltage circuit in such a way that the direct wave which should excite the X-ray tube easily passes it, but it arrests the inverse wave which would damage the tube. The two valves are generally mounted in the circuit according to the diagram shown in Fig. 13, which represents a different type from that of the preceding one. Unfortunately the valves are in themselves also Crookes' tubes, and as such they are exposed to the same inequalities of working and to all the annoyances attending adjustment. They will only be able to accomplish their task satisfactorily provided they be kept in perfect working order, which necessitates constant supervision. In order to avoid the annoyance caused by the use of valves, it is possible to employ ingenious mechanical contrivances based on the principle of "rotary contacts" which enable the inverse wave to be "rectified"

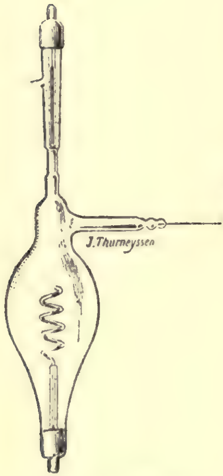



FIG. 12.—Villard valve. The current passes very easily if the top electrode be used as anode (+), but with great difficulty if employed as cathode (−), and if the current has entered through the lower electrode.

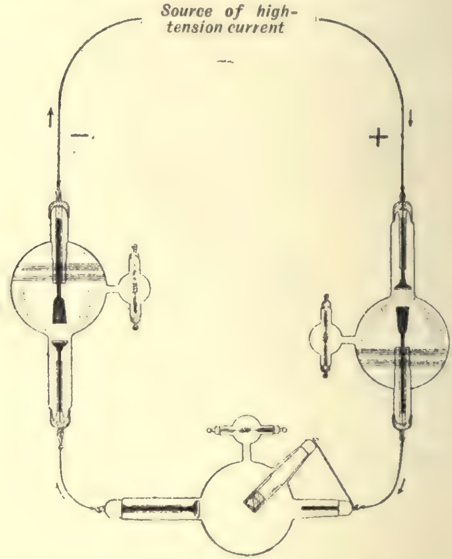



FIG. 13.—Diagram showing the reciprocal connections of the X-ray tube and the two valves intended to arrest the inverse wave and prevent its entering the tube (Pilon).

and passed through the tube in the right direction. Fig. 14 indicates what happens, and the means by which the "rotary contact" thus enables the two waves supplied by the transformer to be utilised, and this obviously considerably increases the yield.

§ 3. **Adjustment of the Tubes.**—Our installation is now completed. The *main* supplies us with any current which we are able to transform into an alternating high-voltage current, and to send into the tube by causing it to be traversed by waves of the same direction only.

Let us now start our apparatus. The current, passing through, lights up the tube, and the whole half of the sphere, situated in front of the plane of the anticathode, becomes green with a beautiful fluorescence, provided the

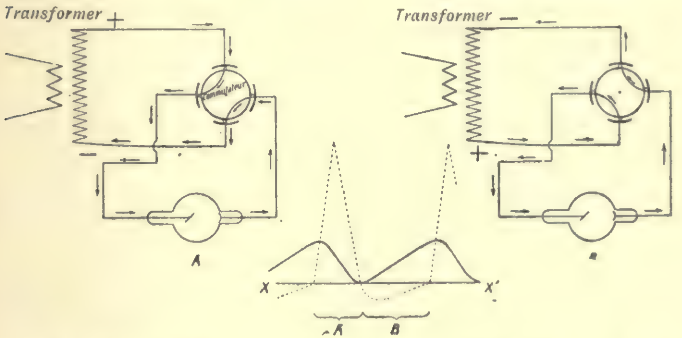



FIG. 14.—Diagram for rectifying the inverse wave by means of the rotary contact device. At *A* the circuit is traversed by the direct high-voltage wave in the direction indicated by the arrows. The commutator turns by one quarter revolution in synchronism with the alternation of the current. During the following period when the wave is inverted it will occupy the position indicated at *B*, and, owing to the change of connections thus produced, this inverted wave will still traverse the tube in the right direction.

connections be properly made (Fig. 15). If not, it will be immediately indicated by the appearance of the tube (Fig. 16), and the error can at once be rectified. Now how is this fluorescence produced? To say: "By the X-rays" would be the incorrect answer which is so very frequently given.

We must remember that, as the current passes, the electrons leave the cathode to impinge upon the anticathode. But at that point many of the electrons rebound in all directions and strike against the glass which they render fluorescent.

Let us bear in mind that when the current passes, the electrons leave the cathode to impinge upon the anticathode, where, however, many of the electrons rebound from all sides and strike against the glass which they render fluorescent. The cathode rays (electrons) *which in themselves are invisible*, have the curious peculiarity

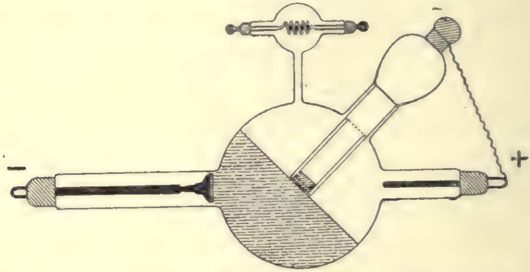



FIG. 15.—Tube working normally. The whole shaded part of the tube, that is to say the whole portion situated at the side of the cathode in relation to the plane determined by the surface of the anticathode, presents a beautiful uniform fluorescence, the colour of which will depend upon the composition of the glass used in its manufacture. Generally it is green, but with some glass of English make it is blue.

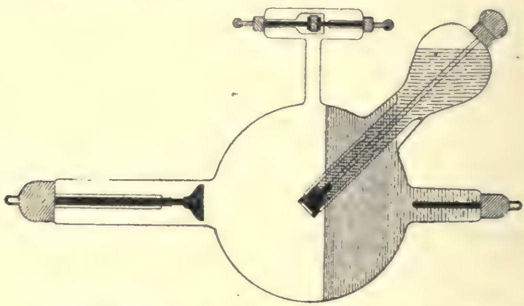


FIG. 16.—The same tube traversed by the inverse wave, or (what amounts to the same thing) wrongly connected up. The cathode thus serves at the same time as anode and as anticathode. It is therefore, on this cathode that the X-rays originate, and from it rebound the electrons which will make the walls of glass fluorescent when they are illuminated.

of rendering numerous substances fluorescent, such as glass (and consequently the glass walls of the tubes), and also most gases.

It is owing to this latter reason that in slightly exhausted tubes where the electrons still meet many gaseous molecules in transit and render them fluorescent, the passage of the cathode pencil is shown by a bluish luminous cone which is quite visible in darkness and can thus be studied very easily. It is evident that these electrons, when arrested by the glass walls of the tube, will produce X-rays, and this secondary radiation may become a source of trouble if it be too evident.

Our bulb was quite new ; it showed bluish reflections, and even enabled the cathode pencil to be detected. It worked regularly and without noise at 2 milliampères, and was easily traversed by the high-voltage current which excited it. We may say that it was *soft*, and that it produced mainly soft rays. But little by little the cathode pencil ceased to be visible, the bluish reflections disappeared, the green tint became modified, a peculiar crackling could be heard, and we saw the needle of the milliampèremeter gradually fall and commence to oscillate irregularly. The passage of the current became more and more difficult, and we may say that the bulb became *hard*. As a matter of fact the internal condition of a Crookes' tube alters very rapidly when in operation. We have stated previously that a very high vacuum has been produced therein. This vacuum, however, is not perfect. The metallic parts which penetrate the interior of the tube, the electrodes and the anticathode (especially the latter), can evolve gases. On the other hand the glass walls, owing to complex phenomena the explanation of which does not come within the scope of this short summary, are capable of fixing and imprisoning the gaseous particles which they will no longer evolve. The state of the "interior atmosphere" of the tube will consequently be constantly modified during its working, the pressure being alternately increased or decreased.

If the tube runs at a rather higher pressure, or during a lengthy period, so that its anticathode becomes red-hot, then the metal will evolve gases, a part of which only will be reabsorbed by it when cooling, and another part will be definitely fixed on the glass walls. Hence it is only when we know how to regulate the working of the tube properly, so as to keep its degree of vacuum constant, that we shall obtain satisfactory and constant results. Only an experienced technical man will be able to handle his tubes judiciously, and keep them in good working order for a long time. But in spite of all precautions, the tubes, with a few rare exceptions, will have a constant and increasing tendency to become *hard*, the more so if they have been used by inexperienced persons, as the walls will always absorb gaseous particles which cannot be released.

As this rarefaction increases, the working of the tube becomes more and more irregular and capricious; and, at last, there comes a time when the vacuum may be considered as absolute and the current entirely ceases to pass through it, and the tube then becomes useless. In order to remedy this defect, which is the principal cause of "break-downs" and other troubles met with in the course of radioscopic and radiographic examinations, various appliances have been invented to enable gas to be introduced into the tube when necessary.

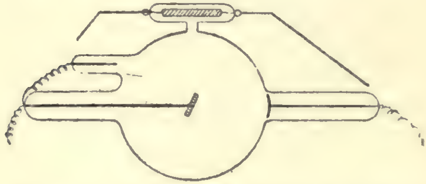


FIG. 17.—Tube with chemical regulator, operated by the passing of a current which evolves a certain quantity of gas from the substance used (mica, carbon, etc.). See also Figs. 7, 13, 16.

To do this, it is possible to attach to the tube a reservoir containing, for instance, some such substance as carbon or mica, which has the property of containing a large quantity of gas and of releasing it gradually when current is passed through it. These are the so-called *chemical regulators* (Fig. 17).

Another method consists of fitting to the bulb a small window of porous material, mercury-proof but not air-proof, and protected by a column of mercury. One stroke of a pump suffices to lower the column of mercury, which opens the porous window through which a little air immediately passes into the tube. Then the mercury rises again and the window is hermetically reclosed. The strength and number of the strokes of the pump enable one to graduate the desired effect and to repeat it at will. This is the *air regulator* or Bauer regulator (Fig. 18).

Finally, perhaps the most perfect regulator is that based on the well-known property of platinum to become pervious to gas when it is red-hot; this is the so-called Villard's *Osmo-regulator*.

It consists of a simple platinum tube, closed at its free end, the other end being sealed into the wall of the tube in such a way that its cavity is in communication with the interior of the tube.

Should the latter become too hard, the Osmo-regulator is heated by the flame of a gas-jet or spirit lamp and is kept at white heat for a few moments.

Under these conditions the hydrogen emanating from the gas or from the dissociation of the aqueous vapour in the hot part of the flame traverses the platinum, being attracted towards the more rarefied atmosphere, where it is retained as soon as the

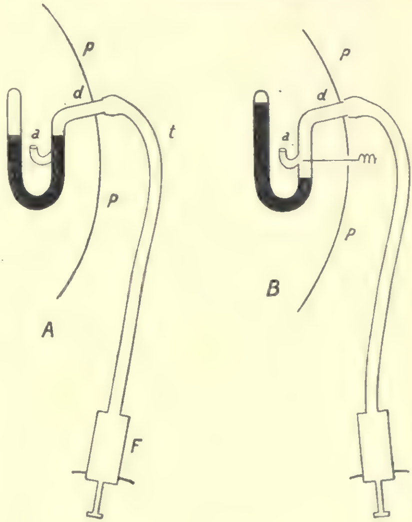



FIG. 18.—The air regulator. At *A* it is seen at rest. A U-tube is sealed into the wall (*p*) of the tube by means of a joint which enables it to communicate with the external atmosphere, and into which there is fitted the nozzle (*T*) of an air pump *F*. This U-tube has a small arm (*a*) open at the bulb end and is separated from the principal tube by a plate of porous material permeable to air. The U-tube is filled with mercury which shuts off communication between the tube and the external atmosphere. At *B* the apparatus is working. A stroke of the pump has driven back the mercury which uncovers the porous plate (*m*). The air then passes into the interior of the tube whenever and as long as this plate remains uncovered.

heating of the platinum has been discontinued, because the latter cools down almost immediately. Thus the vacuum in the tube may be lowered as often and as much as is necessary. For some years past palladium has been used in the manufacture of Osmo-regulators, this metal possessing from this point of view the properties of platinum to a still higher degree.

It must be pointed out that when the tube hardens, when working as we have indicated, and when the needle of the milliampèremeter indicates less current, this increase of resistance may nevertheless be overcome by increasing the voltage of our current. What takes place in such a case may be roughly compared to the effect obtained by forcing water under great pressure into a choked water-pipe in order to remove an obstruction. As will be readily understood it is therefore useful to know the voltage of the current and to be able to measure it. Although simple and handy instruments called voltmeters enable us to ascertain easily these data in the case of low-voltage currents, this is not the case with those of high voltage, and voltmeters which are used for measuring these high voltages are as a rule rarely seen except in physical laboratories.

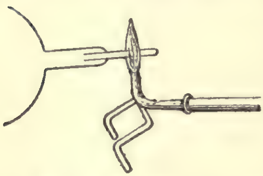


FIG. 19.—Use of the Osmo-regulator. Platinum heated red by the flame of a Bunsen burner or of a spirit lamp becomes permeable to hydrogen, and the gas attracted by the difference of pressure penetrates the tube. The tubes in Figs. 6, 9, 20 are provided with an Osmo-regulator.

Our measurement need not, however, be absolutely correct. What we require above all is a means to enable us to compare the voltages applied to our tube under various conditions; so as on the one hand not to reach the dangerous limits, and on the other hand not to make inferences from the indications thus obtained, as we shall see in the following chapter dealing with the properties of X-rays obtained under various conditions.

Now, if we assume that our tube is connected to the terminals of the high-voltage source by means of conductors, which are not provided with insulators, and if we bring them in contact, there will come a moment when a spark will burst forth between the nearest points of these metal wires. We shall thus have caused what is known as a "short circuit"; this would mean that the resistance opposed to the passage of the current by the layer of air, which at this point is interposed between the two conductors, is less than the resistance of the tube. The current, always following the line of least resistance, is thus closed across the air in the form of sparks.

On regulating by experiment the gap which separates the conductors, we shall determine the exact distance at which the sparks are produced. At that moment the resistance of the tube is more or less equal to the layer of air which separates the conductors. The thickness of that layer or the length of the spark which will be produced at that level will give us the term of comparison we are looking for; this is what we call "the equivalent spark gap."

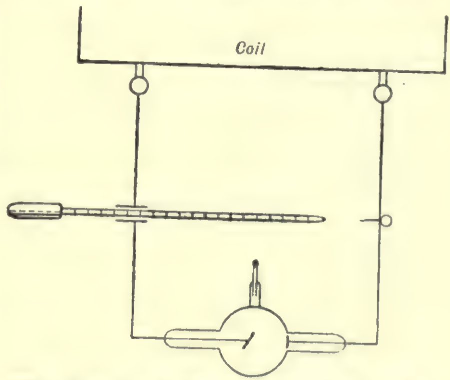



Fig. 20.—The Béclère spintermeter. The graduated bar is held by its insulated handle and pushed towards the opposite conductor until a spark is produced. If read at that moment the graduation will indicate the length of this spark in centimeters.

In order to simplify matters, Béclère has devised a sparking device graduated in centimeters mounted in circuit as indicated in the sketch, and which he has named the spark measurer or *spintermeter*.

The longer the equivalent spark, the greater, speaking generally, will be the resistance or the hardness of the tube, and *vice versâ*.

We have now obtained a tube such as may be seen to-day in most radiological installations, and in its simplest form, in which the anti-cathode serves at the same time as an anode. In France it is represented by the excellent Chabaud tubes. These tubes are very strong and their output is relatively excellent. They are incapable, however, of standing the strong currents required for rapid radiography and of meeting the requirements of modern radiology. At the time when it appeared, this tube, the only one provided with a perfect regulating device (Villard's Osmo-regulator), was unequalled.

To its manufacturer it appeared to be so perfect that he remained deaf to all the requests of radiologists, who wanted to obtain more powerful tubes but had to be content with out-of-date material, or else to obtain tubes from German manufacturers. In this way the almost exclusive monopoly of this article, which could have easily been ours, soon passed almost completely into the hands of our enemies.

Only a few years ago a firm was established in France for the purpose of producing tubes capable of withstanding the highest voltages which would thus compete with German firms. This war has demonstrated that France has succeeded completely in this respect, and led us to appreciate the service rendered to the country by stopping (finally let us hope) the importation of this article.

French industry is now able to supply simple or high-power tubes which are equal, if not superior, to the best German makes.

American industry has also tried, before us, to shake off (at least partially) the German yoke, and even if some so-called American firms are nothing but poorly disguised branches of German industry, there are nevertheless some real American firms able to supply a really excellent article.

It is also from America that we get a new form of tube, the Coolidge tube, which in the near future will undoubtedly oust the present types almost entirely.

# CHAPTER II

## X-RAYS AND THEIR CHIEF PROPERTIES

### RADIOSCOPY AND RADIOGRAPHY

OUR apparatus is now in working order; current passes through the tube, which shows that beautiful uniform greenish fluorescence of its frontal hemisphere characteristic of good working.

The electrons coming from the cathode impinge upon the anticathode and the X-rays are produced at the point of impact. But, as already mentioned, they are not visible to the naked eye. It is only by observing their controllable effects, *i.e.* by becoming familiar with their properties, that we shall be able to ascertain how the tube is working, and make sure that they possess the necessary qualifications for the various uses to which we propose to apply them. We will, therefore, briefly summarise their main characteristics as far as is necessary for an exact comprehension of our subject. In other words, we shall limit ourselves to studying a few elementary considerations:

(1) The laws according to which these radiations pass through bodies.

(2) The characteristics which they possess: (*a*) of exciting fluorescence in certain substances, and (*b*) to having an effect upon "sensitised" or photographic plates. We shall deduce therefrom a few ideas necessary for the interpretation of radioscopic and radiographic images.

§ **4. Permeability of Bodies to X-rays.**—Everybody knows that various bodies are unequally permeable to luminous rays. Some, such as window-glass for instance, which we call transparent, allow them to pass almost entirely; whilst others which we call opaque, such as a piece of wood, stop them entirely. Between these two extremes there are all the intermediate stages. In exactly the same manner, various bodies are very unequally transparent to X-rays.

But from our earliest days we have been accustomed to distinguish between bodies opaque or transparent to luminous rays, because these by acting on the retina are directly perceptible to our sense of vision. This difference in the quality of the bodies which surround us therefore appears quite natural to us owing to habit; but we are surprised to find that the same thing does not necessarily apply to the transparency of the same bodies to other radiations.

Thus two plates of an equal thickness, say 3 millimeters, one of crown glass, the other of flint,* have more or less the same transparency to luminous rays. But though the former allows X-rays produced by a Crookes' tube to pass almost entirely, the latter stops them almost completely. However, if we consider the matter properly, we find that these characteristics are not more surprising in one case than in the other: the surprise they cause is simply due to the fact that X-rays are invisible to the eye and that consequently we are not in a position to determine the transparency of bodies directly by our own unaided vision.

As a result of researches undertaken by the French physician Benoist, a law has been established which is essential to the exact understanding of all the medical applications of radiology, and it is of the utmost importance always to bear in mind that: X-rays as a rule traverse a body all the more easily if its atomic weight be less, but with more difficulty if its weight be greater. In other words, the *X-ray transparency of various bodies stands in inverse proportion to their atomic weight*. Thus, a thick oaken board if interposed between the tube in action and the fluorescent screen will produce only a very faint shadow whilst a thin sheet of lead will entirely obscure the luminous surface.

Atomic weight being equal, it is only the number of atoms (that is to say solely the thickness of the body)

* Window, Bohemian, and bottle glass are light glasses and transparent to X-rays; crystal and strass are heavy lead glasses impermeable to X-rays.

that interferes with the passage of the rays; and the shadow given by an iron plate of 2 millimeters will have, roughly, double the intensity of that obtained by a 1-millimeter plate.

But if we consider the X-radiation emitted by a tube in action, and if we examine its penetrating power as regards a given body, of a certain determined thickness, we shall soon find that that quality will vary considerably every moment according to the state of the tube. At one moment the radiation will be stopped almost entirely by a thin sheet of lead, say a tenth of a millimeter thick; at another it will, on the contrary, penetrate it to a great extent and will even illuminate the screen after having traversed it. In the first case we say that the radiation is soft or of slight penetration; the tube will at that moment be soft, and its equivalent spark will be short, that is to say the difference of potential at its terminals (or the voltage applied) will be small.

In the second case the radiation will on the contrary be called hard or penetrating, and the bulb at that moment will be hard, the equivalent spark will be long, and the difference of potential at the terminals (or the voltage) will be great.

As already stated (Chapter I, § 1), X-rays are produced when the electrons, moving at high speed, are suddenly arrested. If we consider X-rays as being of the same nature as luminous rays—a comparison which, considering everything, we are now not only authorised, but even obliged to make—we must admit that they are electromagnetic vibrations of the ether. These vibrations are created when the electrons are arrested and, as will be readily understood, they may be different in their intensity and consequently also in their physical qualities, according to the speed of the electrons which produce them: that is to say according to the force of the impact.

Now, this speed of the electrons depends entirely upon the difference in potential at the terminals of the tube, and varies in proportion with the latter. The relationship previously explained is thus made clear, and practice enables us to observe daily that the harder the tube (that is to say the higher the voltage of high-tension current which traverses it) the harder or more penetrating are the X-rays produced (the term " penetration " and " hardness " may be considered as synonymous).

Let us now consider a point where an electron is suddenly stopped and starting from which an X-vibration is going to be produced. From the point of emission or the centre of propagation of the X-radiation, there starts a series of waves which extend equally in all directions at a uniform speed equal to that of light. In order to simplify matters, let us consider it from one standpoint only. We shall be able to obtain a concrete idea by comparing them with the phenomena of the undulation of water and by bearing in mind what happens on a liquid surface into which a body has been dropped. From the point of contact with the liquid surface, there starts a series of waves or undulations which form round that point concentric circumferences of increasing radius. These waves of the liquid surface succeed each other; each one is separated from that following by a depression, the depth of which is equal to the height of the wave (Fig. 21).

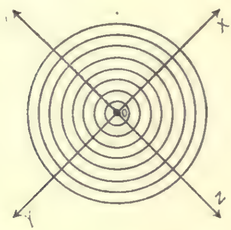


FIG. 21.—This figure represents a diagram of the waves which spread concentrically in every direction, *OX*, *OY*, etc., on the surface of a sheet of liquid, starting from falling-point *O* of any body. These waves may be likened to those which would be produced by luminous vibrations or X-vibrations if they were considered in a single plane only.

Let us imagine what happens along any X-ray *OX* of these concentric circumferences. A very correct idea of the undulatory movement in this respect will be obtained by comparing it to the coiling of a cord fixed at one end, the other being held in the hand and briskly moved to cause rapid undulation (Fig. 22).

Geometrically, the representation of the process following the ray *OX* is supplied, as we know, by a curve like *OX* called sinusoidal (Fig. 23). On this curve distances, such as *OB*, measure *the length of the wave* or radiation under consideration.

From the physical standpoint this length of wave serves to characterise a radiation and determines its properties. Two radiations of an equal length will be identical as regards their properties and their effects; more especially

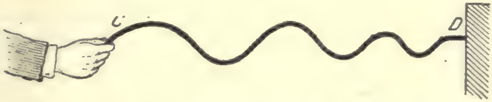



FIG. 22.—A cord is fixed at one end *D*, and if the other end *C*, held in the hand, is moved briskly up and down, a serpentine movement is produced which will give an idea of the undulatory movement of Fig. 21 if we regard it for instance as following the ray *OX*.

as X-radiation with a given length of wave will always have the same penetrating power as regards different bodies.

Thus, the various electro-magnetic vibrations which constitute heat, light, and the invisible rays of the spectrum should be defined by the length of wave, in the same way as X-rays and rays of radio-active substances.

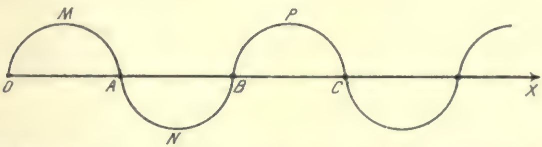



FIG. 23.—This curve, called *sinusoidal*, is a geometrical representation of the vibratory movement caused along the ray *OX*. The portions *OMA*, *ANB*., etc., of the curve are called loops; the points *A*, *B*, *C* the nodes of the vibration. The curve *OMN* is a complete wave and the cord *OAB* the *length of the wave*. The "loops" are here incorrectly shown as arcs of a circle.

The following table indicates the wave lengths which include the principal known radiations:

| Character of the Radiations. | Length of Wave. |
|---|---|
| Hertzian waves . . . . | From 10,000 meters to 6 millimeters. |
| Caloric waves (ultra-red rays) | From 00,3 to 0,00008 cm. |
| Luminous rays (visible spectrum) . . . . | From 0,00008 to 0,00004 cm. |
| Ultra-violet rays . . | From 0,00004 to 0,00001 cm. |
| X-rays . . . . | From 0,00000005 to 0,000000001 cm. |
| X-rays . . . . | From 0,00000002 to 0,000000001 cm. |

Sometimes, in order to avoid an alignment of useless figures, the wave-lengths are expressed in $\mu$ or the thousandth part of a millimeter, and in $\mu\mu$ for a millionth part of a millimeter.* Thus it is the wave-length which finally characterises all radiation, X-radiation in particular, and which determines its quality. The shorter the wave-length, the greater the penetrating power of the X-radiation is considered to be. Or in other words, *the shorter the length of the wave of an X-radiation is, the greater is the velocity of the electrons which produce it.*

This is an aspect which interests us to a great extent because upon it depends largely the quality of the radioscopic and radiographic images we shall now have to examine, and their value from the radio-diagnostic standpoint. It is therefore necessary to be able to estimate and measure it.

But in practice we are not trying to measure the wave length of the radiation under consideration. The methods which would enable us to determine this would necessitate complex manipulations and instruments. Only well-equipped physical laboratories are now able to obtain these data. Moreover, all tubes now used yield electrons of very different speed. On being arrested, they would yield X-rays of different wave-lengths, and the radiation produced would consequently always form a complex sheaf, comparable with the complex and polychromatic pencil of white light, and never a radiation of a single length of wave comparable to a simple monochromatic radiation.

In order to estimate the quality of X-radiation we shall use the *Radiochromometer*, a very simple and ingenious instrument invented by M. Bénoist. Its use is based upon the following theoretical considerations.

Certain bodies, such as aluminium, do not retain the same transparency to X-rays according as to whether it is a question of soft rays (great wave-length) or hard rays (short wave-length). If, for instance, a 1-millimeter

* Physicists employ the C.G.S. (centimeters, grammes, seconds) system and note the subdivisions of the centimeter in powers of 10 with negative sign. Hence: 1 mm. $= \frac{1}{10}$ cm. $= 10^{-1}$ cm. 0,0000000017 cm. will be described as $1{\cdot}7 \times 10^{-10}$ cm.

aluminium plate arrests 80% of a soft radiation which falls on it, it will not check more than 25% of a very hard radiation.

In other words, if a 1-mm. aluminium plate interposed between the tube and the screen produces with the first radiation a shadow of a certain intensity, it would be necessary with the second type of radiation to interpose for instance a 7-mm. aluminium plate in order to produce the same shadow intensity.

On the other hand other bodies, such as silver, present more or less the same transparency (physicists call the same "*radiochroism*"—a term which they have given to that particular property which is said to be the cause of the difference in transparency of coloured screens in the case of certain monochromatic lights) for all kinds of radiation.

Thus a 1/10-mm. silver plate which arrests 40% of a soft radiation falling on it will also check 40% of all other kinds of radiation; that is to say nearly half of all the X-radiations, of whatever wave-length (Fig. 24).

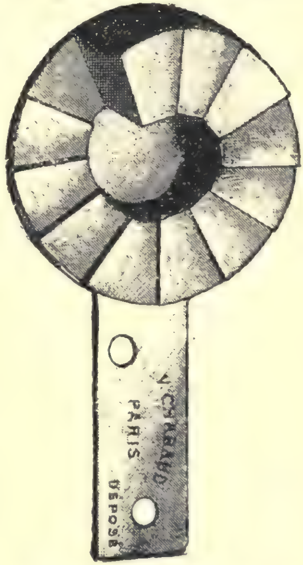



Fig. 24.—The Benoist Radiochromometer, actual size. Note the arrangement of the aluminium sectors of increasing thickness which surround the thin silver plate.

On comparing the relative transparency of aluminium in relation to that of silver for a given radiation, we shall have an easy means of estimating its quality; this will be our procedure on using the radiochromometer. This apparatus, shown in Fig. 24, is formed by a series of 12 aluminium steps, the thickness of which increases gradually from 1 to 12 mm.; they are arranged in the same way as the figures on the dial of a watch. These sectors leave in the centre a circular space in which is mounted a thin silver disc, 0·11 mm. thick.

In order to use it, it is placed against the fluorescent screen on the side nearest to the tube.

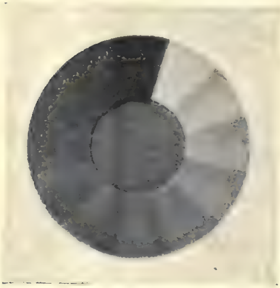


FIG. 25.—This radiograph of Benoist's radiochromometer has been taken with No. 7 rays. We are able to distinguish very clearly the increasingly intense shadows of the six first aluminium sectors. The shadow of the seventh sector is clearly seen, and shows the *same intensity as that of the silver disc.* The average quality of the pencil of rays used was thus of a No. 7 Benoist radiation. The following sectors, from the eighth to the twelfth, have been traversed by a very small number of rays only. They give an intense and almost uniform shadow.

It will then be seen that each aluminium sector produces a shadow of a different intensity. Amongst these shadows there is one the intensity of which may be considered equal to the shadow of the central silver disc which is used for comparison. If, for instance, it is the shadow of the seventh sector, then we say that the rays used are 7 degrees Benoist. It is, however, generally preferable to take a radiograph of the radiochromometer, as this allows a more precise comparison. Fig. 25 shows such a radiograph.*

As correctly expressed by Jaugeas in his excellent handbook, the radiochromometric degree does not absolutely express the power of penetration of the radiation emitted by a tube; because it consists of sheafs of rays of unequal penetration. When we say that the tube emits No. 6 rays, this figure indicates only the average value of the power of penetration of the sheaf emitted at that moment; that is to say that besides No. 6 rays there are for in-

* Various modifications of the Benoist apparatus have been produced, but seem to be only useless complications. The only one worth preserving is the device invented by J. Belot, called the Penetrometer, owing to the advantages it offers when it is desired to follow the variations of the quality of a tube which works in daylight or in a lighted room.

stance No. 4, 5, 7, 8, etc., rays, but in a lesser quantity, and the degree 6 is the resultant of the radiochromometric degrees of the various constituent pencils of rays.

§ 5. **The Screen and the Fluoroscopic Image.—Radioscopy.**—The property possessed by X-rays of rendering certain bodies fluorescent, the principal of which (from the standpoint of practical application) is *platinocyanide of barium*,* is the starting point of *radioscopy*, sometimes still called *fluoroscopy*.

A sheet of cardboard (or of any other substance of low atomic weight, such as wood fabric, etc.), covered with a thin and equal layer of platino-cyanide of barium, and exposed to the pencil of X-rays emitted by a tube, will become illuminated equally, and the more abundant the radiation falling upon it is, the more vivid is the illumination.

If we interpose different substances between the source of the rays and the illuminated screen, they will project on to the screen *a shadow, which will be all the more opaque the less permeable such substances are to the X-radiations* of which they will, consequently, intercept a higher proportion.

Various organs and various tissues of the human body are, however, according to their thickness and their chemical composition, very unequally permeable to X-rays. Interposed between a source of these rays and a screen covered with fluorescent substance they give rise to shadows of unequal density on the illuminated surface due to these invisible rays.

These shadows, which are known as Chinese Shadowgraphs and which present such great similarity to these images, are only transmitted shadows and are formed by the interposition of opaque bodies between the luminous focus and a translucent screen. If they were nothing more, if they projected only the exterior outline of objects giving a uniform shadow, then the images supplied by X-rays would be of little interest. They are fortunately much more complex ; they are superimposed shadows of different densities. For a long time almost all the fluores-

* Amongst the other fluorescent or phosphorescent bodies influenced by X-rays, and offering a practical interest, we may mention *sulphide of zinc* and *tungstate of calcium*.

cent screens used in medical practice were of German manufacture; then screens of British make appeared on the market. Finally two French firms, Roubertie and Caplain-Saint-Andrée, were able to produce screens which could compete successfully with those from abroad. Since the war they have not only greatly developed their output, but also perfected their manufacture to a considerable extent; their screens very successfully replace the best German makes which will now be no longer required.

The illumination of a screen is very variable and depends on conditions which are governed either by the screen itself or by Crookes' tube, or else by the respective distance and situation of the tube and of the screen.

All screens covered with platino-cyanide of barium do not become equally luminous under the influence of the same excitation.

There are in this respect great differences between the screens; these are due either to the conditions of the salt, its purity, etc., or to other complex questions with which we shall not deal here. The fluorescent power of screens also decreases gradually with the duration of their exposure to X-rays, or may even disappear completely under the influence of too great heat.

The same tube at the same distance from the screen will illuminate it quite differently according to the quantity of radiations produced. All other things being equal, the greater the quantity of the rays produced the more vivid is the illumination of the screen. In the same way, all other things being equal, *the illumination of the screen depends upon its distance from the tube.*

The action of the X-rays, similarly to that of light, heat, and of all other radiations, *varies in inverse ratio to the square of the distance.* A screen which shines with a certain brilliancy at a given distance from the focus emitting the rays shines at double the distance with four times less brilliancy; and at triple the distance its brilliancy will decrease nine times. Moreover, the various parts of the screen are unequally illuminated, if struck more or less obliquely by the divergent pencil of rays emitted by the focus.

These are the principal conditions which cause a variation in the physical and objective character of visible radiations supplied by the screen, without considering the luminous sensation provoked by them.

It is with the latter, the action of the eye in front of the fluorescent screen, that we have now to deal. This study is of great practical interest, because the unjustified limitation in the use of radioscopy in medical radiology and particularly in war radiology dealing with the finding of projectiles is due principally to a misunderstanding of the elementary rules resulting therefrom. These studies were made by Mr. Béclère at an early stage of the development of this new science in such a masterly way that the years which have elapsed have changed nothing in his conclusions and have added very little thereto. The following passages have been taken almost literally, as was also the case with the first part of this paragraph, from the remarkable treatise which he himself has written on that subject.*

§ 6. **The Visual Function in Radiology.**—The sense of sight enables us to perceive light, colours, and forms. The perception of light and form are the only questions to be considered for a radioscopic examination. They must be carefully separated from each other: they correspond, at least apparently, to two different functions of the retina.

Thus the physiology of vision includes in radioscopy on the one hand the sensitiveness to light supplied by the fluorescent screen, viz. the *luminous sensitiveness*; and on the other hand the ability to distinguish between the limits and the outlines of various unequally luminous portions of that screen; this is generally called *visual acuteness*, or sometimes, *proper visual sensitiveness* (Charpentier). It is useful to add the examination of a phenomenon which is of some importance when dealing with radioscopy; this is the persistence of retinal impressions.

*Luminous Sensitiveness.*—Everybody knows that after staying for some time in the dark the eye is capable of appreciating a feeble intensity of light which at first leaves it entirely unaffected. This phenomenon plays a very important part in the study of radioscopy. If the apparatus which produces the X-rays is not very powerful

* A. Béclère: *Traité de Radiologie Médicale de Bouchard*, Paris, Steinheit, 1904.

and if the obstacle interposed between the tube and the screen is a rather large thorax of an adult, the person coming from broad daylight into the dark room where the experiments are conducted is always surprised to perceive only a very slight glimmer emanating from the screen without being able to distinguish any image on its surface; whilst observers who have entered the room earlier are able to distinguish moving images such as the beating of the heart and the movement of the diaphragm. A few minutes' patience will enable the new-comer to perceive that the screen begins to get luminous and soon more and more brilliant. He then sees the images which were visible to his predecessors; soon the light of the screen will enable him to distinguish the persons and objects that surround him, and very often he will even discover that numerous cracks allow daylight to penetrate into the room which at first seemed to be dark.

This well-known occurrence is generally explained by saying that it takes some time to get used to darkness; but this is not an explanation. The truth is that these variations in luminous perception obey a very important law, which is called *luminous adaptation*.

The minimum of light perceptible to the same eye is very far from being definite, but changes practically every minute; its value depends upon the average light to which this eye is subjected and adapted.

The stronger the light the higher the perceptible minimum; that is to say, the weaker the luminous sensibility. On the contrary, the weaker the light becomes, the higher the decrease of the perceptible minimum; that is to say, the higher the increase of sensitiveness. If the eye passes from light to darkness, the perceptible minimum decreases with a speed which follows more or less the same law as that of the cooling of bodies. Dr. Parinaud has particularly studied under the name of "adaption to darkness" the increase of sensitiveness resulting from the eye being in darkness for about twenty minutes, and he has noticed that the increase is not the same for the different parts of the solar spectrum. *This increase seems to be slowest in red and quickest in violet light.* Owing to this special faculty of the eye we can see fairly well relatively feeble twilight, moonlight, or artificial light that illuminates the streets. The light emanating from the fluorescent screen is similar to the lights just mentioned, a light of low intensity. There is no doubt, and the simplest observation will prove it, that the adaptation of the eye is an important factor in radioscopic examination and plays a very important part in connection with it. In order to determine this, Mr. Béclère has conducted a series of experiments with his pupils, the principle of which was as follows: The illumination of the screen varies, other things being equal, according to its distance from the tube. The luminous sensitiveness of the various observers is compared by ascertaining, in each case, the distance of the tube at which the fluorescent screen gave the observer the minimum of perceptible light. In any case the degree of sensitiveness which it is desired to find is proportionate to the square of the distance measured from the tube to the screen. These experiments have made it possible to gauge the importance of the adaptation of the eye to radioscopic examination. They have demonstrated the instability of luminous sensitiveness, which varies incessantly according to the receptivity. In view of this instability the figures supplied would not be of absolute value. Such as they are, however, they give an idea of the enormous difference that exists in front of the screen between the retina which is not, and which is, receptive; and also of the almost incredible increase of sensitiveness which is supplied to the retina by a few minutes' observation. *We may say, speaking in a very general way, that under the conditions mentioned the luminous sensitiveness becomes, after a ten minutes' observation,* 50 *to* 100 times larger, and that after a twenty minutes' observation it *becomes* 200 *times larger than at the moment of leaving broad daylight. It increases even after the lapse of that time.*

The comparative study of the individual variations of retinal sensitiveness also supplies other very interesting data. To start with we see that apparently under equal conditions sensitiveness to the light of the screen varies to a great extent with different persons leaving broad daylight. With some it may be four times larger than with others. We see that this degree of increase in luminous sensitiveness may vary, in the course of adaptation, from one day to another with the same person under the influence of diverse conditions, such as fatigue for instance.

Finally, whilst bearing in mind these daily variations we see that a permanent inequality exists amongst the various persons whose receptivity we are studying; and that some of them possess a marked superiority over others, amongst whom only those suffering from night-blindness show an inferiority which is sufficiently considerable to be considered a inhibitory defect from the radiological standpoint.

It is hardly necessary for us to point out the practical consequences resulting from the foregoing conclusions from the standpoint of the darkness of the room, of the necessity of excluding the luminosity of the tube by a black covering, of avoiding sudden penetration of light, etc.

§ 7. **Action on the Photographic Plate; Radiography.**—X-rays act upon the coating of photographic plates in the same way as luminous rays. If therefore we substitute a layer of sensitive gelatine for the fluorescent screen we shall obtain by submitting it after proper exposure to X-rays to the usual photographic manipulations (developing and fixing) an image or *radiograph* which will be an exact materialisation of what appeared on the fluorescent screen. We shall thus have fixed on the plate in their relative intensity the complex shadows which show the difference in transparency to X-rays of the constituent parts of the objects or of the parts of the body interposed between the source of radiation (the tube) and the plate.

It must of course be understood that as in the ordinary photographic process the plate obtained will be a *negative*. The parts which are opaque to the rays, that is to say the dark parts (such as bones, projectiles, etc.) will appear thereon in white, and the transparent parts, such as flesh, in black (with all the relative intensities of white or black, according to the opacity or translucency of the parts affected by the rays). Then by transferring this plate or negative to paper we shall obtain the reverse, that is to say the *positive* in which the opaque parts will be black and the transparent parts light (see Figs. 27 and 28). We are often too apt to forget that radiographs have nothing in common with ordinary photographs except the treatment of plates by developing and fixing baths, etc., but that with the exception of this resemblance in their manipulation the images obtained differ essentially. Whereas photographs give us the exterior form of objects transferred to the plate by means of a lens, and in general with a considerable reduction in size, radiographs are simply and exactly (like X-ray images on the fluorescent screen) projected and generally enlarged shadows which give us not only the projection of an obvious external outline apparent to the eye, but also details of internal structure based on differences in chemical composition (differences of atomic weight) which are not otherwise apparent.

Hence while in a general way properly speaking no interpretation of an ordinary photograph is necessary because everybody understands it perfectly by looking at it and knows what it represents, quite the opposite happens in the case of a radiograph, where the interpretation is everything and the aspect of which reveals nothing or practically nothing to the uninitiated. In other words we must be able to read a radiograph; and whilst it is clearly evident that in order to apply radiology medically it is absolutely essential to be a physician and an anatomist if the reading is to be correctly made, still this is not in itself sufficient, and in order to interpret them correctly we must *constantly bear in mind* certain conditions under which the images have been obtained, otherwise mistakes may be made in reading which would have bad consequences to wounded and sick patients.

We must therefore strongly advise physicians and surgeons who examine radiographic proofs to get accustomed in doing so to observe certain rules to which they will conform later on naturally and to a certain extent automatically; we are sure that by so doing they will avoid many disappointments and mistakes which might have very annoying consequences which occur daily in too many cases. They will moreover gain thereby full confidence in their readings of the plates and will not feel hopelessly bewildered even if they do not have the assistance of a professional radiologist.

§ 8. **Examination of Radiographs.**—When we examine a radiograph of any part of the body, for instance a shoulder, without any further indication as to the side from which it was taken, the first question that arises is whether we are dealing with the right or with the left side. Without some precise rule for examining plates this question cannot be solved. According to whether we examine the radiograph from its glass or from the coated side, so may we assume that we see either a right shoulder viewed from the back, or a left shoulder viewed from the front, or else either a right shoulder seen from the front or a left shoulder seen from the back. Technical reasons and well-established customs in the way in which negatives are taken enable us, as a rule, to eliminate as far as a shoulder is concerned the hypothesis of a front view. Moreover, the appearance of the images would not in this case be absolutely identical, and with a little experience it will be possible easily to distinguish from which side the radiograph has been taken (Chapter III). But between the two alternatives of a right or left shoulder seen from the back according to the side of the plate examined it would be impossible to give a correct opinion.

FIG. 26.—Tracing taken on the screen of a radioscopic image of the right shoulder (seen from back), the patient looking at the tube. Projectile in axilla.

In order to settle all these difficulties we recommend a method which always remains the same and is apparently the simplest and the safest. This consists in taking radioscopy as our basis for guidance.

Let us take the case considered above, namely the shoulder, and let us assume that it is the right shoulder.

If we wish to examine it radioscopically we must place the subject facing the tube, his back towards us, and the screen on which the image shown in Fig. 26 will be produced is then applied *in situ*. If we now take a radiograph of the same shoulder we have simply substituted a plate for the screen. During the pose the sensitive layer applied to the shoulder is turned towards the tube. If after developing and fixing it we look at it from its glass side by turning the gelatine towards the light the image will be seen as shown in Fig. 27, with exactly the same orientation as the radioscopic image of Fig. 26. If therefore ignoring the film side we examine any plate of a shoulder by viewing it from its glass side, it will be sufficient to imagine that we are making a radioscopic examination, that the subject is situated between the luminous source and the operator, and that the plate takes the place of a screen, whereupon we shall immediately ascertain the correct position. This can of course be applied indiscriminately to any part of the body.

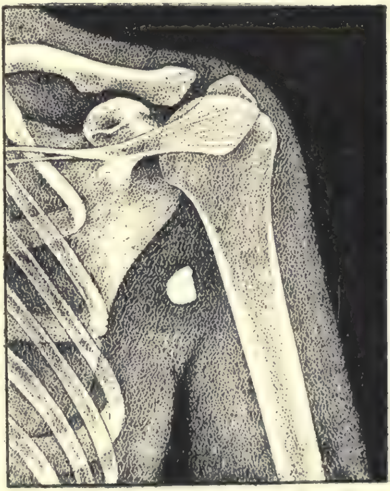


Fig. 27.—Radiograph of the right shoulder. The patient has a metallic foreign body present. This is a negative plate viewed from its glass side. This image is seen in exactly the same way with the exception of details as the radioscopic image of the preceding figure.

If we now have before us a proof on paper of a positive of our plate as shown in Fig. 28, the same remarks will be applicable to it; in order to ascertain the correct position we simply have to consider it as if it were a projection of an X-ray image on the screen. Thus the fluoroscopic image,* the radiographic plate, the positive proof, all the X-ray

* The same considerations apply, of course, to tracings taken from the screen or from the plate.

evidence will be examined in the same spirit and will supply the information desired. This visualisation of images which at the beginning requires a slight effort soon becomes automatic and almost subconscious. It has the great advantage of supplying a practical rule which can be applied in every instance, the only exception being when we use an intensifying screen which causes reversal of the image. This is an eventuality which we hope will become less and less frequent and which we shall discuss shortly after having roughly indicated what intensifying screens really are. Finally, on always viewing plates from their glass side there is no risk of scratching the gelatine and spoiling them by contact with the fingers.

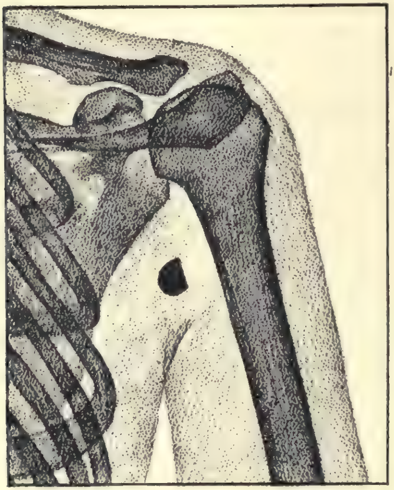


FIG. 28.—The same radiograph of the right shoulder seen from back. We now have a positive and the image is still presented as in the two foregoing figures. We observe the slightly deformed shrapnel bullet in the inner front part of the axilla. Its position on the radiograph enables us to *affirm* that it is *extra-thoracic* and lodged in the *soft parts*.

§ 9. **The Time of Exposure in Radiography.—Intensifying Screens.**—All other conditions being equal, the photographic action of luminous rays depends principally upon the two following factors: (1) the quality (wavelength) of the radiation; (2) the quantity of this radiation which is arrested by the sensitive layer. The respective variations of these two factors determine the length of time during which the radiation used should act; that is to say the *time of exposure* required to obtain a satisfactory plate. Exactly the same thing applies to radiography where a knowledge of the time of exposure is of capital importance. We have seen that the quality of the radiation is estimated in Benoist degrees and the quantity according to the number of milliampères—read with a milliampèremeter—which traverse the tube and to the time, calculated in seconds, during which it works. Let us assume that the sensitiveness of the emulsion is invariable and that the distance from the tube to the plate (for instance 60 centimeters) and the thickness of the part to be radiographed are constant. If, by using Benoist rays 5 and by passing 10 millis into our tube, we have secured a good radiograph of the shoulder in 25 seconds (or 250 milliampère-seconds), we shall always obtain a good image by always returning to the same conditions and by using the same time of exposure of 250 milliampère-seconds (which we can do by either exposing for 250 seconds with 1 milli or for 1 second with 250 millis, etc.).

In general it is best in radiography to use radiations of weak penetration exceeding only exceptionally No. 6 Benoist and the best results are obtained with rays 4 to 5. The images are much finer and richer in contrast, the details standing out clearly. In fact, according to its hardness or softness or, to be more exact, according to whether the wave-length be small or relatively great, an X-radiation will more or less easily traverse the interposed bodies of whatever nature they may be, and will produce more or less clearly contrasted shadows on the screen. The softer the radiation, and the more important the proportion of this radiation arrested by the same difference of atomic weight, the more differentiation there will consequently be on the images, whilst the harder it is the less striking will be the contrast. The images will be "grey." Another great advantage is that it is possible with soft rays to compensate by development the relatively considerable deviations in the time of exposure. With hard rays, on the contrary, the times of exposure must always be absolutely exact if we wish to obtain satisfactory plates, because even slight differences are sufficient to render the radiographs useless. Hence this great drawback more than balances the advantage derived from a shortening of the time of exposure which is possible with these rays.

For thick parts however, and if we have only weak installations at disposal, the length of exposure on using soft rays may become excessive and would constitute an obstacle to its use, were it not possible to remedy it by the use of intensifying screens.

*Intensifying Screens.*—These screens consist of sheets of cardboard on one side of which there is spread a homogeneous layer of some such substance as *tungstate of calcium* which becomes luminous under the action of X-rays, the radiations emitted being mostly violet or even ultra-violet radiations to which the photographic emulsion is as we know particularly sensitive. It is these radiations which intensify or strengthen the action unsufficient in itself of the X-radiation on the plate. With the screens which have been manufactured for some years past the time of exposure may be shortened considerably—in the proportion of 1 to 10. German industry had entirely monopolised this special branch of manufacture; but the war has shown that in this direction we were also able to do without it, and to produce equally good or even better articles. Messrs. Caplain-Saint-André and Roubertie, for instance, at present manufacture excellent intensifying screens. Care must always be taken to secure complete contact between the sensitive layer of the screen and the gelatine of the plate as the effect of the screen is only satisfactorily accomplished when the contact is absolute. For this purpose cassettes are used, the best type of which is at present represented by Drault's aluminium cassettes, which enable the pictures to be taken direct and without reversing the image (Chapter IV). As previously indicated (§ 8) this point is of the utmost importance. Most of the German screens were constructed in such a way that by using them the rays first traversed the glass of the plate, then the sensitive layer and finally the screen. Under these conditions the image obtained on the positive is presented, in relation to the radioscopic view of the same part of the body taken under normal conditions, like an image seen in a mirror. There is therefore a reversal of the image which may easily lead to an error as regards the part affected. Indeed such errors have been very frequent. This great drawback is not counterbalanced by any real advantage. The method which consists in adjusting the plate as usual in relation to the source of rays produces (if a good cassette be used) images which are equally satisfactory from every point of view. *It should, therefore, always be employed in preference to the preceding method.*

Apparently however there is at present a tendency to abuse the use of intensifying screens. The desire to shorten the time of exposure is only justified when it is a matter of taking radiographs of mobile organs. Unless exceptionally powerful installations are used good radiographs in apnœa without a screen will be obtained only with great difficulty. Screens should, therefore, be used for most visceral radiographs, which require apnœa for complete immobility and perfect clearness.* But for bony structures there is no necessity to insist on this reduction in the time of exposure to the detriment of the quality of the image, and plates taken with a screen never give the fine detail shown in plates taken without a screen.

Moreover, after being used for a certain time the screens constantly show defects, spots, etc., which are reproduced on the plates and may be taken for foreign bodies. Such possibilities of error must never be neglected, and care must be taken when searching for very small foreign bodies to use plates only without the aid of an intensifying screen as far as possible.

§ 10. **Secondary Radiation.**—Amongst the important

* We distinguish :

(1) *Slow radiography* for which the time of exposure is counted in minutes. It is becoming more and more exceptional in view of the extension in the use of intensifying screens. The weakest instruments only may necessitate exposures of several minutes for thick parts if intensifying screens are not used.

(2) *Rapid radiography* for which the time of exposure is less than one minute, irrespective of the part to be radiographed. The use of the latter is the most general.

(3) *Very rapid radiography* for which time of exposure varies between one-tenth of a second and one second. It is now commonly used with high-power instruments, and is almost indispensable if it is required to examine certain mobile viscera (alimentary canal).

(4) *Instantaneous radiography* the time of exposure for which is less than one-tenth of a second. It can only be effected with certain exceptional apparatus. It is indispensable for obtaining sharp radiographs of the heart's outline.

advantages which we have pointed out in order to recommend the use of soft rays are images with sharp and contrasting outlines. Their absolute clearness depends, however, upon another important condition which we have so far not mentioned. In fact, it depends essentially upon the smallest possible quantity of secondary rays produced.

When an X-ray strikes an atom of a body, this atom

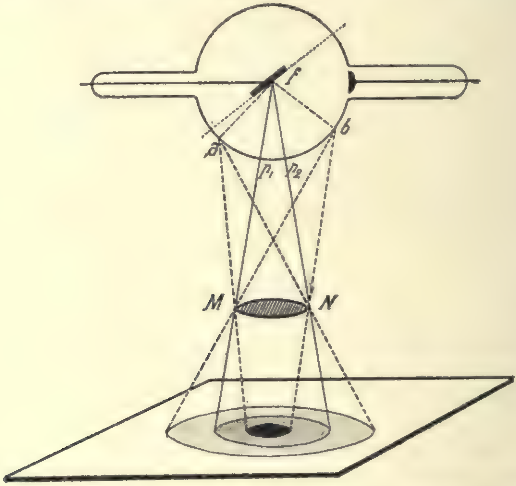



FIG. 29.—Supposing *MN* to be the object radiographed: We see that each of the secondary radiation focuses *a*, *b*, issuing from the walls of the tube will give a penumbra, and we can imagine the diminution in the clearness of the image which will result therefrom. A shield of a substance which is opaque to the rays, without which no tube should now be used, will to a great extent decrease the influence of the secondary radiation emanating from the walls of the tube, as is shown in the following figure.

emits in return another X-radiation which is called *secondary radiation* and the greater the penetration of the incidental radiation (called the *primary radiation*) by which it is produced, the more penetrating is this secondary radiation. This emission of secondary radiations discovered by the French physician Sagnac is of the greatest importance from various standpoints and especially in radiotherapy.

As regards radiography the secondary radiation has so far frequently been the cause of considerable annoyance, because each atom becomes in its turn a focus of rays. The clearness of the image would thus be considerably diminished as each of these sources would supply an image. We should thus obtain multiple images with penumbræ without the formation of a single shadow, and the clearness of the image might be affected to such an extent that it might be impossible to make use of it for radio-diagnostic purposes. If we do not take into consideration the secondary radiation of the air it will at once be apparent that in any X-ray operation we shall have to deal with two main sources of secondary radiation : that the first one will be formed by the wall of the tube and the second by the body to be radiographed.

It did not take long to discover means for eliminating the action of secondary rays emitted by the walls of the tube. Its deleterious influence on the clearness of the image is shown in Fig. 29. The diagram which follows shows that it is sufficient to enclose the pencil of rays emitted by the shield in a cylinder of such proportions that none of the injurious rays reach the screen or the plate (Fig. 30).

These cylinders are called *diaphragms*, and the difference in the clearness of plates taken with and without them is very apparent. Their use is absolutely necessary if it is desired to obtain radiographs which will show fine detail and especially satisfactory images of the osseous structures.

A simple diaphragmatic disc would not be quite satisfactory because it never eliminates more than a part of the secondary radiation ; but it enables us especially in the form of the iris diaphragm devised by Béclère not to be inconvenienced by the limitation and fixity of the area to be examined. This is a very considerable advantage especially in radioscopy which induces us to give it the preference over cylindrical diaphragms. Its influence on the clearness of images is extremely important ; this is especially noticeable when searching for projectiles. Very often when an examination is made with an open diaphragm the projectile is not visible ; it appears however when the diaphragm is closed and only a very small opening is left uncovered. We shall see later on that

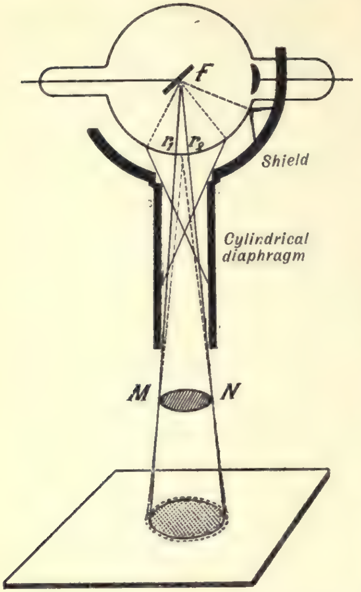



FIG. 30.—The shield itself arrests a considerable part of the secondary radiation. The cylinder diaphragm eliminates the influence of all the secondary rays so prejudicial to the clearness of the image, that escape through the opening of the shield as they are not included in the cone $r_1 Fr_2$. They are arrested on the walls of the tube if the cylinder is sufficiently long and narrow. The secondary rays generated in the zone $r_1$ $r_2$ of the tube's wall, and recorded in cone by $r_1 Fr_2$, will be all the less troublesome, due to the faint penumbra which they may produce, the longer and the narrower the diaphragm.

this is very important for the localisation of projectiles by radioscopic methods.

These devices do not enable us to eliminate the secondary radiation emanating from the body radiographed. It may be diminished by compression and especially by the use of soft rays which produce as already mentioned fewer secondary radiations than hard rays; so far there is no really practical means in existence to suppress it altogether, and its annoying influence especially in radioscopy will still be constantly noticeable in examining the thick parts of the body (abdomen, pelvis) especially of stout patients.

§ 11. **Radioscopy or Radiography, and their Respective Indications.**—Whenever we require to make an examination we shall, therefore, have to employ these two methods which far from excluding each other form a mutual complement to one another. Radioscopy alone enables us to examine organs in motion and to study by palpation and mobilisation under the screen their normal and pathological relations under the most diverse angles of incidence. In the anatomical research for and localisation of projectiles, it is especially adapted (owing to certain technique in mobilisation) to yield information of the utmost value.

If, however, we desire a permanent record, or wish to obtain the most complete details of bony structure, or if we wish to ascertain the presence of metal particles, we must resort to radiography which alone can supply all the minute details which the eye is unable to perceive on the screen. As our examination of the screen is made in the dark, that is to say under conditions to which the eye is not adapted, our *visual acuteness* is far inferior to what it is in full daylight, and does not increase in proportion with our adaptation. As demonstrated by Béclère this is the essential reason for the difference existing between the two kinds of images, radioscopic and radiographic. The following experiment will demonstrate this in a very convincing manner. A good radiograph of the thorax should be taken and examined in full daylight, and the existence of some minute particular detail noted. Thereupon it should be examined in a dark room by the light of a fluorescent screen placed against it. It will then be noticed that the details have disappeared, and that the analogy to a radioscopic image is almost complete. Should there be any difference it arises mainly from the crystalline structure, and granular condition of the platino-cyanide of barium which is less favourable to the production of clear images than the polished surface of the plate.

*It is, therefore, essential in all difficult cases and in all such where it is of importance to obtain complete details, to take a radiograph after a radioscopic examination. Inversely we should not in similar cases be satisfied with a plate, which is an inert document, but should carry out a detailed radioscopic examination aided by our anatomical and physiological knowledge.*

## CHAPTER III

### LAWS OF PROJECTION

### Primary Ideas on X-ray Interpretation

§ 12. **Projections and the Normal Ray.**—Being now able to practise radioscopy and radiography with apparatus and a technical knowledge calculated to give the best possible results from the standpoint of clearness and the detail of our images, and to permit of the elimination of secondary rays, let us now examine more closely the physical conditions contributing to their formation. These studies are in fact absolutely indispensable if radioscopic and radiographic shadows are to be correctly interpreted. By continuing to liken X-rays to luminous rays and their source to a luminous punctiform source we shall find at first that the shadows projected by any body interposed between that source and a fluores-

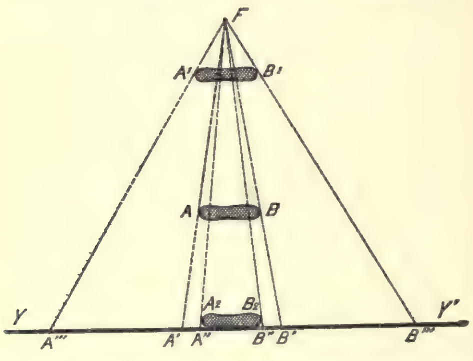



Fig. 31.—*F* being the luminous source, the opaque body *AB* projects its enlarged shadow at *A'B'*. The nearer it is to *F* in $A_1B_1$ the larger will its shadow $A''' B'''$ be. On the contrary if we place it at $A_2$ $B_2$ on a level with the projection plane its shadow $A''$ $D''$ will scarcely be increased.

cent screen or a photographic plate will strictly obey the laws of conical projections.

Thus as shown in the diagram of Fig. 31 the shadow thrown on a surface $YY'$ by a body $AB$ interposed between said surface and the point $F$, which is the source of radiation, will be all the larger the nearer the body $AB$ is to the said source and the further from the plane of projection.

It will be all the nearer to the size of the object the further the latter is distant from the source and the nearer the plane of projection. This enlargement can be very easily calculated and a table prepared of its values. Similar tables have been published from which it may be seen that the enlargement for a source situated at a distance of more than two mètres is almost nil. In practice it may even be considered that the same obtains for a distance of 1 mètre 50. Radioscopy and radiography conducted at this distance (called teleradioscopy and teleradiography) are thus able to supply radiological images of natural size.

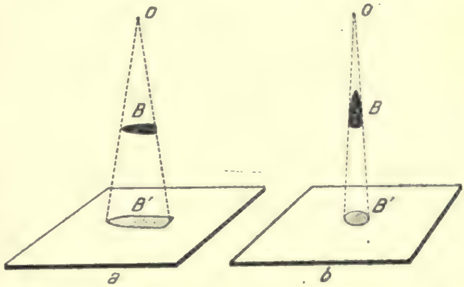



FIG. 32.—$O$ being the luminous source, $B$ a bullet interposed between it and the projection surface, it is possible, by a simple examination of the diagram, to see that according to the position of $B$ its shadow $B'$ will reproduce an enlarged form of the projectile, as shown in diagram $a$; or, on the contrary, it will reproduce a circumference (corresponding to the circumference of the base of the bullet) as shown in diagram $b$, all intermediary forms being also included.

But all radiological images are flat *projections upon one single plane*. The same object could therefore give entirely different shadows, according to the direction in which it is placed with regard to radiation.

Thus the shadow produced by a bullet $B$ might appear, as shown in the diagrams of Fig. 32, under various forms.

*Hence, a plate taken in one direction will not enable us to judge as to the real form of the projectile.* Apart from their enlargement, X-ray images are also strangely distorted unless special precautions have been taken. A moment's reflection will suffice to show that it is the *incidence* of the radiation used in relation to the object examined and to the plane of projection which determines the degree of distortion (the distance of the tube from the plane of projection remaining invariable and the object being supposed to be stationary, in order to simplify the study of the variations). Amongst the three factors which are then to be determined: viz. position of the tube, position of the object (or subject) being examined, and position of the plate (or of the screen), that is to say the plane of projection :—it is most often the latter which has been considered as the most important in influencing the incidence of the ray and determining the other variable factors. If we adhere to this method of operation, and if we inquire which should be the position of the "plane of examination" (that is to say of the organ examined or part supposed to be placed on a plane), then we shall agree with Guilleminot that: "in order to see a region with minimum distortion it is necessary to place the plane of examination parallel to the plane of projection, and (unless there are special indications) select the frontal or sagittal plane, by placing the focus of the tube perpendicularly to the planes of examination and to the plane of projection passing through the centre of the region under consideration." The ray emitted by the focus of the tube, and which remains at right angles to the planes of examination and projection, has been briefly termed the *normal ray*. However, practical necessity soon made it necessary to extend and modify according to the authors who defined it the meaning of that term an exact knowledge and comprehension of which is of the utmost importance.

The most important point in War Radiology and especially in the localisation of projectiles is to maintain the same incidence in relation to the plane of projection and to be capable of re-finding it with certainty as the plane of examination is not necessarily parallel to the plane of projection. It is therefore merely necessary to choose as a normal ray a well-determined ray which could always be found again at will and would always be the same.

But, nowadays, no tube is or must be used without being placed in a shield or protective box, impermeable to X-rays and which only allows them to pass through a determined opening generally circular. Let *BD* be this opening in the shield shown in diagram in Fig. 33. Thus only the cones of the rays *BFD* passing through that opening will be utilised. We can then place the tube in relation to its shield, in such a manner that the perpendicular of the focus *F* on the plane of the opening *BD* will at the same time pass through the centre of this opening, it being of course assumed that the focus is punctiform. It is *this ray* perpendicular to the plane of the diaphragm that we call the *normal ray*, and we say that the tube thus placed in relation to its shield is termed *centred*.

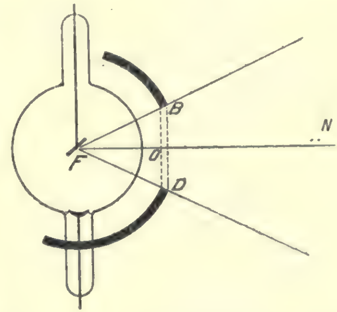



Fig. 33.—Assuming *F* to be the focus of the tube and *BD* the opening of the shield: The cone of the radiation used will be *BFD*. On so placing the tube in relation to the shield that the perpendicular of the focus on the plane *BD* of shield aperture passes through the centre *O* of this opening (that is to say coincides with the axis of the cone *BFD*) we shall then say that the tube is centred and the ray *FO* is termed the *normal ray*.

A simple examination of Fig. 36 will show us at once that if, other things being equal, we assume that the normal ray is perpendicular to the plane of projection or, what amounts to the same thing, if we presume that the plane of projection and the plane of the aperture in the shield (or the plane of the diaphragm) are parallel, then the radiological image of any object placed in the plane of projection will be more enlarged and distorted according as the object is removed further from the base of the normal ray and *vice versâ*.

We must therefore in practice approximate the region to be examined as near as possible to the plane of projection surface; that is to say we must apply it to the plate or screen, and adjust the zone of that region in which we are interested (and which we call the plane of examination) parallel to the plane of protection (plate or screen). Finally and especially we must operate only with a tube which is perfectly centred, so as always to know the direction of the ray which we have defined as the normal ray. It will have to be perpendicular to the plane of projection and consequently to the plane of examination; we shall arrange to allow it to pass through the most

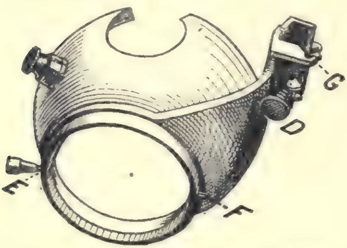



FIG. 34.—Shield of lead glass. The circular opening of the lower part defines the cone of the radiation used, and it is upon this aperture that the diaphragm is fixed.

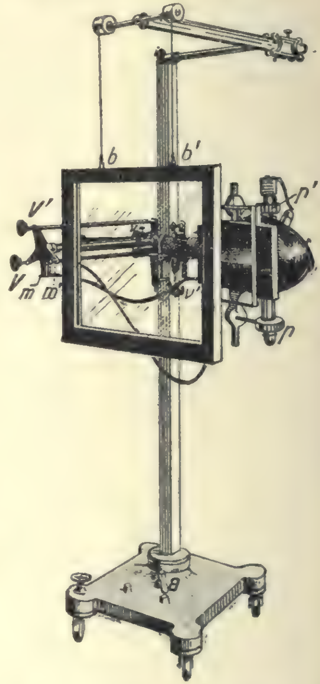



FIG. 35.—The tube placed on its carrier is centred in the interior of the shield which is provided with a diaphragm with movable shutters. The whole is fixed on a large tube stand designed by Dr. J. Belot (Gallot et Cie.).

interesting point of this plane of examination, for instance the projectile, if it be a projectile that we are examining.*

* If the object under examination is too large to enable it to be treated as a point, we must make our arrangements in such a way as to adjust its longest diameter as symmetrically as possible in relation to the normal ray.

A correct comprehension, perhaps a little difficult at first, of the normal ray and of the characteristics of the projections obtained is of the utmost importance in radiology; this is especially the case in the special sphere in which we are interested. Without such knowledge it is impossible to understand completely what is being done and to interpret the images observed. It is also useless to try to localise projectiles without an exactly centred tube.

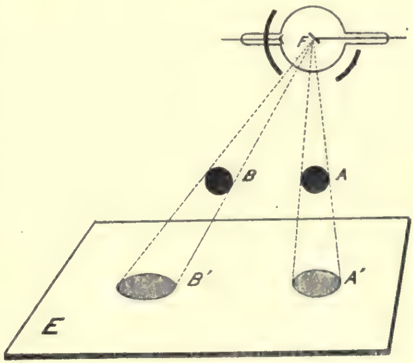



FIG. 36.—The projection (on the surface $E$ of the screen or plate) of a shrapnel bullet $A$ placed in the path of a normal ray will be the *enlarged but not distorted* shadow $A'$. If we place the shrapnel at $B$, outside the normal ray, its projection will be the enlarged and distorted shadow $B'$, and the distortion will increase in proportion as we move it away from the normal ray.

This centring, always very simply and rapidly effected with the instruments now supplied by our great French manufacturers, should therefore always be done on changing the tube. From this, as from many other points of view, everything supplied by foreign industry is much inferior to that obtainable in France. The others are only imitations and very often bad ones. Let us not forget that the first apparatus with tubes adapted to be correctly

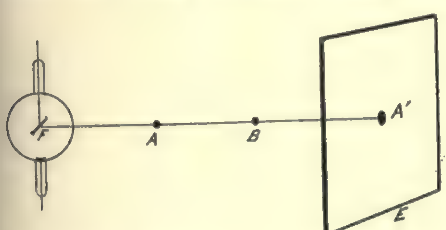



FIG. 37.—The shadows of the two opaque points $A$ and $B$ both situated in the path of the normal ray merge on the fluorescent screen $E$, into one shadow $A'$.

centred were produced in France owing especially to the researches made by Messrs. Béclère, Belot, Guilleminot, etc.

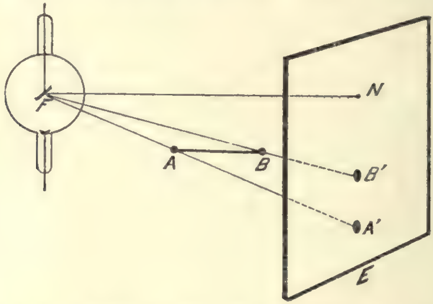



Fig. 38.—Let us displace the straight line *AB* parallel to the normal ray *FN*. The shadows of the opaque points *A* and *B* will be produced at *A'* and *B'*, and the three points *N*, *B'*, *A'* will be on the same straight line.

This is how the centring is effected.

Suppose there are two opaque points *A* and *B* situated on the same axis. Let us make this axis coincide with the path of a normal ray. The shadows of *A* and *B* on

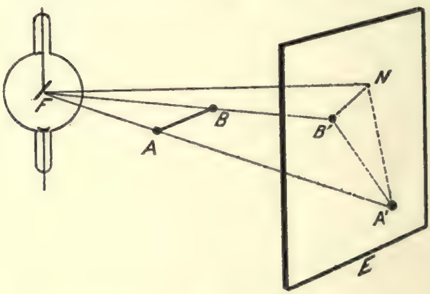



Fig. 39.—If the straight line *AB* is moved in any direction in space no longer parallel to the normal ray *FN*, the opaque points *A* and *B* throw their shadows at *A'* and *B'* upon the fluorescent screen *E*, but *A'*, *B'*, and *N* are no longer on the same straight line.

the plane of projection will merge into a single shadow *A'* (Fig. 37). Let us now displace the axis *AB* parallel but out of the axis of the normal ray.

The shadows $A'$ and $B'$ of $A$ and $B$ will become separated, and the distance between them will increase in proportion

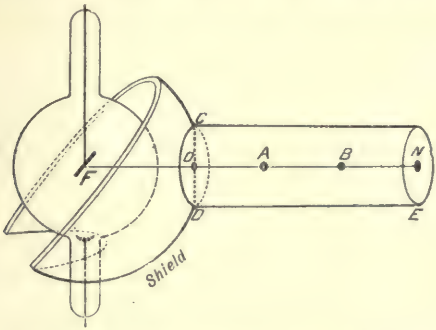



FIG. 40.—The tube is placed correctly into its shield, it is *centred*. The central ray of the focus $F$ of the tube perpendicular to the plane of the aperture $CD$ of the shield passes through the centre $O$ of said aperture (normal ray). It thus passes through the axis of the tube indicating the incidence, and the two opaque points $A$ and $B$ of this axis project their shadows on to a single spot $N$ on the small fluorescent screen $E$ fixed at the free end of the tube.

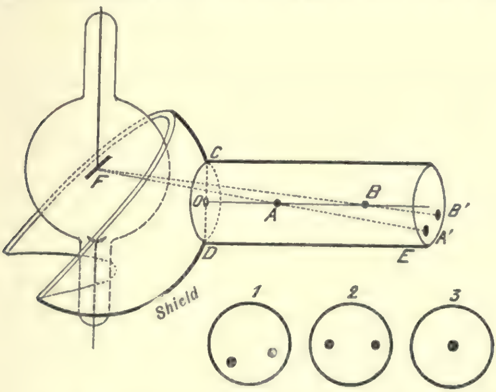



FIG. 41.—The tube is centred in the cupula. The opaque points $A$ and $B$ form their shadows at two different points $A$ and $B'$ of the fluorescent screen $E$, which is shown in front elevation at $I$. In order to centre the tube, it is first lowered vertically into the shield, until the screen shows the two shadows according to Fig. 2 finally it is moved horizontally until the two shadows coincide as seen in Fig. 3.

to the distance of the straight line $AB$ from the normal ray $FN$, the three points $N$, $A'$, $B'$ remaining on the same straight line (Fig. 38). Let us now displace $AB$ at random; the three points $N$, $A'$, $B'$ will no longer be situated in the same straight line (Fig. 39). This procedure will at once give us a means for constructing a simple and precise centring device. Let us fix two opaque points upon the axis of a metal tube $T$. Let us fit this tube on to the shield in such a way that its axis passes through the centre of the aperture in the shield, perpendicularly to the plane of said aperture. If the tube be well centred the normal ray will pass through the axis of our tube and, if we place a small fluorescent screen $E$ (Fig. 40) at its free end, the opaque points will merge their shadows upon it into a single one at point $N$.

On the contrary, if the tube be not centred, the normal ray will not coincide with the axis of the tube, and the points $A$ and $B$ will project their shadows upon different points $A'$ and $B'$ of the screen (Fig. 41).

All that will be necessary then is to displace the tube in relation to its shield, first upwards and downwards and then from left to right, in order to obtain a coincidence of the shadows $A'$ and $B'$.

When these shadows coincide and form a single image the tube will be centred.

In practice, each of the two opaque points is represented by the point of intersection of two metal wires. The centring device is a metal tube, in the interior of which there are two crossed metal wires, their intersection corresponding with the axis of the tube. One of the ends is mounted so as to fit accurately to the opening of the shield, and so that the axis of the tube can pass through the centre of this opening; the other end is free and carries a fluorescent screen on which the shadows of the crossed wires projected. By means of adjustments, provided for the purpose on the tube supports, the tube can be moved within the shield, at first in a vertical and then in a horizontal direction, until there appears on the screen only one well-defined shadow of the cross wires (Fig. 42). All these manipulations are easily effected by means of special screws on the tube-supports, the arrangement of which differs only in points of detail.

It follows from what has been said before that if we wish to interpret a radiograph correctly we must know where the end of the normal ray which indicates the zone of least distortion falls upon the plate. It will generally be found in the neighbourhood of the centre of the image

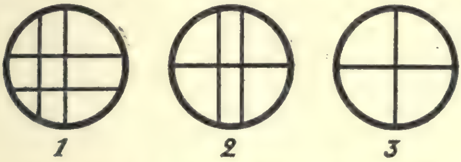



FIG. 42.—Diagrams 1, 2, and 3 show the aspects under which the crossed metal wires should appear successively on the small fluorescent screen, when a tube is centred by means of a centring device with crossed wires.

because we shall of course be careful to place the most interesting zone as exactly as possible near the centre of the plate.

A few examples will enable us to understand more fully the importance of the normal ray and the necessity for having a carefully centred tube if we wish to make any radiological examination, and especially if we have to localise a foreign body, because without it this operation would only lead the radiologist and surgeon into error.

Let us assume that the subject has a rifle bullet in his forearm which must be extracted. The surgeon must know where and how to make the necessary incision. The radiologist must therefore tell him exactly under what point of the skin the bullet is lodged. Let us pass the normal ray through the centre of the projectile $P$, and mark its virtual point of issue $P'$ (Fig. 43) on the skin. To do this it will be sufficient to make a screen examination with a well-centred tube, to place the patient's arm in such a position in relation to the tube that the shadow of the bullet will appear on the screen in the centre of the luminous region determined by the diaphragm, and then to slide a metal rod opaque to the rays under the screen and in contact with the subject's skin until the shadow of its point coincides on the screen with the middle of the shadow of the projectile.

If leaving the point of the rod on the spot we cut off the current and remove the screen, then we can mark on

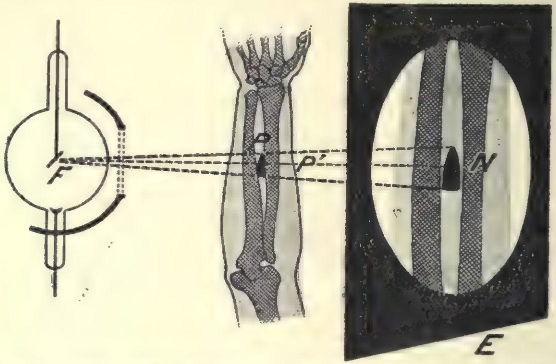



FIG. 43.—The tube is centred. The normal ray passes through the centre $B$ of the projectile, and the end $N$ of the normal ray is in the centre of the shadow of the projectile on the fluorescent screen $E$.

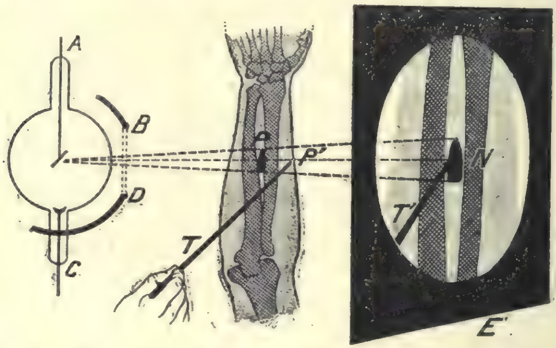



FIG. 44.—By means of a metal rod $T$ opaque to the rays which we slide along the skin under the screen until the shadow of its point coincides on the screen with the centre $N$ of the shadow of the projectile we determine the point $P'$ of issue of the normal rays (passing through the centre of the projectile) on the skin of the forearm. The projectile is situated under that point.

the skin with a dermographic pencil (or by any other means) *and thus indicate definitely the point of issue of the normal ray* (Fig. 44).

This very simple manœuvre is of the utmost importance in radio-diagnosis of projectiles and we shall meet with it continually. It is an essential part of all radioscopic localisation. In the example under consideration it will indicate to the surgeon his line of incision, because he

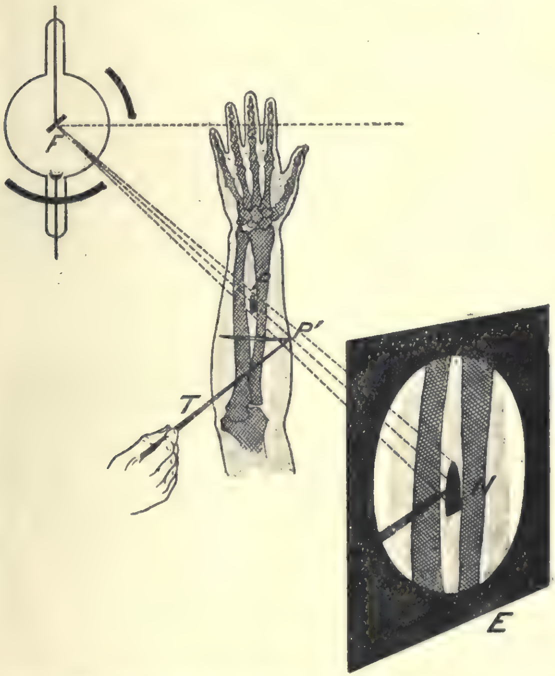



FIG. 45.—The tube is no longer centred. We have used an oblique ray *FN* and determined its virtual point of issue *P′* on the skin of the forearm. The projectile will not be situated under this point and the deviation may be sufficiently large to prevent an incision, made at the level with that point, from reaching the projectile.

knows that the projectile is lodged vertically in the tissues under the point marked.

Let us suppose, however, that the tube is wrongly centred and that the rays follow an oblique route shown in the diagram (Fig. 45). In that case the point marked on the skin will be the emerging point of any one of these oblique rays, and will cause the surgeon to make a mistake because he will be guided by it and will be searching in vain for the projectile in the tissues underneath that point.

In this connection we must note how the least difference in the determination of the plane of examination will give rise to a deviation in the emerging point of the normal ray on the skin.

Fig. 46 shows diagrammatically with reference to a

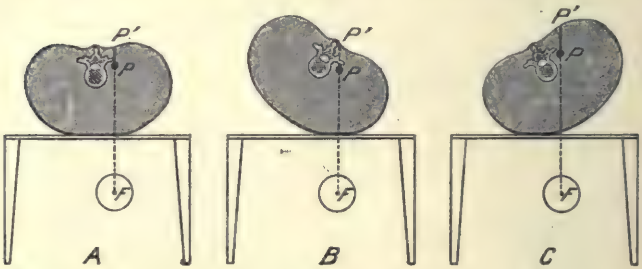
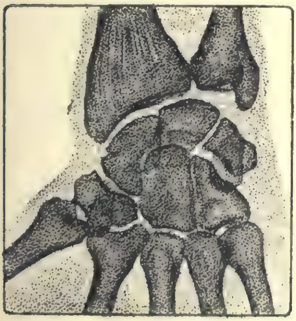



FIG. 46.—Let us assume that *P* is a shrapnel bullet close to the spine situated slightly in front of a transverse process. The patient is placed on his abdomen on an X-ray couch in a position suitable for extraction. According to whether he is situated exactly in ventral decubitus—Diagram *A*—or slightly inclined to the side—Diagrams *B* and *C*—the point of issue on the skin *P′* of the normal ray passing through the projectile will be subject to considerable deviations which may cause it to pass over the median line or even to the other side of that line.

projectile close to the spine the utmost importance of this orientation in localising foreign bodies.

We have now to examine a radiograph of the wrist in order to determine the state of the radio-carpal articulations and the existence of any bony anchylosis. We have directed the path of the normal ray upon the joint (this is called in X-ray language *centring* the joint). The plate shows that the articular spaces are clear and intact, there is no anchylosis (Fig. 47). But here is another plate (Fig. 48) not correctly centred; the path of the normal ray corresponds more or less to the middle of the forearm.

The articular spaces have disappeared and are covered with distorted projections of the bones of the carpus and of the forearm. If we have sufficient experience we shall not express any opinion with regard to this plate which is of no value to us and we shall take another under proper conditions; that is to say with a perfectly centred tube, being careful to centre the proper region. But we may easily err in the diagnosis and pronounce the existence of anchylosis if our X-ray experience is not sufficient or if a too hasty and superficial examination of the plate has not enabled us to judge correctly of the superimposition of the shadows of the inferior extremity of the radius and of the bones of the first row of the carpal bones which



FIGS. 47 and 48.

immediately shows the distortion of the image and the absence of correct centring.

These examples could be multiplied *ad infinitum*. They demonstrate the absolute necessity of using only perfectly centred tubes, and of verifying the centring from time to time. Henceforth when we speak of any X-ray operation it will be understood implicitly that this condition has been fulfilled.

There may be however some instances where it is advantageous to use oblique rays. This was very forcibly demonstrated by M. Béclère, when making an X-ray diagnosis of interlobar sclerosis.

Fig. 49 shows us the layer of sclerosis, and makes it clear that the normal ray and all the rays which meet it almost normally traverse it very easily in view of the slight thickness of the indurated tissue to be traversed.

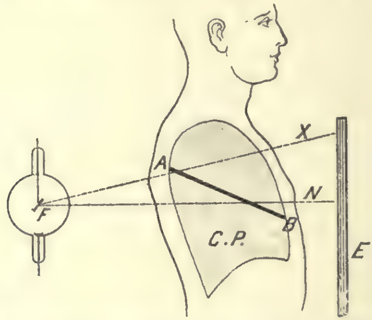



FIG. 49.—Let us assume that $AB$ is an interlobar patch of consolidation situated in the pulmonary region $CP$ and irradiated from the back towards the front. The rays $FN$, $FX$, etc., which are emitted from the focus $F$ of the tube and illuminate the fluorescent screen $E$, have only to traverse the thickness of that thin layer of consolidation (quite insignificant even if taken slightly obliquely and consequently unable to stop them) and so no shadow will be produced. This condition therefore will pass unperceived during the examination.

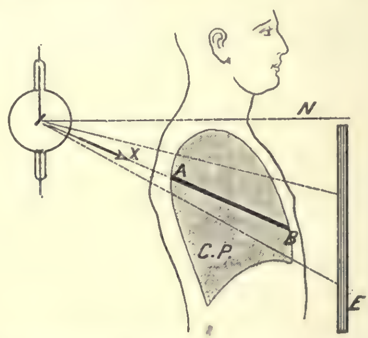



FIG. 50.—If on the contrary we place the tube so as to use oblique rays in the same direction as the layer $AB$, it will be seen that rays such as $FX$ will have to traverse the layer $AB$ along its whole length. They will, therefore, be stopped to a great extent and the shadow of the layer of consolidation $AB$ will appear on the fluorescent screen $E$.

It will, therefore, not produce any shadow on the screen and will evade our radioscopic examination. Let us, however, arrange the tube (Fig. 50) so as to utilise oblique rays. These rays, the obliquity of which will be the same as that of the layer of consolidation in their path, will have to traverse the whole length of that layer (that is to say a considerable thickness of indurated tissue). They will, therefore, be stopped and we shall see on the screen the shadow of the indurated pleural band. These considerations apply especially to thin pieces of metal which, seen from the front, are very transparent and very often escape detection, but seen from the edge they appear immediately. It is, therefore, always necessary to move the tube during a radioscopic examination in all directions in order to find the projectile (Chapter V).

We have so far had under consideration X-ray images as conical projections only. A knowledge of the normal ray enables us to obtain on the screen *orthogonal projections*. By means of various pieces of apparatus, such as those of the Béclère type, or of the tube holders constructed by Drault and by Gaiffe (model of Dr. J. Belot), we are able to move at will the normal ray in space. It is thus possible to make this ray follow tangentially the whole circumference of an organ such as the heart. By marking successively on the screen each of the points of that circumference we shall be able to determine the orthogonal projection of that organ because we shall have operated with parallel rays. This process is called orthodiagraphy (Fig. 51).

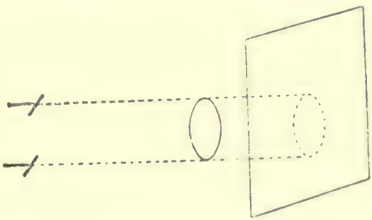


FIG. 51.—Diagram showing how an orthogonal projection is obtained by displacing the normal ray parallel to itself.

We shall thus be able to obtain the actual measurements of objects and organs and especially to determine easily the characteristics of the embedded projectiles if we can ascertain their principal diameter. If for instance a bullet can be perceived radioscopically along its main axis, we shall only have to pass the normal ray at first through its base and then through its point and mark each of these points on the screen in order to obtain its length. It is however sufficient to examine Fig. 32 in order to understand that the orthodiagram of an organ varies essentially with the aspect of that organ in space. Therefore before taking into consideration the outline obtained as indicating the true size of the heart it will be necessary, in order to avoid a too frequent error, to make certain that the large axis of that organ is parallel to the plane of projection.

We have seen already that teleradioscopy and teleradiography enabled us also to obtain practically orthogonal images which are however subject to the same restrictions.

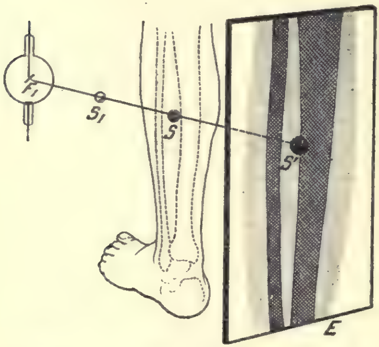



FIG. 52.—Whatever the position $S$, $S_1$, etc., of a projectile on the course of a normal ray projected from the focus of the tube $F$, the position of the shadow $S'$ of that projectile will not be modified on the screen $E$, or on a plate. Only the size of the shadow will vary (according to laws which we have already explained). The image obtained in this position cannot, therefore, show us the exact site of the projectile along the normal ray.

As regards war practice, in which we are almost entirely taken up with measuring projectiles, our orthodiagraphy will be limited to marking on the screen the normal projection of the ends of the projectile in one or perhaps two diameters, a method for the first development of which we are indebted to Destot.

§ 13. **Interpretation of X-ray Images.**—Whilst keeping in mind the preceding considerations we shall now be able to undertake the practical study of X-ray images. Let us consider any foreign body, say a shrapnel bullet retained in a part of the body, say the leg. Let us make an antero-posterior examination, that is to say with the posterior surface of the leg nearest the screen (or plate).

The diagram in Fig. 52 shows at once that the position of the shadow of the bullet on the plate will be exactly the same, whatever the position of the projectile as to the normal ray, in other words *whatever its depth*. It may even be situated outside the limb—above or below—and the image will not be modified except as regards the size of the shadow. A plate taken in one direction does not therefore enable us to form an opinion as to the real position of the foreign body, which, if the tube has been well centred and if the projectile is lying in the course of the normal ray, will be found situated at some point on that normal ray, between the focus of the tube and the plate (or screen). Let us now place the leg sideways, its external surface on the plate, viz. 90° from the preceding position, and let us make another examination either with the screen or with a plate.

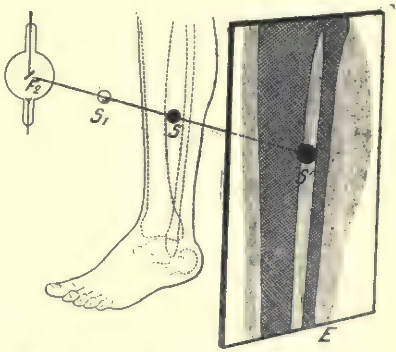



FIG. 53.—If the examination is undertaken in another position, at 90° from the former one, the same considerations will apply to the image obtained. But we have now obtained *two* distinct images, and on each of these we know the point of entry or exit of the normal ray which corresponds to the shadow of the projectile, which will therefore be situated at the point of intersection of the two rays.

The above considerations may still be applied (Fig. 53). The foreign body is situated in the path of the normal ray which is perpendicular to the preceding one. If we consider a section of the limb according to the plane passing through the projectile and determined by the two normal rays, it is evident that the projectile is situated at their intersection (Fig. 54). The two plates at right angles will enable us to imagine these two rays in space, and to form an approximate opinion of the position of their point of intersection from the standpoint of topographical anatomy. We shall see later on how these data can be utilised for the purpose of obtaining a more exact localisation of the site of foreign bodies.

We thus see the absolute necessity of having images in two directions at right angles to each other, if we wish to be able to obtain an idea of the real respective position in space of the parts whose shadows have been projected on the plates (or screen), because a single image in a single plane does not signify anything, either as regards the form or situation of the projectile radiographed. This shows clearly how much to blame was the inexperience of those who at the beginning of the war were carried away by first impressions and thought that they knew sufficiently accurately the position of a projectile of which they saw the shadow on a plate as to be able to extract it at once surgically. Their failures soon showed them their mistake.

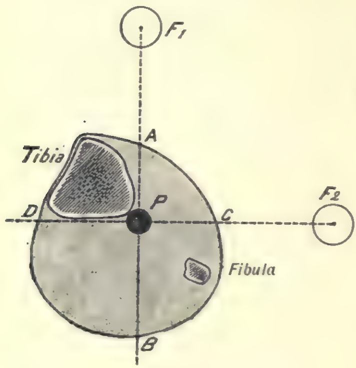



FIG. 54.—Let us imagine a section of the leg according to the plane determined by the two positions of the normal ray shown in the two preceding figures. Let us suppose it is the superior segment of the section. The projectile is situated at the intersection of the two rays. If we materialise these rays by marking on the skin their points of entry and exit, *A*, *B*, *C*, *D*, we see that we can find out almost exactly the position of the projectile in the tissues, that is to say we can localise the projectile.

The X-ray examination of fractures also shows us very clearly the necessity for two plates—or two radioscopic images—at right angles if we wish to find out the displacement, reduction or union, etc., without committing grave errors. The diagram (see Fig. 55) is sufficiently explanatory. Let us also remember that radiography alone enables us, as explained in § 12, to find out the exact condition of bony injuries.

Very often it is of great advantage to be able to examine a region not only in two planes at right angles to each other, but in various other planes. This is where radioscopy comes into its own, and offers an indisputable superiority. In fact under the screen the limb may be rotated and made to assume any position required. We could thus make sure for instance, in the case of a projectile the shadow of which seems to lie within the tibia on the plate, that it is not actually without the bone, and we can thus affirm that this projectile is intra-osseous. The same degree of certainty could not be obtained, even if we ascertained that its shadow still remained intra-osseous, on two plates taken at right angles to each other, because this appearance could have

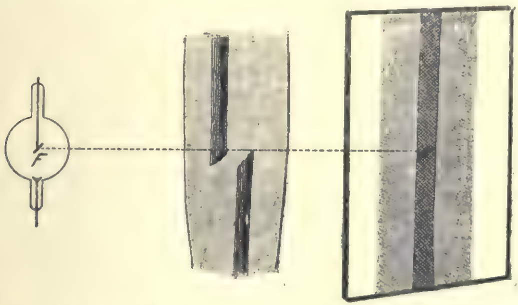



FIG. 55.—At the angle shown in this figure, we obtain an image which might make us believe, were we satisfied with it: (1) that there is union between the fragments, and that the fracture is uniting; and (2) that the position after reduction is quite straight. This shows, however, how erroneous these conclusions would be.

been due, in the case of a projectile in the soft parts, to the alteration caused by taking the two plates in a different position, owing to movement in the soft parts.

This does not mean to state that sometimes an image on a single plane may not allow an experienced radiologist to make deductions as to the real site of a projectile. The aspect of a bony injury, for instance the presence of an area of decalcification, would often justify the conclusion that the projectile was intra-osseous, but even then—we shall discuss this later—the diagnosis would have to be made carefully because of the numerous likely causes of error.

Moreover, in order to be able to estimate bony injuries correctly, it is necessary to have an absolute knowledge of the normal forms and aspects. But the projection of the same portion of the body may evidently assume the most different forms, varying with the different positions of the tube or of the plane of examination or projection. It is, therefore, usual to consider for each region one or two typical positions generally taken if possible one in a frontal plane and the other one in a sagittal plane. Most of the X-ray atlases reproduce them and are very useful for purposes of comparison to those who have not got these typical appearances sufficiently in mind or have not at their disposal a complete collection of normal plates. Amongst others the reader could refer to Hauchamp's atlas. A more or less trained radiologist can recognise at once by examining a plate under what circumstances it has been taken. For instance, he will be able to distinguish immediately whether he has before him an image taken from the anterior surface or the posterior surface.

Finally, it is necessary to know not only the normal X-ray anatomy of the skeleton but also all the variations and abnormalities of form and of number (supernumerary bones, etc.), in order to avoid grave mistakes which are being committed every day. It should never be forgotten that in case there is the least doubt as to the appearance observed, a plate should be taken of the corresponding part of the body on the other side for purposes of comparison. Great experience is also necessary in order to be able to distinguish the differences in the intensity of the shadows, so as not to mistake for instance a sequestrum for a projectile. We shall deal with this subject later on (Chapter V). As regards pathological images, experience only will enable one to interpret them correctly and to deduce thereby useful information for the surgeon. We cannot of course enter into explanations of this subject here, even in a general way, as the domain of clinical medico-surgical radiology has been enormously developed and is increasing day by day. We can only advise those who are interested in the matter to study special books and to read the *Journal de Radiologie.*

But the few indications given here will suffice to give some idea as to the difficulties and importance of a correct and complete interpretation of X-ray images, and of the necessity of acquiring a perfect mastery of the technical knowledge required, in order to obtain all the information which radiology is now able to supply in any given case as regards the question of the search for and localisation of projectiles. We are still very far in many cases from deriving the fullest benefit possible on account of our inability to interpret correctly what we see.

## CHAPTER IV

### INDISPENSABLE X-RAY APPARATUS. MEANS OF PROTECTION

§ 14. **Radiographic Apparatus.**—To start with we must distinguish between the apparatus proper for producing X-rays, which includes on the one hand the means for producing the high-tension current necessary for working the tube, and also the tube itself, and on the other hand subsidiary apparatus for purposes of conducting the examination, such as tables, screens, etc. We shall not dwell very long on the part of the apparatus for producing the rays, because as regards this we may say that all or almost all installations are suitable for finding, marking and extracting the projectiles radio-surgically. In fact, any installation enabling us to pass through the tube from one to two milliampères with a sufficiently hard tube (that is to say with a spark gap which is equivalent to about a dozen centimeters at the most) will supply us, if we use it judiciously and especially if we possess well-seasoned stable tubes, all the intensity required for our radioscopic examination (provided always that the installation is a good one).

*A. Installations.*—Every type of installation which is able to fulfil these conditions and to produce regular working may be considered good. Such is sufficient for our radioscopic requirements and can supply very good plates in experienced hands, the only difference being an increase in time of exposure. We shall therefore not describe specifically the numerous models of weak or strong installations supplied by the manufacturers. They may be all narrowed down to practically two well-known types, either the induction coil (Fig. 56) or the rotary transformer (Fig. 57), the advantages and disadvantages of which we shall not discuss. Special treatises and the constructors' catalogues give the reader all the necessary information on these points by giving him a description of the essential constituent parts of these instruments (interrupters, coils, etc.) and will explain to him their working should he not know it. It is hardly necessary to add that the apparatus used on the X-ray cars of the Health Service are perfectly adapted for all requirements within the limits of our subject.

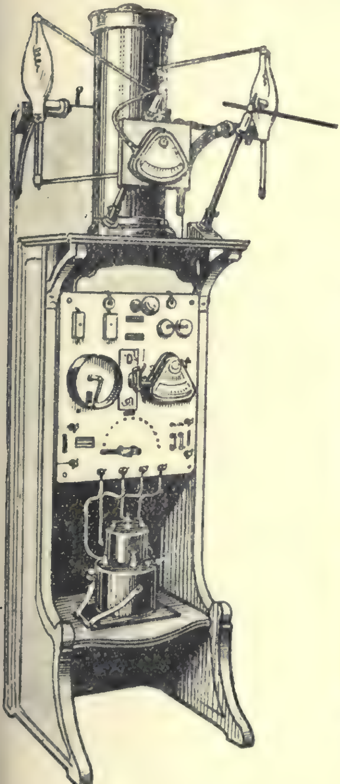


FIG. 56.—Set of apparatus produced by Gaiffe (Gallot & Co.). The high-tension current is supplied by the coil seen at the top of the shelf. On each side of the coil can be seen the valves the purpose of which is to stop inverse current (Chapter I. § 2).

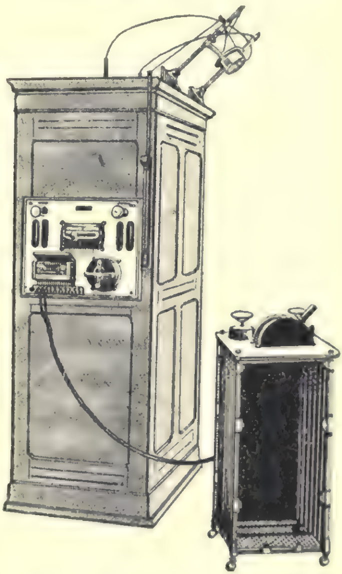


FIG. 57.—Small transformer by Drault (Chapter I. § 2). The two Figs. 56 and 57 were not made to the same scale and do not therefore admit of comparison in size.

We shall only mention that the constant increase in X-ray examinations has caused X-ray laboratories to be installed as additions to almost every surgical service of any importance, and the custom of removing projectiles under the screen has made it desirable to create apparatus which, whilst answering all the requirements for complete examination and marking, are easily portable for the purpose of being used in operating theatres.

So-called "Portable" installations, the essential purpose of which was the obtaining of radiographs at home or at country places away from a fixed installation, have been in existence in rather large numbers, but as they almost all of them were based on utilising accumulators as the source of current, the intensity supplied by them was hardly sufficient and they hardly answered the purpose for which they were needed. One of us has therefore had constructed by MM. Gallot-Gaiffe an apparatus which answers all the latest requirements.

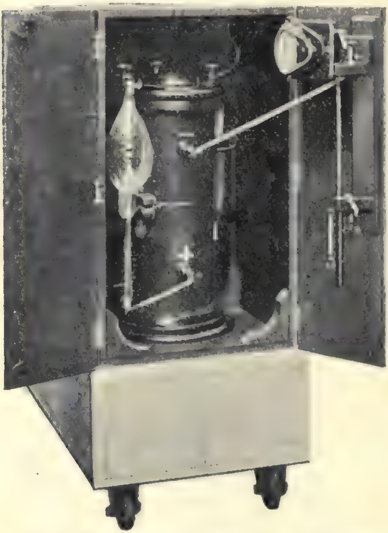


FIG. 58.—Radio-surgical cupboard by Dr. Ledoux-Lebard seen from the front which is open and shows the coil, the valve tube, the spintermeter and the milliampèremeter.

*Portable Radio-surgical Apparatus.*—The object desired was to combine absolutely *all* necessary radiological material, with the exception only of the operating table in the smallest possible compass, in the shape of a piece of furniture which would contain it completely and could be easily moved from one room to another and be adapted to all the usual lighting mains.

Its total height, including the castors, is 1·02 m., its width is 0·62 m., its depth 0·41 m. It is made of white varnished wood and the strong double castors which support it are covered with indiarubber. The whole apparatus is thus fitted together and is dust-proof and also proof against accidents and interference, with a single safety key which locks the different doors. The whole piece of furniture is divided into two superimposed parts, each part forming a cupboard.

The lower part contains various accessories: such as the fluorescent screen and localising apparatus, opaque gloves, spectacles, bonnet, etc.; in short all that the radiologist requires for finding, localising and extracting projectiles by means of a screen examination.

Fig. 58 shows this arrangement from the front. We can see the valve, the coil, the spintermeter and the milliampère-meter. Fig. 60 shows the back part of the cupboard with the controls and interrupter. We may add that this piece of apparatus which has been constructed to work on an alternating current of fifty periods at a voltage of 110 can also be made to work with continuous current

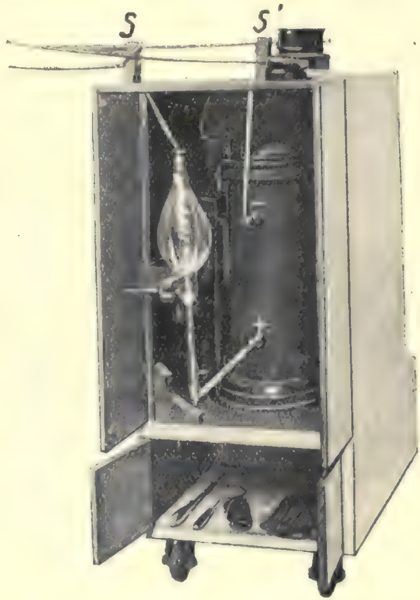



FIG. 59.—In order to use the apparatus all that is required is to pull out the holder which carries the valve and to lift out the spintermeter and milliampère-meter. All that remains now is to connect the tube to the extremities $S$ and $S'$ of the spintermeter. The small lower compartment containing the various accessories is shown closed in Fig. 58 and open in Fig. 59 in which we can see the various accessories (such as gloves, spectacles, pointers, ink marker).

There only remains the addition of the X-ray couch—which can be used as an operating table—of one of the types to be described later on, in order to have a complete and easily movable unit containing all necessary accessories. It is very easy to start the apparatus working, all that is required being to lift out the spintermeter

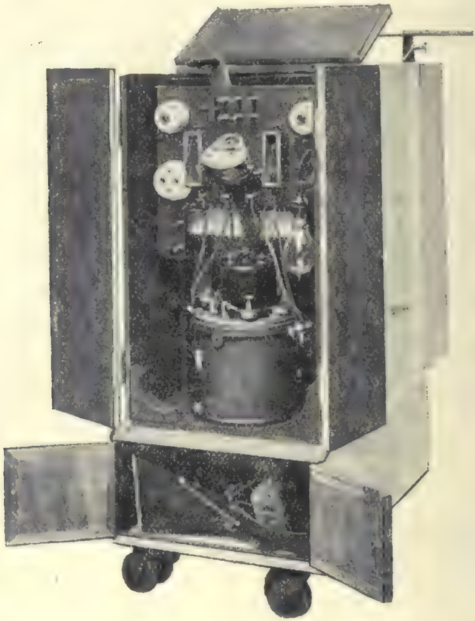


Fig. 60.—Radio-surgical apparatus by Dr. Ledoux-Lebard seen from the back which is open and showing the interrupter and controls. The small lower compartment is open and shows the cryptoscope of Dr. Dessane.

which we see hanging along the panel in Fig. 58 and to bring the valve tube forward. After this the tube should be joined to the two ends of the spintermeter (Fig. 59).

With this appliance and the X-ray car it is easy to be able to undertake a complete examination anywhere, and to proceed with the extraction of projectiles by means of the screen in any operating room. (It is also possible to place a set of apparatus of the usual type on rollers and to render it thus portable to a certain extent.)

*B. Tubes.*—Any tube will be suitable which can carry for some time a current of 1 to 2 milliampères with a spark gap of 12 centimeters. For low intensities up to 1 milliampère no tube is better suited as regards strength

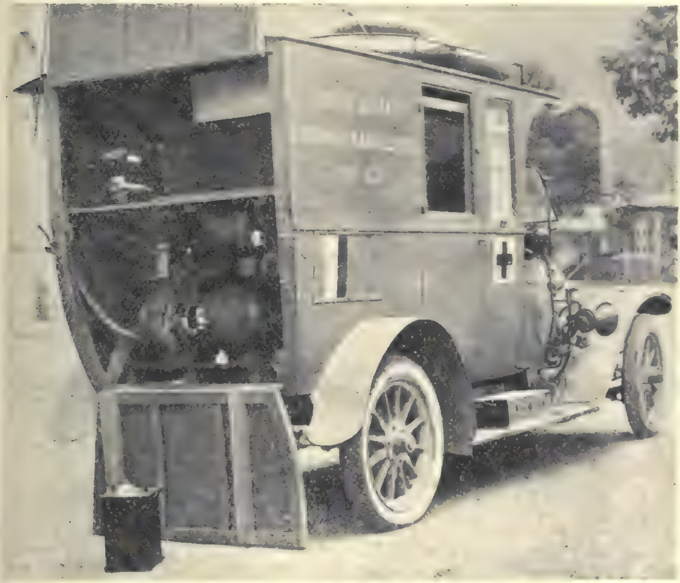


Fig. 61.—X-ray car constructed by the firm Gallot, a type used by the armies and at the bases.

and capacity than the Chabaud tube. We wish to point out that it is a mistake to use large tubes on weak installations and to work say a large Pilon OM, on a coil the maximum capacity of which is 1 milliampère, because these tubes will tend constantly and inevitably to harden very quickly and will not work satisfactorily.

It is advisable of course to choose tubes provided with regulators, preferably with Osmo-regulators.

An indiarubber bag filled with gas can be used easily to take the place of the usual jet when there is no available gas supply in the vicinity. It would be useful to have, for the localisation and extraction of projectiles, tubes with a double anticathode. Unfortunately, their construction offers from a technical standpoint very great difficulties when it is desired to obtain tubes able to support a sufficient strength of current (1 to 2 milliampères per anticathode) for long periods, and the present conditions of manufacture do not lend themselves easily to new attempts in that direction. However, the firm Pilon has been able

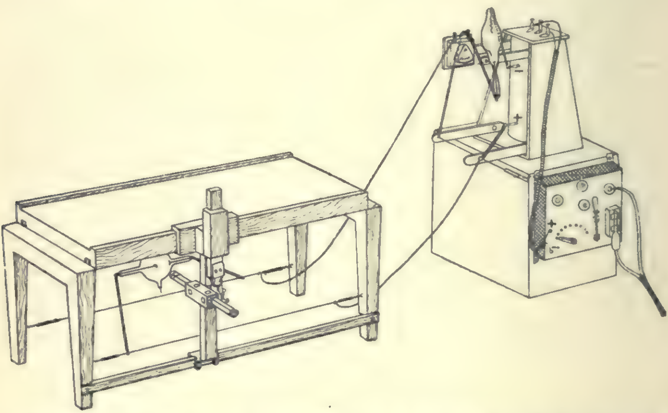


FIG. 62.—X-ray table belonging to a motor car fitted up with Delapchier apparatus and diagram showing the arrangement (military X-ray apparatus, Gallot & Co.).

to construct a remarkable tube with a double water-cooled anticathode and we believe that we shall see in future a more frequent application of these tubes, probably in the form of Coolidge tubes, in view of the exceptional facilities they afford under numerous circumstances.*

*C. X-ray Shields and Tube Holders.*—It is of course evident that a tube must never be used without being fitted into a shield and placed in a holder.

* Particulars relating to these tubes from the practical and theoretical standpoint will be found in the following article: R. Ledoux-Lebard et A. Dauvillier, "Les ampoules à double anticathode" (*Journal de Radiologie*, 1916).

It is thus possible to obtain a correct centring of the tube and to limit at the same time the pencil of X-rays in the required direction, and to obtain a protection against the greater part of the lateral rays, which are of no use to the examination and which are a source of danger to the operator.

We must point out that the centring of the tubes must be effected very carefully whenever the tube is changed.

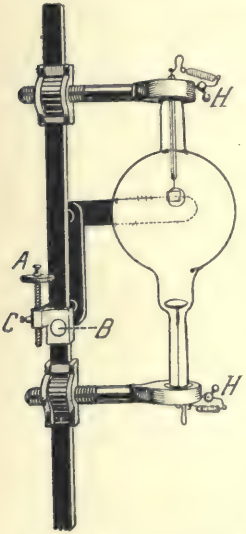



FIG. 63.—A tube fitted into its holder as seen from the front.

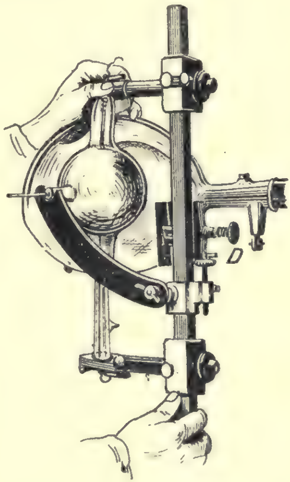



FIG. 64.—A tube fitted in its holder and placed in a shield in which it should be centred (from the back).

It should also be possible to fit on the shield a movable diaphragm—a diaphragm worked from a distance by means of a flexible connection

§ 15. **Apparatus for conducting the Examination.**—This includes first of all the arrangements for moving the tube and for examining the patient, the proper X-ray material and especially the cryptoscopes and X-ray accessories (intensifying screens and their cassettes), and also all the usual accessories of a character not strictly radiological.

We are not describing here special appliances for localisation, because they will be described later on.

*Examination standing up and lying down. Tube Stand. X-ray Table.*—Up to a few years ago X-ray examinations were generally made in a vertical position by means of a tube stand enabling the position to be changed in every direction, behind a screen of thin wood or of other material, against which the subject to be examined was placed. A movable fluorescent screen was placed near the observer and, if desired, could be replaced by a carrier capable of holding a plate with or without an intensifying screen. The Béclère and Guilleminot stands, impudently imitated and copied by Germans and Austrians, were the prototypes of the appliances now generally used and of which they served as a direct model.

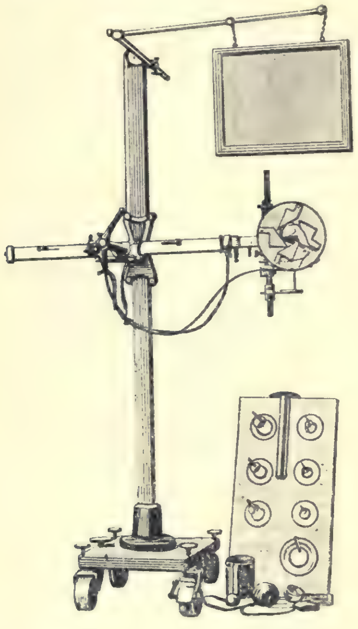


FIG. 65.—Large tube stand by Drault and Raulot-Lapointe which enables the tube to be moved in every direction.

The large stand by Drault and the large one by Bellot-Gaiffe are at present the most perfect models of these stands (Figs. 35, 65). These tube stands or others of a simpler design are also used to take radiographs by placing the subject on the table and by fixing him in the required position for the part to be examined, as shown in Fig. 66.

Wounded soldiers were at the beginning of the war often examined in a vertical position. But as they have to be operated on in a recumbent position and as the changing from one position to another may bring about important changes in the relative position of the organs and consequently also of the projectiles, it was soon found neces-

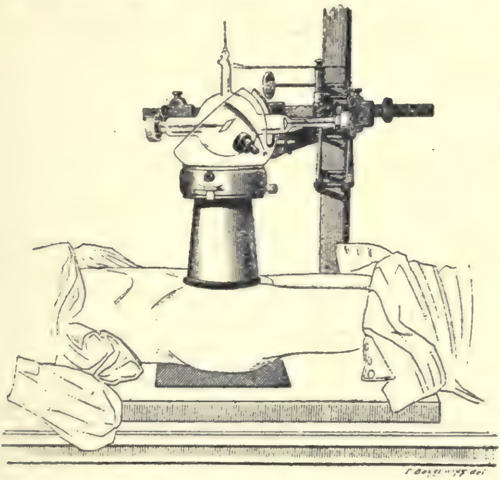


FIG. 66.—Fixed on a tube stand, the tube is centred in its shield to which is fitted a compressor tube. The patient is placed on the table and a radiograph is about to be taken of his right thigh in an antero-posterior direction.

sary to carry out the marking in the operation position (see Chapter VIII). Thus a start was made with screen examinations in a recumbent position. To that effect the existing stands were used, as shown in Fig. 67, under a table. But this expedient, useful in case of necessity, is

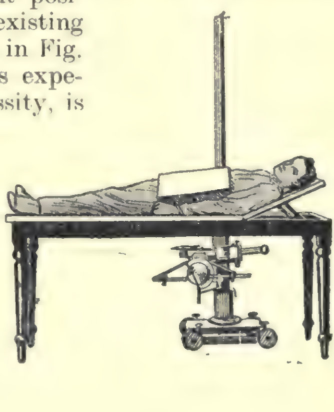


FIG. 67.—A tube stand provided with a tube centred in the shield is placed under a table, so as to be able to undertake a screen examination (and eventually to take a plate in an upward direction) of the patient placed on that table. But this is only a make-shift appliance.

rather uncomfortable if it is to be often repeated. Moreover, the foot of the tube carrier is rather in the way when it is necessary to operate by means of a screen and completely hinders the movements of the surgeon's assistant.

We therefore strongly advise the use of X-ray tables specially provided with a carriage enabling the tube to be moved in every direction under the table and parallel with

FIG. 68.—X-ray surgical table by Dr. R. Ledoux-Lebard (Gallot & Co.) made entirely of metal. Its height is adjustable by means of a bayonet arrangement in its legs. The height can thus be adjusted as required to suit the height of the surgeon, or if only one side is lifted it can be inclined as much as is desired for abdominal explorations.

the table of the type such as have been used for some years already by radiologists examining the digestive organs, especially the large intestine (for instance with a bismuth meal according to Aubourg's technique).

Béclère's table (Drault and Raulot-Lapointe) and Dr. Belot's new universal table fulfil all necessary requirements to a perfect degree. Without interfering to any degree with their transparency to X-rays and in order to make the surface more aseptic, it is possible to cover the top of the table with thin sheet aluminium (about 2 mm. thick will do).

*X-ray Surgical Table.*—If the method of examination to

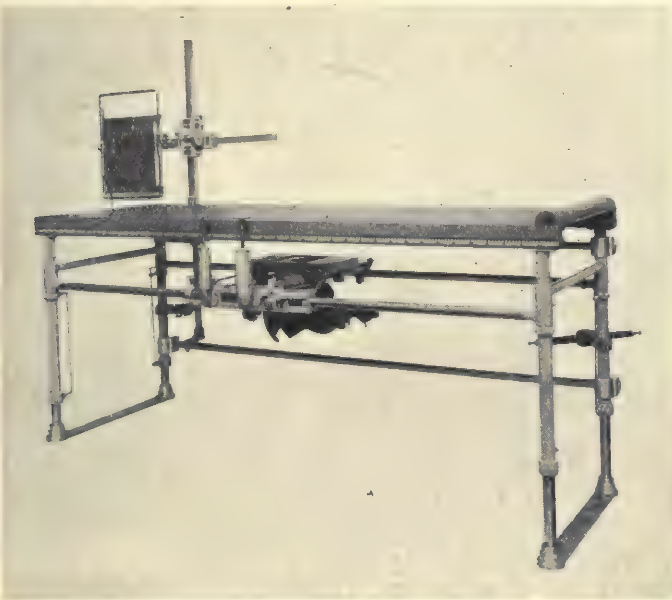


FIG. 69.—X-ray surgical table by Dr. Ledoux-Lebard (Gallot & Co.). Its frame is made entirely of metal and consequently very solid and perfectly rigid, whatever the height or the inclination adopted. The carrier is designed from the universal X-ray table by Dr. J. Belot and has all its advantages and is as easily worked. We see in this figure and in the preceding one the bathymeter by Dr. Dessane supported by a sliding arm which can also be used as a stand for the tube carrier and can be raised if required. In this sketch the legs have been purposely raised unequally at the ends.

be followed is that of extraction by means of the screen (see Chapter XII and following), and if it is necessary to operate constantly on an X-ray table, it is even advisable to use a table made entirely of metal, and one of our colleagues has had a model of an X-ray surgical table made by Messrs. Gallot, which has the additional advantage, so much appreciated by the surgeon, of a movable top the height of which can be instantly adjusted (Fig. 68) and the surface of which can be inclined at will for abdominal explorations. We may mention here that in 1904 Dr. Haret submitted to the Congress of Milan a model of an X-ray surgical table which was the first really practical

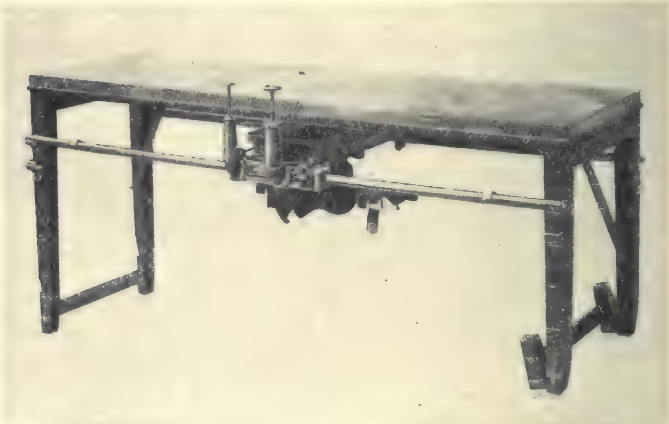


FIG. 70.—X-ray surgical table by Dr. Réchou. It will be noticed that the arrangement of the legs allows of two different heights and a certain range in angle.

attempt to solve the problem which has now actually been done.*

Wullyamoz has also designed a model in which the whole plant for generating the rays was grouped on or under the table.

By adapting the movable X-ray appliance described at the beginning of this chapter to the X-ray surgical table we obtain an absolutely complete apparatus enabling us to proceed with the search for and localisation of projectiles. This installation which can be immediately connected to any electric light main offers the additional advantage of

* See Chapter XIII.

being easily portable from one room to another, from the X-ray room to the operating theatre.

Unfortunately, the price of the tables which we have just described, even that of the excellent table by Réchou (Fig. 70) built to a large extent of wood, and of the most simple construction, is rather high (1,000 to 2,500 frs.). The model of the table in the X-ray motor lorry outfit supplied by Messrs. Gallot-Gaiffe (Figs. 62 and 71) is of a more modest price and quite suitable, especially if the Delapchier appliance is adapted to it. But this obstacle is not insurmountable and those establishments which have only modest resources at their disposal should not allow this to stand in the way of adopting our method of extraction. With a little ingenuity and patience it is possible for most radiologists to construct with the labour at their disposal appliances enabling a tube and its diaphragm to be moved under the table and parallel to it.

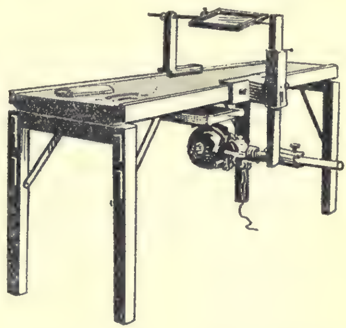


FIG. 71.—A simple table of the Gallot X-ray cars. The screen is carried on a movable holder.

Although X-ray tables thus constructed do not offer all the perfection and all the working facilities of those which we have described before, they are nevertheless quite sufficient in practice to be of great assistance. In the ninth district particularly very successful improvised couches of this description have been made by Messrs. Dauneau, Maillard and Taveneau. Fig. 72 shows one of these tables.

Every X-ray couch must be provided, for the purpose of screen examinations, with an appliance allowing the screen to be fixed at a desired height with movement in two directions parallel to the surface of the table. For the same reason it must also be fitted with stops enabling the tube to be moved an exact distance. These stops, which differ according to the models of the table used, can be easily fixed and are at present supplied by every manufacturer.

It should also be provided of course with an adjustable rectangular diaphragm, and it would be as well to be able to add in certain difficult cases a diaphragm-opening as described later on (Chapter IX).

*Apparatus for Screen Examination: Screen and Cryptoscope.*—The fluorescent screen is one of the most indispensable elements in X-ray apparatus. But besides its classical form, which is too well known to admit of further description, and the 30 mm. × 40 mm. size of which represents

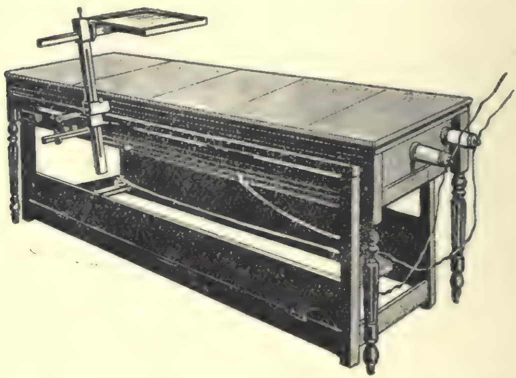


FIG. 72.—An improvised X-ray table designed by Dauneau.

one of the most suitable models we have seen, there has appeared in the course of this war, and rightly so, the revival of the cryptoscope, the *human eye-glass* invented at first by Segui and which is simply a small portable dark chamber fitted with a fluorescent screen. By its use the observer is able to adapt himself whilst remaining in a lighted room. He will thus be able to make an examination, to see a projectile in an operating room and guide the surgeon during his work if he operates on an X-ray couch. In its classical form it is represented by a box made in the shape of a pyramid. The bottom is taken up by the screen and the top is surrounded by a piece of material which enables the face to fit in closely and prevents any light entering when it is applied to the head. This is effected by an elastic band which is passed over the head and keeps the cryptoscope tight; for this reason the latter is also called a band fluoroscope or cryptoscope.

Mr. Wullyamoz of Lausanne has invented a very ingenious fluoroscope which enables a screen examination to be made with one eye whilst the other eye is in the light. But as we shall see later on it is almost impossible to effect delicate observations under these conditions, and if a perfect observation is to be obtained the two eyes should be in the dark.

Fig. 73.—Radioscopic X-ray screen and fluoroscope by Dr. Réchou (Gallot & Co.).

Fig. 74.—Fluoroscope by Dr. Dessane (Gallot & Co.).

It seems to us that M. Réchou's fluoroscope made of leather (Gallot & Co.) is the lightest and the most practical of all the simple models (Fig. 73).

But if it is a question of an operation which lasts several hours it is very painful to have the face continuously hidden in the fluoroscope, the weight of which although slight is sufficient to become very inconvenient. Moreover, it is often of great importance for the radiologist to be able to *see* what is going on, and to follow the phases of the operation. But if he removes the fluoroscope he has not the time (about ten minutes) for his eye to become sufficiently receptive again when the surgeon requires him. These rapid and repeated changes from light to darkness and vice versa are, moreover, very disagreeable and extremely trying.

Under these conditions the idea of wearing extremely dark-coloured closely fitting glasses naturally occurs to us. A pair of glasses similar to motor car glasses with india-rubber rims and either violet or brown lenses, very dark, and fixed over the head by an elastic band, may be worn without fatigue and enable the wearer to follow closely all that is going on in the theatre. At the desired moment the glasses can be slipped over the neck with the eyes closed and the fluoroscope is then adjusted. As soon as the screen observation is finished the operation is reversed: the fluoroscope is taken off with the eyes closed and the glasses are put on again. We have often adopted this measure during numerous and long operations in daylight and have never experienced the least difficulty in seeing the image on the screen.

But a pair of glasses constitutes an additional accessory. It may be forgotten or a glass may be broken. It is therefore preferable to have a hood which enables one to do without it. To achieve this it is sufficient to divide the hood into two parts, the lower of which contains the fluorescent screen and the upper one has a movable shutter fitted with very dark-coloured glasses. As soon as the screen observation is finished the lower part is taken off, and the upper part after lowering the shutter is retained and thus takes the place of a pair of glasses. Should the surgeon require the services of the radiologist for a minute, the lower part is rapidly fixed by lifting the movable shutter. Following these principles M. Bouchacourt has modified a fluoroscope which he had formerly invented, and to which he has given the name of Manudiascope, but as its use is much too restricted it is not very practical.

It is, moreover, a mistake to have pieces of apparatus which can be thus separated and placed anywhere. They have to be looked for when required, and they may have been mislaid. We therefore strongly advise the use of a fluoroscope (Fig. 75) designed by M. Dessane when in the Central Service of Radiology at Tours, and made by

Gallot & Co. Fig. 76 shows the radiologist with the bonnet on. As soon as he has finished his observation he lifts the lower part which stands up whilst the shutter of opaque glass comes down automatically (Fig. 76). The position of the hood when lifted does not allow the weight of the instrument to be felt so much as it leans against the head, as shown in the diagram.

This fluoroscope by Dr. Dessane seems to us to be the right instrument. Its size (13 × 18 cm.) is sufficient to enable the operator to undertake the search for projectiles

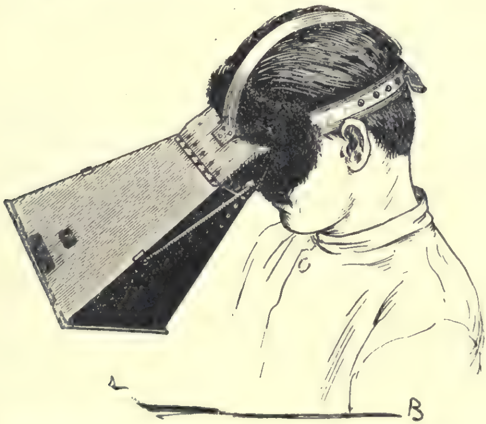



Fig. 75.—An X-ray examination with the Dessane fluoroscope.

which is indispensable—this not being the case with the manudiascope—and also it can be adapted for all purposes.

But some surgeons are deprived of competent radiologists. In this case they will generally be able to train one of their assistants rapidly in the art of handling the fluoroscope. As long as he has some notion of anatomy, and is intelligent, he will soon become an able assistant with a week's training. It may however happen that such an intelligent assistant is not available and that the surgeon must become his own radiologist, unless he wishes to forgo the benefits of screen examination. He is then faced by two opposing necessities. The first one is to see clearly and to have a good light if he wishes to be able to operate easily in difficult places and in deep wounds. The second is to be in darkness or at least in an obscured light to be able to have recourse, if necessary, to screen examination during his operation. This shows that there is no really satisfactory solution of this problem ; he must resign himself to operating with difficulty under unsatisfactory conditions, which are often dangerous to the patient, if he remains in the darkness and contents himself with the fluorescence of the screen as a source of light. The same difficulties exist, although in a lesser degree, if he operates by a monochromatic light—for instance red—as advocated by M. Bergonié and M. Petit (of Château-Thierry), or violet as being theoretically excellent, not to speak of the considerable complications which would result therefrom.

FIG. 76.—The radioscopic examination is finished. The radiologist has raised the lower part of the fluoroscope which leans against his head and he can see what is going on thanks to the deep violet glass which comes down when the lower part of the fluoroscope is raised. On the other hand, when the lower part descends, the glass "eclipses," leav- the view of the screen clear.

On the contrary if we operate in daylight the change from one to the other is no longer possible. We shall discuss this matter of technique later on (Chapters XII, XIII, XIV), but we think that the least unsatisfactory solution in that case is for the surgeon to operate by artificial light (ordinary electric light) and to use himself Dr. Dessane's fluoroscope, the glass to be chosen preferably of a violet colour not too dark. An assistant can lower it each time when it is necessary to undertake a screen examination, and then lift it on to the operator's forehead. With the aid of X-ray cars of the Gaiffe type, it will be possible to improvise almost anywhere, very easily and without any costly installations, operating rooms enabling examinations under the screen to be conducted under relatively satisfactory conditions.

To have an appropriate light it will be sufficient to make use of a portable lamp with a conical reflector which an assistant can direct towards the wound. This method is much less disagreeable to the surgeon and to his assistants as it prevents the numerous accidents from happening which may be ascribed to monochromatic light, which may allow anæsthetic conditions or hæmorrhages to occur unobserved, and it avoids the considerable fatigue caused by rather long examinations made under this illumination, especially red.

We have also tested a double fluoroscope devised by M. Dessane (Fig. 77) which enables two people to carry on the observation. The surgeon is thus able, if he has no

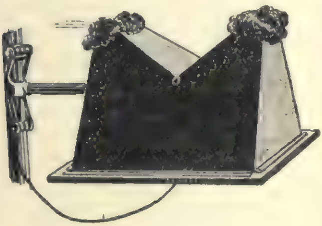


Fig. 77.—Dessane's double fluoroscope enabling an examination to be conducted by two observers at the same time.

Fig. 78.—An examination made by the radiologist and by the surgeon at the same time by means of Dessane's double fluoroscope.

experienced radiologist, to follow on the screen what is taking place. This instrument may be fixed on a stand or held in the hand, and Fig. 78 shows the way it is used. Later on (Chapter XV) we shall speak of various accessory non-radiological appliances for the exploration of projectiles, such as electro-vibrators, telephone probes, etc., which are however quite useless if a screen examination is available. A continuous rather powerful electro-magnet however may be very useful as an instrument for extraction in certain difficult and deep operations and especially for brain surgery. With this the existence of a continuous-current service of sufficient intensity is of course essential.

*X-ray Appliances.*—We are not concerned here with photographic material such as plates, papers, and all that is required for their manipulation. We shall content ourselves with pointing out the absolute necessity of: (1) being very careful with the intensifying screens if we wish to make good use of them, and in order to prevent errors, (2) to use them only in cassettes which do not reverse the image. The aluminium cassette made by Drault and Raulot-Lapointe appear to us to be at present the best model of its kind (Fig. 79).

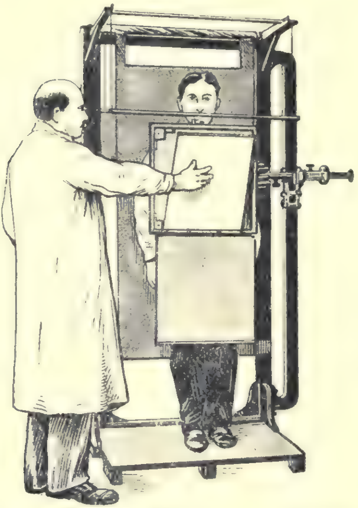


FIG. 79.—Magazine fluorescent screen fitted on a movable arm, adapted to a stand, suggested by Béclère and enabling the use of an aluminium cassette containing intensifying screens (Drault and Raulot-Lapointe).

§ 16. **Accessory Material.**—Finally we consider it necessary to mention some other accessories of which the negative viewing box is the most important.

*The Viewing Box.*—All those who have examined X-ray plates know that, in order to take full advantage of the negative and to study all its details, we must be able to look at it on a uniformly lighted background, the lighting intensity of which can be varied. Appliances constructed for this purpose (the most ingenious of which has been designed from particulars supplied by Dr. J. Belot) are called viewing boxes. But the high price of these appliances, especially in war time, prevents many X-ray installations from making use of them. In our opinion it is essential to examine all the plates with a viewing box, if we wish to avoid reading them imperfectly and omitting many important details. Such an appliance may be constructed without any expense with cardboard, for instance by aid of boxes in which X-ray plates are packed, and a perfectly suitable viewing box may thus be obtained. A variable resistance may be added to it, if necessary, in order to obtain the required variation in intensity of light. Figs. 80 to 83 give the details for the construction of this apparatus, which may easily be fitted up anywhere and which was designed by Dr. Dessane. Its low cost will enable it to be installed in the operating theatres of the surgeon, who will be able during the operation to avail himself of the information thus provided by the plates.

We shall constantly be required to mark on the skin various important points required for localisation. This may be done by means of a skin pencil, but its marks

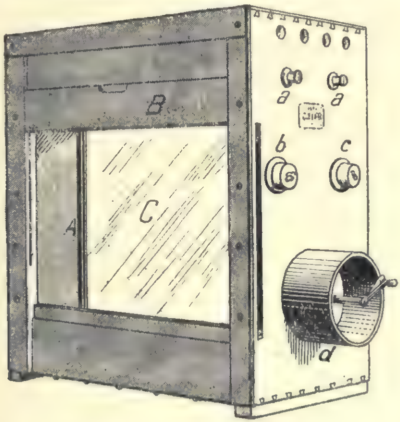



**Fig. 80.—Viewing box of Dr. J. Belot.**

disappear rapidly. It will therefore be necessary, if we require them to last several days whilst waiting for an operation, to mark them again either with silver nitrate or with a thermo-cautery. But the incandescent end of the latter often causes suppuration, and this may cause a septic place to develop which is not to be desired. On the other hand if the marking is light it sometimes disappears completely or else cannot be distinguished from many other cutaneous scars (acnæ, etc.).

Tattooing will generally be preferable and to that effect we strongly advise the use of Dr. Henry Béclère's tattooing needles. They are immersed into a sterile solution of China ink and a cross or a point is made on the skin at the desired place with the needle which is sterilised in a flame after each patient.

As the mark is indelible this process must of course not

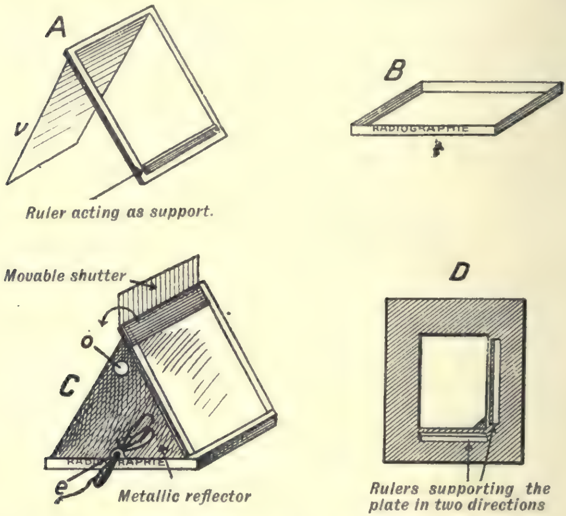



FIG. 81.—An improvised viewing box by Dr. Dessane. An old non-exposed plate is placed in the bottom *B* of a plate box (size 30 × 40 cm.). This will be used as a reflector and on it is placed an incandescent lamp of 50 or still better of 100 candle power. The lid *A* of the box is cut in the form of a shutter *v* which is moved back so that the lid takes the form of a trestle. To this is nailed a small ruler which carries another undeveloped plate or a piece of ground glass. We thus can obtain a uniform luminous surface on which we can place the plate to be examined. The diagram *C* shows the complete apparatus by sticking black paper, with white paper inside, on the free surfaces of the trestle. An opening *o* is made for air and an opening *e* for the passage of the socket of the lamp. On *D* are shown intermediate sizes of holders which are simply placed on the ground glass to receive plates of smaller sizes.

be used on the face or else only a very slight tattooing point should be made. The Pravas needle may also be used and a drop of China ink injected under the skin, but this complicates the matter to a certain extent and causes

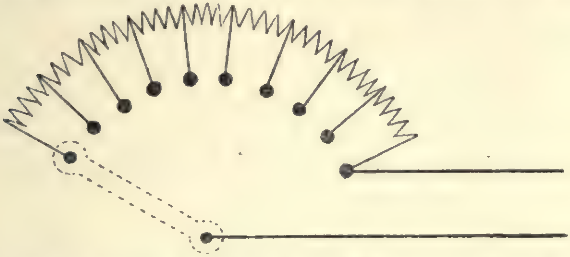


FIG. 82.—A simple model of a metal rheostat enabling the light intensity of the viewing box to be varied at will.

more work such as the sterilisation of the syringe, the needle, etc. Another appliance which is very often used in place of the skin pencil carried in a metal case, so often used by radiologists, and which necessitates considerable exposure of their hands to the rays, is the ink marker designed by Messrs. Gallot (Fig. 84).

Its long hollow stem contains a Bowden cable terminating in a wick soaked in dye. When the end of the stem is placed on the desired point a mark is made. We should add to our collection a few more accessories which, although not strictly radiological, will be found useful. First of all a meter rule together with a smaller ruler or a double decimeter ruler.

Callipers, compasses, a skin pencil, also a pencil which can write on the glass of the fluorescent screen or a stylographic pen will be very useful.

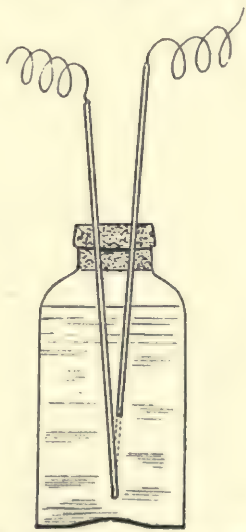


FIG. 83.—Another model of variable resistance for Dr. Dessane's negatoscope by means of a liquid rheostat, which is worked by increasing or lessening the distance between the two metallic rods (thick pieces of wire).

As we are now in possession of satisfactory apparatus and a well-regulated tube and of all the appliances we may require, we are in a position to commence our examination. As however we are going to expose ourselves to

FIG. 84.—A Gaiffe ink marker. A long and rather strong metal stem (30 to 40 centimeters long) or a wooden rod of the same length with a small lead ball attached to the end will often be found useful, but the spintermeter rod will always do instead. String, iron and copper wire, lead wire and a few sheets of lead rubber, combination pair of pincers, a screwdriver, a switch and adaptor which can be attached in any place when there is electric light complete all the necessary implements whenever it is required to make use of the electric mains. We need not mention here accessory electric appliances such as electro-magnets which are mentioned in a separate chapter (Chapter XV).

the action of X-rays it is essential that we should know the truly grave dangers which threaten us and what means there are of protecting ourselves against them.

§ 17. **Biological Effects and Dangers of X-rays.**—Everybody knows now that X-rays possess particular biological properties the knowledge of which has served as the basis of the enormous but as yet incompletely developed science of radiotherapy. Indeed X-rays have an effect on all living cells. Given the same cellular substance and the same quality of rays this action depends entirely on the amount absorbed. But all cellular substances are far from being equally sensitive. As far as human tissues are concerned the white cells of the blood and the cells of the testis and ovary are extremely sensitive, and the quantity of X-rays required for their destruction is infinitely small. Retinal cells and the malpighian cells of the cutaneous layer are also sensitive but require larger doses, whilst certain elements such as cartilaginous cells appear to be relatively immune. Moreover, speaking generally we may take it for granted that younger cells and also those cells concerned in reproduction are the most sensitive to X-rays.

Important researches, made on the basis of laws to which it is only fair to attach the names of Bergonié, Tribondeau and Béclère, give full particulars on these various points which we are not dwelling on here and for the study of which we may refer to the *Traité de radiothérapie de Belot*,* a very valuable source which since its publication has inspired numerous works which have appeared in German on that already vast subject.

It is these effects, mostly destructive and necrotic, which explain so many accidents imputed to the X-rays and about which we must say a few words. From the practical standpoint these accidents result especially in skin injuries, such as X-ray dermatitis, because although the cells of the skin are not the most sensitive they are nevertheless, as we mentioned before, sufficiently sensitive and they evidently receive such a much larger proportion of rays than other parts that the difference of quantity is sufficient to explain the relative frequency of their occurrence.

X-ray dermatitis may be acute resulting in an intense destructive action due to the absorption of a large quantity of X-ray radiations. It may be compared to a burn, and like this is of three degrees. It occurs mostly in patients exposed to X-rays, and especially after radiotherapy, which does not concern us, but it has become, for some years, so exceptional in radiography that there is no reason for fear, except in cases of a long examination, multiplied and repeated within a short time.

In civil life this only happens in the case of patients who intentionally conceal the fact, from the radiologist consulted by them, that they have been previously examined by X-rays by other specialists without his being aware of it, and even then an experienced physician, accustomed to question his patient closely, will as a rule become suspicious and take additional precautions. Unfortunately in military practice in time of war this is not always the case. Repeated examinations are, in fact, the rule rather than the exception, and it is difficult to avoid them in the absence of written documents sent with the patient when he is moved. Fortunately it is only very seldom that these examinations take place within a short time of each

* J. Belot, *Radiothérapie*, 2e éd., Paris, Steinheil, 1 vol. in 8°. A third edition is in preparation.

other, and as a rule the time interval is sufficient to ensure no harm being done, and although we have frequently seen patients who had been screened ten and twelve times, we have seen only two who have undergone multiple examinations (more than six) in less than two months. And nothing happened to them. As a rule it is the "curious case" or the difficult case, which is repeated, studied and shown on every opportunity, which runs risks. (Personally we have seen only two cases of dermatitis, even then only slight, in patients with difficult projectiles, who had been sent from one hospital to another.)

Although large doses of rays cause an acute form of trouble, a repetition of small doses during a long period is still more dangerous, because they act cumulatively without any sign or warning, until the day when there appears the condition of chronic X-ray dermatitis. All those who practised radiology during those times when this danger was ignored have made this sad discovery. In the end they noticed characteristic changes in their hands and especially on the back of their left hand which was constantly exposed to radiation, either for the purpose of showing to the uninitiated the X-ray appearance of a hand or especially in order to determine by that appearance and by the degree of contrast of the image seen on the screen the degree of softness or hardness of the tube. This chronic dermatitis manifests itself at first by a state of dryness and particular roughness of the skin with constant itching, by the falling out of hair on the skin, by a brittleness of the nails and then by their loss, and by the appearance of small cutaneous and very painful cracks, by hard nodules and by small epithelial warts. It is on these that there very often develop those cutaneous epitheliomata the frequency and spreading tendency of which render it so difficult to give a prognosis on the professional injuries of radiologists. This prognosis is the more difficult because once affected by the rays the affected tissues not only do not become immune, but on the contrary become more sensitive as if some singular anaphylaxis had taken place. Thus once established a radiologist's injuries do not tend to recovery. Whatever the precautions taken by him the infinitely small doses of rays which he receives are sufficient to maintain the injury of which in the early stage he can be completely cured only by giving up his profession definitely —or at least for many years.

It is because they remained so faithfully attached to their profession that about a hundred radiologists have become victims to neoplastic changes in their injuries and that so many others only owe their existence to numerous early and mutilating operations.

Once we know the danger we must to start with take precautions to avoid it ; we consider that this is possible without neglecting any branch of radiology and without renouncing in any way radioscopy—this essential cause of accidents, because it is in this way, especially when examining a patient standing, that the observer is exposed to the direct and very close action of rays emanating from the anticathode.

In fact, we have seen when studying the principal physical characteristics of X-rays (Chapter II) that they can pass more easily through bodies of lower than higher atomic weight. If we place ourselves inside a cabin the walls of which are lined with sheet lead of sufficient thickness (3 mm.) we shall be practically protected from any danger.

But although we may be able to have access to that absolute remedy in some of the large and perfectly organised services, it could not be used as a general proceeding especially in war time. Its application would moreover be restricted by the fact that, although it is easy to place in a leaded cabin all the necessary articles and to remain there whilst the plates are taken or during treatment, it must be left in order to undertake radioscopic examinations which, as we have seen, are the principal source of danger. If we renounce these we take off at least half of the value of radiology, and no real physician or radiologist would or could do without these. Generally it would be sufficient to shelter during the taking of radiographs or during radiotherapy, behind a screen opaque to X-rays (Figs. 85 and 86). We consider however that even in continual daily practice the radiologist who is always careful and takes all the precautions which we are about to enumerate, may for many years be unaffected provided that he has not been yet affected.

If we place the tubes into opaque shields (as seen in

§§ 10 and 14) we limit the outlet for rays to the opening in these shields. The constant use of a diaphragm the shutters of which are also opaque should still more reduce the injurious beam and restrict it in such a way that the area covered does not attain and especially never exceeds the limits of the fluorescent screen. The latter, consisting of a salt of a rather high atomic weight, stops in itself a very important proportion of rays, but we must always cover it with lead glass, and we must arrange on its two ends two handles protected by metal shells in order to protect the hands which hold it.

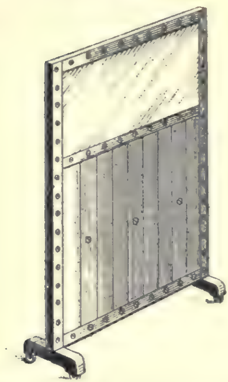


Fig. 85.—Screen opaque to X-rays.

We also advocate the systematic and extensive use, at all X-ray proceedings, of an aluminium filter (2 to 3 tenths mm.) which does not in any way interfere with radioscopic vision or with the beauty of the plates, but protects the patient and operator against that softening of the tube which is so dangerous to the skin, because soft rays, being mostly absorbed by the surface, are the most dangerous to the skin.* Thus the quantity of harmful rays reaching the observer during the

Fig. 86.—A radiograph of spectacles and of gloves opaque to X-rays.

* One of our colleagues has published recently (*Société de Radiologie*, 1914) a very simple device designed to that effect by M. Drault. Whatever the apparatus used an aluminium filter can easily be placed between the source and the patient.

examination will be extremely weak and will be reduced to some thousandths of the original radiation. If moreover he protects his eyes, which are sensitive organs, by means of spectacles of lead glass, the best model of which is the type of spectacles with large glasses (similar to motor car spectacles, produced by Messrs. Gallot according to particulars supplied by Dr. J. Belot), and if he wears an apron of opaque material, then he will have protected sufficiently the most sensitive portions of his body, and will have run no danger whatsoever. Now, as regards his hands. They are the most exposed parts because, being generally required for various manipulations, they are nearer the tube than the rest of the body (law of the square of the distance) but especially because certain examinations require manipulations behind the screen and thus they receive the rays directly. They must therefore always be covered with opaque gloves, but the usual type which only protects the back of the hand does not seem to us to be sufficient. We therefore advocate the use of gloves which have two thicknesses of opaque material at the back and one on the palm side. Of course they are not supple, but here again we find ourselves with two contrary necessities, suppleness on the one hand and opacity to the rays on the other, but it is the latter which is the more important, as it is on the latter that the protection of the hands depends. By this we wish to say that those surgeons who are tempted to operate under a screen by exposing their hands will have only an illusive protection by covering them with an opaque paste such as is advocated by M. Mauclaire. They will only have themselves to blame if they contract some injury, when there are simple appliances which protect them absolutely by preventing any contact whatsoever with the rays (Chapter XIII). Need we insist on the necessity that the radiologist should only expose his hands, even gloved, to the direct action of X-rays in cases of absolute necessity and then as seldom as possible ? In fact, in spite of all the precautions and the thickness of the opaque materials used by us, a small quantity of very penetrating rays will always reach them, and a repetition of these weak doses will be sufficient to constitute a danger.* By this we

* It is impossible to discuss the whole question in detail, because

mean to say that the radiologist who practises the search for and localisation of foreign bodies must not use skin pencils with metallic cases—these are too often used for the purpose of marking the points on the skin under the screen. This necessitates a direct exposure of the hand to the rays, whilst by using a long stem such as the Gallot marker or any other appliance (§ 15 and Chapter VIII) the result is obtained without any contact with the rays. In the same way when trying to move foreign bodies by palpation under the screen, a sufficiently long rod should be used (generally the rod of the spintermeter will do).

To sum up: The hands must never be placed under the screen in the path of the rays if it is possible to avoid it. By proceeding thus and by remembering all the precautions we have enumerated, we think that radioscopy can be practised without danger, even every day and for long sittings, provided of course that the protection used is real, that is to say that the opacity of the spectacles, gloves, apron, shields and especially the lead glass of the screen have been tested (the glass must be at least 3 mm. thick, a fact not often observed in most instances).

Once we know how to protect ourselves we may pass to the practical use of the apparatus with a view to finding and localising foreign bodies in patients entrusted to us for examination.

in this rapid survey we do not touch at all on the action of secondary radiation which in practice is, however, insignificant.

# CHAPTER V

## SEARCH FOR FOREIGN BODIES. CONFIRMATION OF THEIR PRESENCE OR ABSENCE. CAUSES OF ERROR

§ 18. **History of Case and Clinical Examination.**—A rational X-ray examination of any subject supposed to have a foreign body in him must in the first place be clinical. It should be a short but precise examination. Without attaching too much importance to all that the patient states, the radiologist will make the patient tell him in a few words the principal events: date of the accident, nature of the agent that caused it, situation of the wound of entry if already effaced, complications, etc. He will inquire carefully as to any former X-ray examinations, trying to find out if possible their precise number, result, nature (radioscopy or radiography), the radiologist who made the examinations, and especially the date of the last one, in order to avoid the effect of cumulative doses (causing dermatitis) should it have taken place too recently.

Written documents on the subject will, of course, dispense with a part of this examination. But in war time it is extremely rare to find any useful written documents. Very often one has to go by the particulars supplied by the patient. Sometimes the hospital notes or the observation chart mentions: "X-ray examination." As these documents do not contain the name of the radiologist, and only indicate the result of the examination in very exceptional cases, and even then insufficiently, this evidence is generally valueless. The examination must therefore be always commenced afresh and very often patients are seen who have been examined with the screen or radiographed more than ten times and who have to be examined again. This repetition of examination which is very costly to the State and possibly dangerous to the patient can only be avoided with great difficulty. This subject will be discussed later on and we shall then indicate what precautions we take to remedy this defect.

If radiographs, tracings, etc., have already been taken but they are not as clear as might be desired, or if there is any doubt as regards their definition or their authenticity, another examination must always be made especially with regard to military patients. Under no circumstances must the statement of the patient be taken for granted as to the presence or absence of a projectile.

A rapid examination of the patient by feeling carefully the skin, by looking at the places where the projectile or projectiles entered and left and by taking into account the principal functional troubles will often lead to some presumption as to the site and nature of the foreign body. But the absence of a visible place of exit will not be a sure indication that there is a retained projectile, just as the absence of a perceptible place of entry will not prove that a projectile is not present. Nothing but a complete X-ray examination will enable us to make a definite statement to this effect.

§ 19. **Undiscovered Projectiles** are extremely common. Whilst some patients complain in quite good faith of considerable and generally subjective pain on account of very small fragments of metal retained in places which anatomically might be considered to be innocuous, radiologists who have examined wounded soldiers know how often it is possible to discover projectiles, even very large ones, which had not been suspected by the patient to be present. This is mostly the case with rifle or machine gun bullets which may have penetrated without causing any pain, and which are generally tolerated much more easily than fragments of shell.

Fig. 87 shows a German bullet which was retained in the first interosseous space and was discovered during a radiographic examination of the hand undertaken for the purpose of verifying the state of the fourth metacarpal struck by a piece of shell which had been previously extracted.

Figs. 1 and 2 of Plate I. which is still more singular, show an almost complete German bullet, deformed only at its base, which was lodged in the right maxillary sinus without any clearly visible wound of entry and without its presence being suspected by the patient.

It happens still more frequently that projectiles are found in situations which are very distant from the wounds of entry and from the region in which the patient locates the pain due to their presence. One of our colleagues published, together with Mr. A. Gosset, in 1914 a very curious example before the war started.*

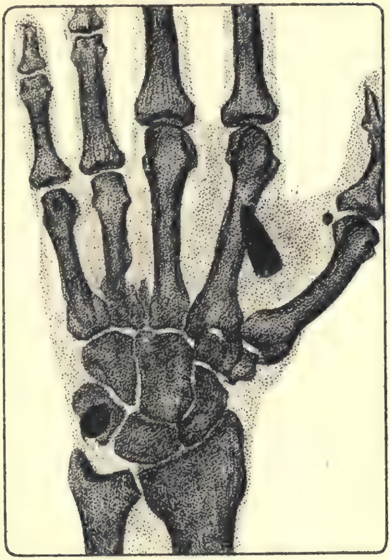


FIG. 87.—Radiograph of the right hand, seen from its palmar surface. A German bullet projects at the level of the first interosseous space. This man was wounded by a machine gun and a bullet had already been extracted from the front part. He never suspected the presence of the second projectile which has probably entered through the same orifice as the first to which no doubt was due the fracture of the fourth metacarpal. The appearance of the pisiform bone should be noted as it could easily be taken at a first glance for a shrapnel bullet. The sesamoid of the thumb should also be noted and also that of the fifth metacarpal seen through the head of that bone.

The case was that of a young girl who shot herself three times with a revolver, one shot lodging in the præcordial region. Although the orifice of the entry of the latter was clearly visible and there existed indisputable clinical signs of hæmothorax. the screen examination, which it is true was made rather hurriedly owing to the grave state of the patient, did not show the projectile, neither did it appear on the plate. After her recovery the patient

* A. Gosset et R. Ledoux-Lebard, *Bulletin de la Société de Radiologie*, 1914.

was again examined on the screen this time very thoroughly, again without success. Plates from the head to the pelvis were all negative. The plate of the pelvis being rather faint was taken again on a larger plate which included also the top part of the thighs. The bullet was found at the bottom of the left thigh in the adductor muscles. It seems that it could have lodged there only by taking a sinuous course which we shall not try to explain.

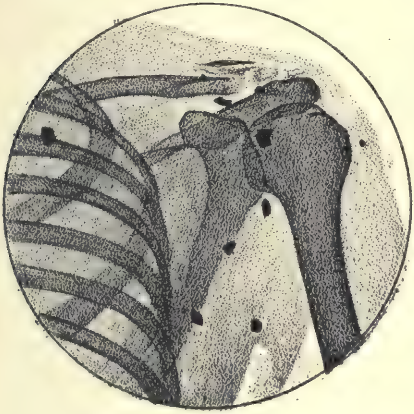
Similar appearances not less paradoxical often take place with our wounded men, and the force of penetration of projectiles easily explains that a bullet or a fragment comes to rest at a great distance from the point of entry, and is able to penetrate almost the entire length of the body. Similar occurrences do not surprise us nowadays.

An examination is only complete when a patient has been examined from head to foot, and this practically can only be done by radioscopy.

§ 20. **The Radioscopic Examination.**—The first examination to be made is of course radioscopic. It should naturally start with the suspected region, and it is only after being carefully explored without results that all the other parts of the body should be examined successively if the examination is to be complete.

Besides anomalous projectiles to which we have alluded before we find, in the course of this war, numerous examples of patients with multiple projectiles, and some men are, so to say, filled from head to foot with metal fragments (see Figs. 88 and 89). With the advent of trench warfare which has generalised the use of grenades, aerial torpedoes, etc., these cases have become more and more frequent (see several diagrams on our plates). The possibility of rapidly and completely exploring a body in all its entirety is not one of the least advantages of radioscopy. It is therefore surprising that in a great many units projectiles are still looked for by taking radiographs, resulting in long and costly examinations which often yield no results as very often the projectile is not on the plate. And one would not obviously attempt to take radiographs of every wounded man from head to foot. Although it is not possible on active service to make a complete screen examination of every patient, it is at least easy to undertake an exhaustive examination of those who show symptoms which are not explained by a clinical examination, and when a projectile has not been found in the region of the wound.

It is necessary therefore to protest vigorously against the ban which has been so often pronounced against screen examinations in spite of the constant teaching of M. Béclère and of the meritorious efforts of our eminent



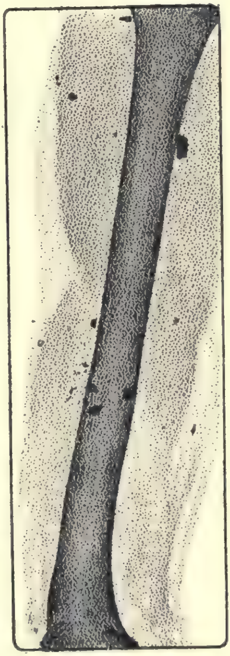


FIG. 88.—Radiograph of the right shoulder seen from its posterior aspect. (It will be noted that the external extremity of the clavicle has been fractured and some parts are missing.) Eight metal fragments of rather a large size can be counted in the region of the shoulder. The wound was caused by a shell.

FIG. 89.—Radiograph of the left arm seen from its posterior aspect. Multiple metal fragments disseminated in the soft parts (grenade).

colleague and friend Haret. This is not only the case in France, but also in Germany. The disfavour into which it has fallen may be explained by two principal reasons :

(1) Many radiologists and most surgeons imagine because many projectiles escape their screen examinations made too rapidly and with imperfect appliances that a screen examination shows only foreign bodies of a large size situated in transparent regions.

## PLATE I

Fig. 1.—Radiograph of the left knee seen from its outer side. We notice in the soft parts behind the shadow of the femoral condyles a metal fragment of the size of a pea. The appearance of the tibia should be noted. This is not as we might at first be led to believe an injury to the bone caused by a projectile but the point of ossification of the tubercle of Gerdy (patient nineteen years old).

Fig. 2.—Radiograph of the left knee seen from its outer side. In the soft parts behind the condyles we see the shadow of the sesamoid of the knee which must not be taken for that of a projectile or of an abnormal bony loose body. There is a fracture of the patella with a metal wire surrounding it. The wire is broken. By comparing the two plates (1 and 2) we shall notice that it is the difference between the intensities of the shadows which enables us to distinguish the projectile from the sesamoid. (See also Fig. 98, p. 125.)

Fig. 3.—Radiograph of the left hand seen from the back. A metal fragment of the size of a pea is seen at the level of the head of the fourth metacarpal. Small pieces of metal wire from a grenade which has caused the wound will be noted in the soft parts between the lower parts of the articulations of the middle and ring finger.

Fig. 4.—Radiograph of the forehead seen in profile from the left side. Very small metal fragments will be noticed at various points. The large opaque body of which the shadow is seen in the orbit is not a piece of shell but a glass eye (made of lead glass).

PLATE I

FIG. 1

FIG. 2

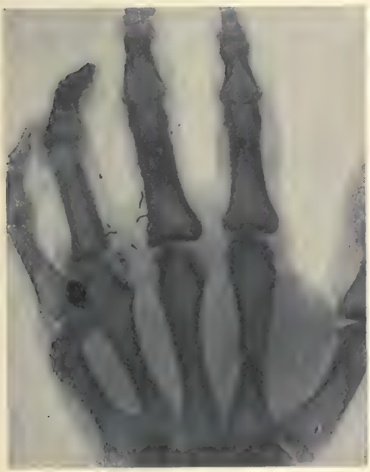


FIG. 3

FIG. 4

(2) The very justifiable fear of radio-dermatitis degenerates too often with radiologists into unreasonable alarm which keeps them from employing this method and they communicate this fear to the surgeons. We shall not dwell here on this second point which has already been dealt with in Chapter I and which we shall discuss later on (Chapter XIII), but shall consider here only the first reason. It will be very easy to demonstrate that it is fallacious.

*Visibility of Projectiles on the Screen.—Its Conditions.*—Our personal experience which is now based on the minute examination of over 5,000 wounded men enables us to affirm that with the exception of the eyeball (Chapters XI and XIV), and perhaps of some very rare cases which we have not yet encountered of particularly opaque subjects, every projectile the extraction of which may reasonably be undertaken by the surgeon, that is to say which has a diameter of at least 3 millimeters and which consists of any metal but aluminium, can always be seen on the screen, even in the thickest part of the body, the cranium, spine or pelvis. But in order that this may be done it is necessary—and it is sufficient—that the examination is made by a competent radiologist according to certain conditions.

There are three conditions which we shall explain successively and which contribute to the increase or diminution of the radioscopic visibility. These conditions depend:

(1) On the apparatus.

(2) On the nature of the body looked for.

(3) On the operator.

(1) *Conditions depending on the Apparatus.*—We have already examined these conditions in §§ 14 and 15, in sufficient detail. It is therefore unnecessary to dwell upon them and we only wish to state again that almost all instruments which are now being constructed enable one to make all the screen examinations necessary for finding projectiles in a perfectly satisfactory manner, because to do so it is only necessary to have one to one and a half millis with 10 to 12 cm. of equivalent spark, as long as we have at our disposal a good and well-seasoned tube (Chabaud or Pilon) and the appliances necessary for the manipulation of the diaphragm.

The X-ray cars which have been mobilised since the war

## PLATE II

FIG. 1.—Radiograph of the left shoulder seen from the back. Rifle bullet (German) which is embedded base first in the head of the humerus. Its intra-osseous position can be diagnosed almost with certainty from this plate alone, owing to the presence of a very sharp area of rarefaction of the part of the humerus which corresponds with the bullet (verified by operation).

FIG. 2.—Radiograph of the left thigh seen from behind. Pocket revolver bullet lodged in the soft parts of the antero-internal aspect of the thigh.

FIG. 3.—Radiograph of the left knee seen from its inner side. We see a projectile which seems to be embedded in the tubercle of the tibia by its base. The projectile seems to have penetrated base foremost (the wound of entry was in front of it in the skin at the same level) and is of a singular shape (? a projectile purposely deformed by the enemy).

FIG. 4.—Radiograph of the right leg seen from its inner side. We see embedded in the soft parts behind the fibula the shadow of a metal fragment which was only a piece of the ring of a suspender worn by the patient. This indirect projectile was driven into the tissues by the explosion of a grenade which made a serious wound in the calf.

FIG. 5.—Radiograph of the left thigh seen from behind. We see towards the neck in the middle of the inter-trochanteric line the shadow of a slightly misshapen shrapnel bullet. The great trochanter shows on its outer border traces of a perforating injury. Small pieces of metal, evidently detached from the shrapnel bullet, cast their shadows over the whole surface included between the external border of the large trochanter and the projectile. This information enables us to conclude that the bullet is in all probability within the bone, although no area of decalcification is apparent. We have noticed that this decalcification is much less accentuated and very often totally absent in cases in which the projectile is a bullet (verified by operation).

FIG. 6.—Radiograph of the right lumbar region seen from the back. The shadow of a very large metal fragment (piece of a shell) is seen in the soft parts at the level of the second and third lumbal vertebra.

Fig. 1

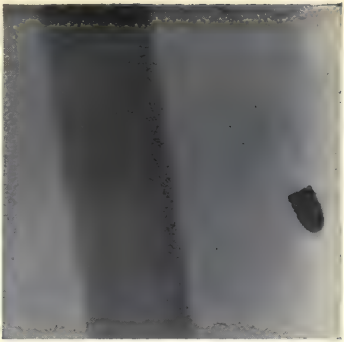


Fig. 2

Fig. 3

Fig. 4

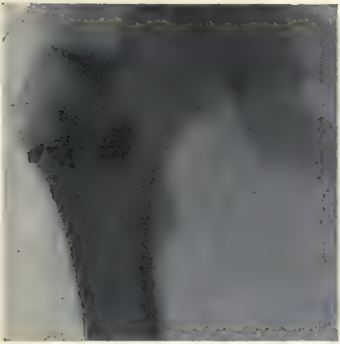


Fig. 5

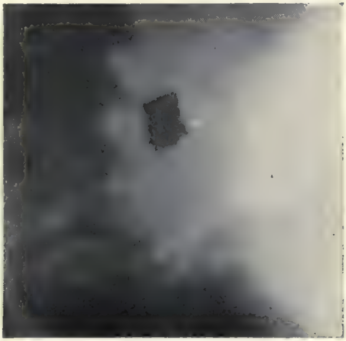


Fig. 6

started are of course perfectly suited to this kind of work and especially lorries of the Gaiffe type.

We need not speak here about the room required: it must evidently possess the general conditions of lighting and space needed for any screen examination.

We also know that it is possible to undertake screen examinations in rooms illuminated either by daylight or by artificial light if we use the fluoroscope which we describe in § 15. But although this very useful appliance is quite sufficient for finding large projectiles or for following during a surgical operation a metal fragment of a very small size, the position and shape of which are however known to us, it is not adapted to all the requirements of a first exploration in difficult cases, for which the radiologist must not only be in a condition of good visual receptivity, but must also have means of examining large segments of the body at the same time and in addition every liberty of movement so as to be able to carry out all the various accessory manœuvres required. Therefore the use of the fluoroscope, which has its definite uses for the extraction of projectiles by means of the intermittent control of the screen, is restricted to the search for a projectile relating to urgent cases and can only be used exceptionally for complete and definite examinations.

To sum up: conditions favourable to radioscopic vision while depending on the installation, on accessory material and on the provision of suitable premises, can almost always be easily obtained anywhere.

(2) *Conditions depending on the Nature of the Bodies looked for.*—We have already seen several times (Chapter II) that with the same thickness the transparency of various bodies to X-rays depends upon their atomic weight and diminishes proportionally as it increases, whilst with an equal atomic weight the transparency diminishes in the same degree as the thickness increases. If we express in figures the degree of relative transparency of bodies and if we take into consideration their atomic weight and their thickness we shall find that a shrapnel bullet or a bullet from a German or French rifle is quite visible in view of its relatively considerable opacity to X-rays in any part of the body, to an observer working under good technical conditions (the most important of which is the visual

adaptation) and who is conversant with this kind of examination. In fact, very simple calculations based on transparency tables of equivalents published by Mr. Benoist show that $\frac{1}{10}$th of a millimeter of lead, $\frac{4}{10}$ths mm. of iron, 8 mm. of aluminium or 45 cm. of soft tissues will project on the screen a shadow of the same intensity. If therefore the diameter of a shrapnel bullet is 1 cm., 45 cm. of soft tissues would have to be interposed between the shrapnel and the screen to produce the same opacity of shadow. The shadow produced by the shrapnel bullet covered with such a thickness of soft parts should still be visible, because it should have a double intensity according to the absorption of rays by the 45 cm. of soft parts and by the shrapnel bullet. But two troublesome phenomena interfere. The first one is that starting from a certain intensity of shadow, it becomes difficult to distinguish on the screen degrees in that intensity. The second one which is the most important is that the image becomes blurred owing to the production of secondary rays, and the more soft tissues there are interposed and the harder the rays used the more intense does this become. It may therefore be considered that in practice as regards thick parts a projectile ceases to be clearly visible on the screen if it is included in soft parts the opacity of which, whether resulting from their thickness or from their atomic weight, is equal to that of the projectile.

It is evident that other things being equal the visibility will diminish with the atomic weight of the metal of which the projectile is composed and with its size. But, with the exception of aluminium the employment of which in the fuses of shells is known to all from the rings made from it by the soldiers in their leisure hours, there are only heavy metals which are now used in the production of bullets and of various parts of shells, such as lead, brass and iron.* Therefore we only must take into account the sizes of the projectiles retained. If guided by the above-mentioned figures we take a piece of lead the thickness of which is supposed to be at least 1 mm. in its largest diameter or a piece of iron the largest diameter of which is 4 mm. we see that 45 cm. of soft parts will be required to produce an

* We have not seen yet on the French front glass bullets the use of which has been mentioned on the Russian front.

equivalent shadow before we shall lose the shadow of the foreign body from the quantity of the secondary rays produced. And there can hardly be a case in whom we should have such a thickness of soft tissues interposed between the projectile and the screen. And should even such a thickness exist there is always a direction in which the thickness is less and the patient should be moved into different positions to find it and it should be possible to obtain on the screen a shadow of the projectile which is more accentuated than the shadow of the surrounding parts.

Similar calculations also show that if bony structures intervene it will be necessary to have such a thickness of calcareous tissue to absorb the radiation to the same degree as the metal fragments that they can always be seen, as previously mentioned, whenever it is a question of projectiles the dimensions of which are such that operation is indicated. (It will take 53 mm. of bone to give the same shadow as 1 mm. of lead or 4 mm. of iron.)

(3) *Conditions depending on the Operator.*—These are of a very different nature. We have already studied in detail the conditions of visual receptivity, and have shown the absolute necessity of staying in darkness before commencing any examination. The importance of this is such that we cannot insist too much on it. Insufficient receptivity is even now the principal cause of the want of confidence in screen examinations shown by a certain number of radiologists and by many surgeons who always hard pressed for time have never had the leisure to conduct completely and under favourable conditions a search for a projectile with the screen, and who having themselves seen nothing on the screen can very often hardly believe that others could have been able to do so except with the eye of faith. But even if the observer's eyes are in a suitable state of receptivity we must still take into account his personal capacity for this observation. We have seen that there are considerable individual variations in visual acuity in dark surroundings. If we except real "night blindness" which alone would constitute a real obstacle to his ability to undertake the study of radiology because in this case he would be incapacitated from making any screen examination, we may consider these variations can be

almost always overcome by a sufficiently complete preparatory adaptation, so that in practice this need not be taken into consideration. It is thus evident that the value of an examination will depend upon the experience and personal knowledge of the radiologist and especially from his mastery of radioscopic technique.

§ 21. **The Radioscopic Technique.**—As in any other medical application of exact science the technique of the examination on the screen plays an important part provided good accommodation is realised. We must know how to look for the foreign body. To do this efficiently the patient must be examined not only in one position but the suspected region must be placed at every possible angle, both by moving the patient and by moving the tube.

We shall thus clearly recognise the position in which the foreign body under examination is most easily seen, whether it is in its longest diameter or in the axis in which there is the least interference from bony or soft parts.

But one of the most important points in the examination lies in the manipulation of the diaphragm, the use of which is indispensable and without which it is absolutely useless to undertake a systematic search for projectiles by screen examination.

Let us remember that it is only its judicious use which enables us to eliminate a part of the secondary radiation, an essential cause of trouble and of absence of clearness in screen images, the absence of clearness being the more evident in the regions where the soft parts are thickest. The narrower we make the pencil of rays the clearer the image will be. The use of the diaphragm which is necessary for finding projectiles will also be shown necessary for the localisation of projectiles and we shall also demonstrate the difficulties of satisfactory vision which interfere with its use in certain methods of radioscopic localisation.

A complete examination search for and study of projectiles can be undertaken with the patient lying down. It is however extremely convenient although not indispensable, especially for intra-thoracic projectiles, to be able to examine him also standing when it is much easier to keep him in various oblique positions which may be needed. It must not be forgotten that a projectile, even a very large and opaque one such as shrapnel, if it is placed in the walls of the thorax in such a way that it coincides with the shadow of superposed ribs could perfectly well fail to be seen on the screen, the thickness of the bone being then represented by the superposition of the segments of the rib under consideration, which thickness may exceed 10 cm. and thus reach, especially if we add rather thick soft parts and an intense secondary radiation (very open diaphragm), the limits fixed by our previous calculations for the visibility of a projectile on the screen.

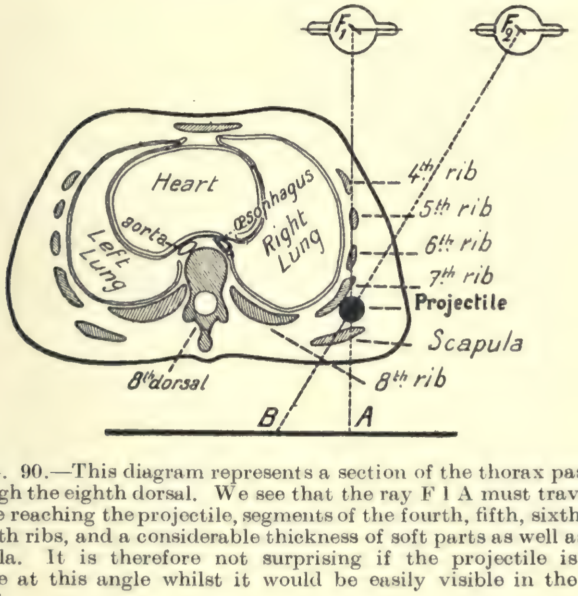



Fig. 90.—This diagram represents a section of the thorax passing through the eighth dorsal. We see that the ray F 1 A must traverse, before reaching the projectile, segments of the fourth, fifth, sixth and seventh ribs, and a considerable thickness of soft parts as well as the scapula. It is therefore not surprising if the projectile is not visible at this angle whilst it would be easily visible in the line F 2 B.

Very often by making the subject breathe deeply so as to lower the diaphragm or by examining him laterally we may discover standing out in the clear pulmonary area a projectile which may have passed unobserved in the shadow of the dome of the diaphragm as shown on the diagrams in Chapter XI. These various manœuvres will also enable us to show in numerous cases thin metal films which would only give a clear shadow if seen edgeways, as the interposed thickness of the metal in front of the screen would be sufficient to render them quite visible.

The head should always be examined not only from the front but also and especially from the side and if necessary at various angles.

There are in almost every region little technical rules all of which tend to increase the visibility and which are all very simple, but which require a real training on the part of the man who is carrying out the examination if they are not to be forgotten and if they are to be applied more or less mechanically and quickly. One is thus sometimes quite surprised to see an experienced radiologist find the projectile immediately during a screen examination where a novice has been trying to find it for a long time and in vain. We shall have an opportunity of discussing all these details again when we shall study the marking of projectiles for each special region (Chapter XI).

§ 22. **Radiographic Examination.**—We have said that every projectile which can be extracted surgically is visible on the screen. But should a screen examination, even well conducted and under satisfactory technical conditions, not have shown a foreign body, this does not prove that one is not present. It only enables one to be almost certain (if the examination has been undertaken by a competent physician-radiologist) that the patient has no large projectile in any region and to be quite certain of its absence in transparent and easy regions such as the limbs. But even for limbs and in any case for the thorax and the abdomen one must be careful not to come to a too hasty conclusion and state only—if the examination is not being continued—that from the screen examination no projectile was visible. The examination may have been carried out under unfavourable conditions, due to defective apparatus (the tube being too soft which there was not time to harden or the tube being too hard), to fatigue or a hasty examination on the part of the operator (a large number of wounded have to be seen in war time in certain emergencies) or to the projectiles being very small or the patient being very thick, etc.

It has often happened that one of us has found projectiles after a screen examination where other radiologists have previously made a negative examination and it is quite probable that some projectiles have been missed in rare cases where a negative diagnosis has not been verified by a plate. Moreover as we have previously shown in § 7 a plate possesses an X-ray sensitiveness which the human eye placed under abnormal conditions of work cannot equalise. The plate will thus supply details which may completely evade our eye.

For this reason it is a valuable and indispensable adjunct to every screen examination. If the examination has been negative it ensures that no important fragment has escaped and shows the number, position and shape of the small fragments or pieces of dust which may exist without being visible on the screen; if it is positive and especially in case of projectiles of which the extraction is likely to be difficult it supplies additional particulars as to the state of the bones or of the surrounding soft parts, etc.

Without in any way entering into details of radiographic technique, which would be out of place here and for which the reader should consult various books of radiology and especially the excellent hand-book of Jaugeas, we wish to point out that to obtain good plates easily it is essential to use soft rays and to immobilise the patient completely. Almost all the existing installations even the simplest ones enable anyone with a good technical knowledge to take extremely satisfactory plates of the limbs and of the head the taking of which does not in any way necessitate powerful installations. Even for plates of the thorax, kidney, intra-abdominal viscera in apnœa X-ray cars can be quite satisfactory. It is only for projectiles with communicated pulsation requiring, if it is desired to obtain sharp images, instantaneous radiographs that the most powerful and most modern installations are necessary.

§ 23. **Reading of the Plates.**—(Refer to Chapter III) It is extremely important to obtain in every case plates which are technically faultless, because they will become a source of information very often of extreme value if they have been well taken, well examined and especially correctly read.

In the case of a positive examination a plate gives us information with regard to the number, the shape and the nature of the projectiles.

*The Number.*—This is evidently necessary ; at the same time it must be pointed out that a group of adjacent projectiles or even two projectiles lying at a great distance from each other may only figure on the plate as a single projectile if, at the moment of being radiographed, they lie on the line of the same normal ray (Fig. 91). This happens very rarely but the possibility of such an eventuality should not be forgotten.

*The shape* and the nature of the projectile may be inferred

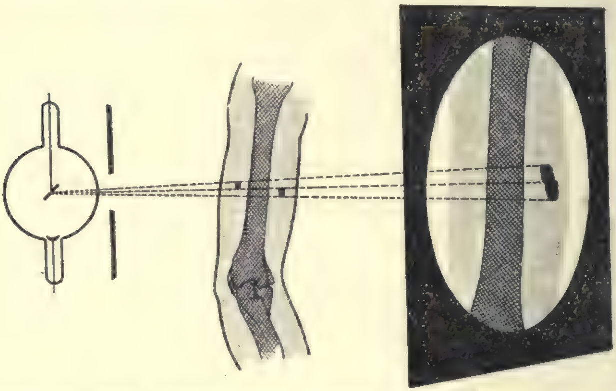


FIG. 91.—This diagram shows how two small projectiles may give a single shadow and simulate a larger projectile.

to a certain extent from the examination of the plate, and this is a consideration of some interest not only from the medico-legal standpoint but also from the operative point of view when it is necessary to know whether it is a question of a magnetic projectile or not, which is sometimes of importance in selecting the technique to be employed for its extraction.*

* The shape which most often gives valuable information as to the kind of projectile with which we are dealing—German or French bullet, shrapnel, fragment of a shell, etc.—and consequently also as to its nature, must of course be deduced from the appearance of the shadow with all reserve imposed by the knowledge of projections of a body of three dimensions on a plane, according to the laws, previously referred to, of authogonal projections.

In reality it would be necessary to be able to supply more correct

The nature of the metal is deduced from the density of the shadows. Although this information is not of very great importance it has however some value. It may though be extremely difficult to distinguish between certain eburnated sequestra which give very opaque shadows and metallic bodies. We shall refer later on to their differential diagnosis. But the information which the plate is able to supply to anyone who knows how to read it is not limited to these physical data. Omitting for the present the characteristics of radiological pathology inherent

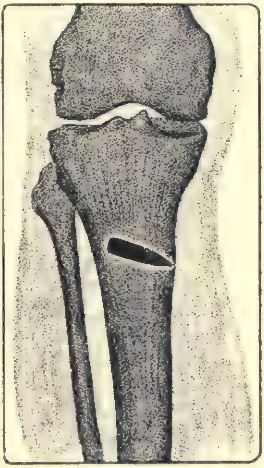


FIG. 92.—Radiograph of the knee and of the upper third of the left leg seen from behind. The shadow of a German rifle bullet is seen in the shadow of the tibia and round it we notice a clear thin zone of about 1 mm. which follows its shape and seems to indicate the existence of an area of decalcification round the projectile. From this we may conclude with every probability, but not with certainty from a view of the plate, that the projectile is within the bone (verified by operation).

to each organ and which for certain viscera such as the lung would necessitate a complete monograph to describe them (we shall speak of the great importance of these later on when discussing the topography of projectiles) we obtain from the plate information of immediate and often vital interest to the surgeon: for instance whether the projectile under consideration is or is not within the bone. If it is necessary, for the purpose of being absolutely certain on the subject, to examine two plates taken at right angles to one another, it

details to take in every case two radiographs in different directions, and as far as possible at right angles to one another or else stereoscopic plates. But as these radiographs give also important and sometimes sufficient information as to the depth of the projectiles, we shall refer to them again when we come to the chapter dealing with localisation; we shall therefore leave it for the present.

often happens that the examination of a single radiograph, if it is clear, can give information which is diagnostic.*

In fact there is generally produced round the projectile contained in the bone a zone of rarefying osteitis which is shown on the plate by a darker border (on the positive by a clearer border) which corresponds to the localised decalcification. Fig. 92 gives a good example of this.

But much importance should be attached to this appearance only if it is very clear because in certain cases, perhaps in consequence of the secondary radiation emitted by the metal, one can see a very slight halo round a shadow of a projectile not included in the bone, and this would easily lead to a mistake if we contented ourselves with this appearance unless it is very marked.†

Sometimes the aspect itself of the bony injury is sufficient as may be seen by an examination of Figs. 1 and 3 of Plate II.

Of not less importance is the study of the particulars in the vicinity such as cracks, fractures, splinters, deposits, sites of osteomyelitis, osteomata, pseudarthroses, etc., shown by the plate and which do not form part of this work (Plate III, Fig. 3, etc.).

A viewing box is of course a quite indispensable instrument for the study of all these details and we refer the reader to what has been said in the chapter "Apparatus" about the construction of a simple economical but perfectly satisfactory model (§ 15).

§ 24. **Fictitious Projectiles.**—If it is necessary to make a complete examination and to try as far as possible not to leave a foreign body undiscovered, it is perhaps of still more importance not to make the error of considering as projectiles shadows seen on the screen or plate, which are due to other causes. Contrary to what we may be led to believe at first if we have insufficient experience of the subject it is very easy to make such a mistake

* See the recent book by Barjon, *Examen radiologique du thorax* (Paris, Masson, 1916), in which the reader will find a lucid and authoritative statement on this interesting branch of medico-surgical radiology.

† The most conclusive proof will generally be supplied by a radiographic examination carried out by moving the limb under consideration and by making certain that the shadow of the projectile is included in the shadow of the bone.

especially with a screen examination if we do not possess the necessary anatomical and technical knowledge. In such cases we must not speak, as has been often done especially with regard to fractures, of errors of radiography. X-rays and the sensitive layer of the plate or of the screen obey only invariable physical laws and cannot "be mistaken," and it is only the human interpretation which is at fault if the radiologist is not sufficiently competent or, which is very often the case, especially now in view of the large number of radiographs taken by non-medical amateurs, when physicians and surgeons examine the plates by themselves and draw from them too hasty and faulty conclusions.

Screen images are simply projected shadows and the density of these shadows, which alone serve as a guide in our deductions as to the body which projects the shadow, is determined by two factors: the atomic weight and the mass of the body under consideration. It is therefore evident that there is a possibility of an infinite number of circumstances under which dissimilar bodies may give shadows of an equal density. It requires all the skill of an experienced radiologist who is perfectly well acquainted with and master of his technique and of the delicacy of interpretations to make a correct diagnosis by a series of rational deductions and by conclusions by analogy. This means that there is a great risk of frequent error. As they may lead to the most deplorable consequences by exposing a man to a serious operation which would be unnecessary and avoidable if proper precautions were taken, we think we are justified in explaining here rather fully all those errors the possibility of which has been shown to us by our own personal experience and by the experience of other people.

First of all we shall pass quickly over those errors which photographic imperfections may cause: defects in the emulsion, holes in the gelatine or partial melting when drying (often caused by microbic colonies), defects in the developing and fixing, and especially spots on the intensifying reinforcing screens, which are particularly important, especially in war time, in view of the almost constant and, to our mind, excessive use of these screens in most of the units which have only installations of a low capacity to reduce the time of exposure and to save the tubes.

It will be sufficient to recognise the spots on the screen used and their shape to avoid grave mistakes if it is not possible either to eliminate the spots or to replace the screens. A written interpretation of these marks made by the radiologist and signed by him will enable others to avoid them in the case of proofs which may have been examined by men in other units or during his absence (we refer to this later).

Shadows made by jewellery, buttons, pins, buckles of trousers or by any other bodies belonging to the clothing of the patients examined, or to their dressings (Michel's hooks, etc., not forgetting the bismuth spots on the shirt in examinations which necessitate the use of that substance) have frequently caused errors of diagnosis which a little care and the precaution of always removing the clothing as far as possible from the region to be examined would have prevented. But generally, even if there should be on the plate shadows thus produced, their regular and often characteristic form (for instance buttons with their two or four holes, etc.) should be sufficient to make them immediately recognisable.

We wish however to mention specially products of dressing of a high atomic weight and more particularly the iodised products, the first place amongst which must be given to iodoform, which may not only give shadows on the plates taken without removing the dressing (a very useful precaution whenever possible to do so without inconveniencing the patient) or without making sure of its composition, but may also adhere to the skin after the dressing has been removed and cause grave errors if no precautions are taken. Thus iodoform powder which remained on the skin has often given rise to a wrong diagnosis of "metallic dust persisting in the tissues."

These cases form a kind of transition between the causes of preceding errors which are purely extrinsic to the organism and the intrinsic causes. Heavy metalloids (iodine, etc.) or metals (zinc, iron, etc.) and their derivatives which are used for dressing, a complete list of which we cannot give here, may penetrate into jagged wounds and remain there, even after cicatrisation, imbedded in the tissues. In the latter case the differentiation from the metallic dust caused by the projectiles is sometimes impossible. The mistake would not be serious as it does not lead to operation. At the most it might have an effect on the mental state of the wounded if he were aware of the diagnosis. But in that case it is generally easy to alleviate his apprehensions by showing him the smallness of the particles.

If there are fistulous passages, care should be taken to ascertain that they do not contain iodoform gauze and that no iodoform or other substances or Beck's paste or any suspension of bismuth have been introduced.

It should not be forgotten that subcutaneous and especially intramuscular injections of medicaments of a high atomic weight such as mercury salts, iodised derivatives, etc., may cause opaque deposits which sometimes persist for many years, the aspect of which is fortunately in general sufficiently characteristic to draw one's attention to it.

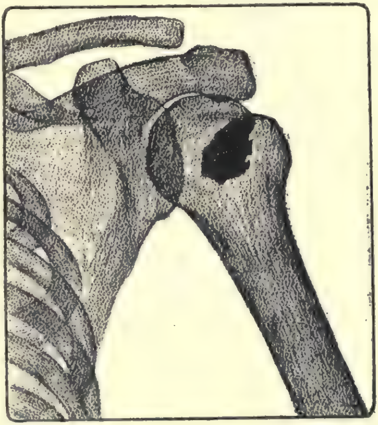


Fig. 93.—Radiograph of the right shoulder seen from the back. A very dense irregular shadow which closely resembles the shadow of a metal fragment is seen on the shadow of the humeral head. It is an iodoform dressing in the head of the humerus.

When dealing with the face we must always bear in mind stopped and crowned teeth and various other dental devices which in oblique view may produce metallic shadows giving rise to difficulties in diagnosis. We should also keep in mind opaque injections and dressings, without any apparent external wound, inserted through the mouth or nose into the normal cavities of the face.

But one of the most frequent causes of this kind of error and very often the most difficult to avoid in a rapid examination or when the observer is not very experienced is often the result of "fillings" of bony cavities with iodoform so frequently inserted after scraping necessitated by osteomyelitis. We show one of these "fillings," the regularity of its oval circumference will be noticed. However the diagnosis from a misshapen shrapnel bullet may be difficult should the patient say that he was struck by a shell which was not the case with this patient (Fig. 94).

FIG. 94.—Radiograph of the lower third of the right forearm seen from the front. In the loss of substance of the radius, in the shadow of a trail of an osseous proliferation there will be noticed two dark spots which may be taken for metallic fragments: they are two sequestra.

Besides intrinsic causes of error due to treatment, of which we have mentioned the principal ones without however exhausting the list, there are also metal bodies introduced into the organism by the surgeon for the purpose of prosthesis, such as trepanning plates, Lane's metal plates and Lambotte's metal plates, deep metal sutures in the bones or elsewhere, anastomotic buttons in gastro-intestinal surgery, etc., which we mention in passing.

Opaque foreign bodies in the alimentary tract: mercurial or iodised pills, powders or pastes composed of bismuth, fruit stones, as well as the remains of opaque lotions of bismuth or baryta, etc., may also be mentioned.

On the contrary pathological products of the body must be gone into more carefully.

At first we must mention abnormal bony growths which may lead to confusion and especially old and eburnated sequestra which become so opaque that it is very easy to take them even on excellent plates for metal fragments unless there is one of these fragments of sufficient size also present to show the difference in the density of their shadows. We have ourselves had occasion to extract rather large sequestra from the cranium and from other regions which had mostly been taken for projectiles and had been searched for without success.

Next we may mention pathological concretions: calcul, of different kinds, from the salivary glands, gall bladderi kidney, ureters, bladder and prostate; the phleboliths, pelvic blotches, etc., are of little interest in this connection, but the concretions of bacillary origin and those due to atheroma are in practice sometimes of great importance.

M. Béclère has described formerly and all professional radiologists are now acquainted with those multiple calcified glands from whose presence a whole segment of a body may appear to be filled with projectiles. We know without laying stress on the fact that calcification is extremely common in lymphatic glands in many situations, but more especially in those groups which are clinically most frequently affected with tuberculosis. The opacity of the shadow produced is in direct proportion to the density of the calcareous deposit. Although a clinical examination of the neck and of the sub-maxillary region is generally sufficient to eliminate all chance of error, the same does not apply to deep groups of glands which are inaccessible to palpation such as those of the abdomen and especially of the thorax.

FIG. 95.—In this diagram we see various sesamoid bones as well as the commonest sites of condensation or rarefaction of bone.

There is no doubt that errors of diagnosis are most frequently made in the last-mentioned region, and that shadows due to organic calcification may easily be taken for metal fragments.

In the region of the lung, although this is the easiest organ to examine with the screen, there are many sources of error, especially if the observer is not an experienced radiologist.

Taking into consideration the frequency of intrathoracic calcification even in relatively young patients in any given series of cases we are certain to find instances which will give rise to difficulties in diagnosis. As regards the lungs the great opacity of certain of these concretions seems to be considerably increased by the extreme transparency of the organ in which they are situated. By always obtaining a short history of his case from the patient we shall be able to avoid making a diagnosis that a projectile is present in the lung of a patient who has never been wounded—we have seen this mistake made—but if the patient has been wounded and especially if there is a thoracic wound present there may be a legitimate cause for doubt as to diagnosis, because the abnormal glands may take any shape or position, such as large and round single glands resembling a shrapnel bullet, small multiple shadows or a small isolated one (generally too round for a projectile and easier to recognise), and may be situated either in the lung tissue far away from the hilus or close to it in the mediastinum. Moreover, they may all show communicated pulsation. (See also Chapter II.)

The difficulty is still greater when we have to deal with calcareous plaques which are often found in the lung and in the pleura, and even in the pericardium. If they are taken on edge when they give a fairly dense shadow, they may easily be mistaken for a thin fragment of bullet casing. We are not at all ashamed of having extracted a calcareous plague from a man wounded by a shell on the same side of the thorax. The patient was suffering from hæmoptysis and complained of acute pain. In this case we had noticed before the operation the relatively slight opacity of the shadow of the projectile on the control plate which we always take in these cases.

The reader who wishes to know more about this interesting subject will study with advantage the excellent articles by Albert Weil whose beautiful plates published in the *Journal de Radiologie* (Volume I, 1914) show very clearly the typical aspect of these calcified glandular shadows. We shall however again refer to this in Chapter XI.

For particularly difficult or doubtful cases we recommend that plates should be taken at different angles, and that a fragment of metal of about the same size as the suspected body should be fixed on the skin of the region examined. In screen examinations the same procedure should be adopted by comparing the shadow of the fragment of metal with that of the suspected body.

As regards plates they must of course be taken while the patient holds his breath, and when the shadow is pulsatile they must be instantaneous.

FIG. 96.—Radiograph of the left hand seen from its palmar aspect. The shadow of a piece of metal will be noticed superimposing the scaphoid. Three minute metal fragments are seen on the shadow of the os magnum, whilst the hook of the unciform and the pisiform give a much less dense shadow which could easily cause a mistake to be made if we had not the metal fragments present to compare it with.

The same remarks naturally apply to atheromatic calcification of the aorta, but this occurs much less frequently. Not only abnormal or pathological shadows seen during a screen examination however may lead an inexperienced observer into errors of diagnosis. Shadows of normal bony structures may be equally misleading. In view of the importance and of the increasing development of this method of diagnosis and localisation we must insist on the commoner errors and point out to beginners in radiology the absolute necessity of a complete knowledge of osteology, not only of its normal appearances but also of its abnormal variations.

Let us take the different regions of the body in order.

*Skull.*—It is easy to mistake various processes for metal fragments, but by changing the direction of the head the error can generally be avoided. A very dense mastoid may sometimes cause a novice to take it for a large metallic fragment.

In the *Neck* Chassaignac's tubercle and in the *Lumbar Vertebræ* the free end of a transverse process when its union with the process is not easily seen, which may often be the case with a thin negative, may cause a second of hesitation.

*Thorax.*—During an examination in an oblique position the sternal end of the clavicle may be seen in the clear mediastinal space and may be mistaken for a shrapnel bullet if a control plate has not been taken. We have seen a similar case. In the upper limb the sesamoid bones of the hand (Fig. 95) have caused numerous errors of interpretation, and the hook of the unciform (Fig. 96) and sometimes the pisiform bone and in the head of the humerus the two tuberosities, which are very opaque to the rays, may cause confusion.

But one of the most frequent and real causes of error in the region of the shoulder is supplied by the coracoid process, which during an examination in a lying position is seen on the screen in the form of a simple round spot which has absolutely the same aspect and dimensions as a shrapnel bullet. In the case of a patient who had a shrapnel bullet in his right shoulder we have known a radiologist misled by a too hasty examination to suggest to the surgeon an operation on the left side on account of this appearance and we have several times seen this erroneous diagnosis made from the plates (Fig. 97).

Fig. 97.—Radiograph of the left shoulder seen from front. It will be noticed that the shadow of the free extremity of the caracoid process resembles a slightly deformed shrapnel bullet. The resemblance is still more perfect on the screen. This aspect is however much less accentuated if the shoulder is examined from the back (see Fig. 93).

In the lower limb the sesamoid of the knee is the most frequent source of error (Fig. 98), or an area of dense bone, situated underneath the cotyloid ridge giving the appearance of a small fragment of shell, and finally but less often the small trochanter has been taken for a shrapnel bullet.

As regards bony abnormalities (supernumerary bones of the carpus or of the tarsus, rare sesamoids, etc., areas of calcareous condensation in various bones and especially in those of the carpus) we shall not dwell upon them here, and shall content ourselves by drawing general attention to them and warning the observer against these innumerable causes of error, especially novices and certain photographers who imagine that they are immediately able to interpret any screen or radiographic images without any anatomical knowledge and without any previous study.

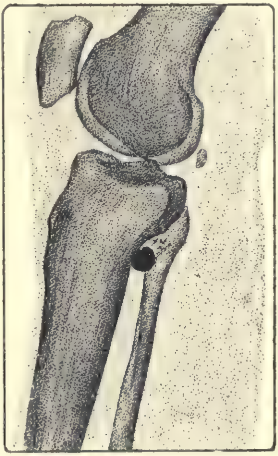


FIG. 98.—Radiograph of the right leg seen from inner side. The small oval shadow the size of a pea which we see behind the shadow of the femoral condyles corresponds with the sesamoid of the knee. Seen at the upper extremity of the interosseous space there is a shrapnel bullet which must however have come into contact with the bone to judge by the few metal particles which have become detached from it. (Compare also Figs. 1 and 2 of Plate I.)

§ 25. **Result of Examination : Written Interpretation.**—Let us suppose that we have avoided all these difficulties, and that our first examination, the object of which was simply to look for a foreign body, is terminated.

We have now obtained information as to the presence or absence of a projectile. In order to leave behind a proof of our examination so that the patient may benefit by it and to avoid a repetition which is useless and costly to the State (a matter of frequent occurrence), we must put down the result in writing and sign it, thus accepting the responsibility for the results given. This means that we must only state facts of which we are sure. We may write for instance: "No projectile visible from screen examination of the thorax" (if this is the region examined) but we must not say: "No projectile visible from screen examination" unless we have screened the patient's body, and still less: "There are no projectiles," a formula which is often used quite wrongly.

If plates have been taken we must say: "No projectile visible from a screen examination of the thorax or on the plates taken," etc.

If our examination is positive we must supply particulars as exactly as possible of the dimensions and of the nature of the projectile. Dimensions indicated in millimeters are naturally the most precise and in general use. Nevertheless comparisons with the size of various seeds, fruits, etc., are currently used and on account of their simplicity may be employed. The millet seed, the grain of corn, the small pea, the haricot, the hazel nut and the filbert are considerably used in this kind of description (see next chapter).

Besides the information relating to the projectile itself it is of course necessary to give any additional details relating to the state of soft parts or bony structures shown by the X-ray examination. In Chapter III we have already insisted on these points, so we shall therefore only reproduce here as a specimen one of our reports (see Chapter IX).

| Central Service of Radiology of the IXth district. Chef du Centre, M.A.M. 1st Cl., R. Ledoux-Lebard. | X-RAY REPORT | No. 2.693 Radiological Laboratory Place de Tours. Chef du Laboratoire, M.A.M. 1st Cl., Chabaueix. |
|---|---|---|

Name and Christian name, V. Ernest. Corps, Xth Infantry. Hospital 53. Physician or surgeon in attendance, Dr. Prouse.
Region examined: Finger joints of left hand.
Age 27 years.
Clinical diagnosis.
Date of the wound, September 8th, 1914.
Wound caused by bullet.
X-ray examination required for: Stiffness of joints of left hand, stiffness of the phalangeal joints.
N.B.—Care should be taken that patients sent for X-ray examination are quite clean.
(*To be filled by the attending physician.*)
(*This sheet must be attached to the official report of the wounded and never be communicated to him.*)
Examined October 1915.
Process utilised: Screen examination: Radiograph, No. 2,693. Size, 13 × 18.

Injury found : Amputation of the middle finger. There is only a small portion of the base of the phalanx, ankylosis of the index.
Innumerable metal fragments scattered everywhere especially in the fingers, the largest of which is of the size of a grain of corn and is situated in the third interosseous space.

N.B.—Localisations will only be undertaken for patients belonging to units having a surgical department.

The information relating to the patient given in this report may appear rather complex, but it is absolutely necessary for a correct X-ray interpretation. In another chapter we shall see a copy of a report used in our district for giving the result of localisation.

We must also again point out here the advantage of not telling the patients the result of the examination and especially not letting them know that they have retained projectiles if it happens that they are not aware of the fact (this is however very rare now in spite of the very wise official instructions which have appeared on this subject in view of the number of X-ray examinations and of the frequency of localisation which naturally indicate the presence of a projectile).

To supply particulars as to the kind of projectile present we must first know the principal types now used in the armies, because some information of their nature may render great service to the radiologist by giving him exact details of the metal used and thus enabling the surgeon to use the right instruments. In the next chapter we shall deal with this subject.

## CHAPTER VI

### PROJECTILES AND THEIR EFFECTS

§ 26.—In the previous chapter we have given a general indication of the value of knowing, from a surgical standpoint, the characteristics of the projectile to be extracted. Thus to extract a French bullet from the depth of a wound we would not think of using a continuous magnet nor would we make use of an electro-vibrator in order to find a shrapnel bullet which being of lead would not vibrate. On the other hand we shall see in the following chapter how the determination of the depth of a projectile could be facilitated if we knew its exact dimensions. A knowledge of the real nature of a projectile, whether a bullet from a German or Austrian rifle, shrapnel bullet, fragment of a shell, etc., often gives us useful information by enabling us to know of what the projectile consists or what its dimensions are.

To this end and without desiring in any way to exaggerate the importance of these indications, which are often rendered deceptive by the change of shape of the projectiles or of their images, we think it advisable to pass here rapidly in review some elementary facts relating to the principal projectiles of the small arms and of the artillery used by the principal belligerent or neutral nations. We have taken them almost textually from the very remarkable and lucid works of MM. Nimier and Laval * the study of which we strongly recommend. We have completed them as regards the modifications in armaments which have taken place since their publication.

* Nimier and Laval, *Projectiles of War Arms ; their Mutilating Action* (Paris, Alcan, 1899, one volume 16 mo); and by the same authors, *Explosives, Powders, Projectiles for Training : their Action and their Mutilating Effects* (Paris, Alcan, 1899, one volume 16 mo).

First of all let us point out in a general manner that all projectiles of firearms of the present day must be considered from the double standpoint of their mass and their velocity, as their mutilating power is measured by the product of one by the square of the other.* We draw a distinction between artillery or *large* projectiles and small-arm infantry or *small* projectiles.

## I. Infantry Projectiles

§ 27.—Since their first appearance on the battlefields portable firearms have undergone many modifications

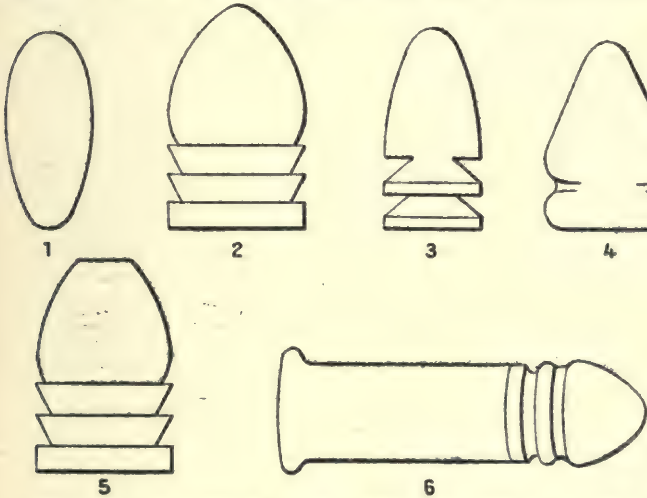



Fig. 99.—Some types of portable arm projectiles in use in the European armies from 1840 to 1886 : (1) Minié rifle, France (1842) ; (2) Prussian needle rifle (1872) ; (3) Chassepot (France, 1866) ; (4) German rifle, 1871 ; (5) Martini-Henri rifle (England, 1871) ; (6) Gras rifle, model 1874.

and, from the surgical standpoint, their principal effects are :

(1) To reduce the mass of the projectile ; (2) to in-

* The mutilating power depends for each projectile upon its actual force $F$ which is measured by the half-product of the mass $m$ by the square of the velocity $v$ according to the formula $F = \frac{1}{2} mv^2$.

crease the actual force by which it is propelled. The rapidity of shooting of modern portable arms is also of some surgical interest. Brought to its maximum with the machine guns it has remarkably contributed to modify in the present war the number of wounded and especially their density in a given time if we may be allowed to use that expression.

Whilst the projectiles previous to 1886 (Lebel rifle) were of more or less different shapes the shapes of projectiles of the present time are almost identical. The former have only a retrospective interest for us and if we give in the enclosed figure the diagrams of some of these early forms it is only as a documentary evidence as the patients in whom the radiologist or the surgeon may still find them retained in the tissues are becoming very rare. Their principal characteristics are as follows :

| Name of the Rifle. | Country and Date. | Calibre in mm. | Composition. | Weight in gr. |
|---|---|---|---|---|
| Minié rifle . . . | France, 1842 | 18·25 | Soft lead | 36 |
| Needle rifle . . . | Prussia, 1872 | 15·43 | — | 21·5 |
| Chassepot . . . | France, 1866 | 11 | — | 23 |
| Infantry rifle . . | Germany, 1874 | 11 | — | 25 |
| Martini-Henry rifle . | England, 1871 | 11·43 | {Lead 12, Zinc 1} | 32 |
| Gras rifle . . . | France, 1874 | 11 | Lead | 50 |

We shall deal more extensively with the modern projectiles. Their cylindrical body is terminated at their apex by a point and at the base by a circular flat or slightly excavated surface. Sometimes the point is truncated at the apex and thus represents a flat surface of about 1 mm. in diameter (S bullet or Italian bullet). The external surface, generally smooth, may present at its base a groove which corresponds to the impression produced by the neck of the cartridge. The calibres vary between 6 and 8 mm. and as a corrective for the reduction of the calibre ballistic requirements necessitated a prolongation of the projectiles which fact, from the surgical standpoint, constitutes a troublesome condition. This elongation which is particularly noticeable in our bullet

D compensates, at least partially, for the reduction of its calibre in relation to the mass of the projectile.

The length of a bullet is expressed in millimeters as well as in calibres, that is to say by the relation that exists between this length and the diameter of the cylindrical part or the calibre. Recent bullets measure in length on an average four times the calibre.

The weight of modern bullets is far less than that of their predecessors, but the main change that has taken place is due essentially to the construction of the case of the bullets. Most of them are formed of a core of hardened lead covered with a resisting metal envelope (the case), whence the name of cased bullets.*

As soon as the rifle is fired the projectile presents, besides the molecular vibrations by which its mass may be set in motion, three kinds of movements :

(*a*) *The Propulsive Movement* ordinarily called speed which varies according to whether it is considered when leaving the rifle (initial speed) or at a certain distance after having left it when it is modified by the resistance of the air and by the action of the weight (residual speed). It is the residual speed which alone is interesting from our standpoint and its study will enable us to foresee the differences which exist, all other conditions being equal, between the wounds under observation according to the distance at which they may have been produced.

(*b*) *The Rotatory Movement.*—Communicated to the projectile by the grooves to enable it to overcome the resistance of the air and to keep the pointed cylindrical bullet moving horizontally forward with its point in front. As this movement is practically constant it has no particular interest for us.

(*c*) *Abnormal Movements.*—As the centre of gravity does not coincide with the centre of the mass of the present very long bullets they have a tendency to pitch, to turn and to strike obstacles obliquely or crosswise. The same fact is also observed, to a higher degree, when the bullet even without being misshapen touches in its passage

* French bullets being all of solid copper are of course an exception ; the new British bullet with an aluminium core, the details of which we have given in our tables, is the only one of its kind. See interesting booklet by Dutertre.

an obstacle or when it passes through a non-homogeneous body. A pirouetting movement is then produced which contributes espécially with projectiles which ricochet to increase still further the extent of the point of impact. To obtain a clear idea as to the deformities produced by bullets in the tissues it is not sufficient to know their normal physical qualities; notice must be taken of the modifications which the latter undergo and especially of the modifications of form which cause such considerable differences in the transmission of the actual force of the projectile. The change of shape has the double effect of enlarging the striking surface and of increasing the time of its action by slowing down the course of the bullet.

In cased bullets the case lessens the change of shape of the core which is less resistant than the case; but if it gets torn it more or less opens and the lead of the core tends to escape. Wounded soldiers are often met with in whom the case of the bullet is found to be deformed and in the adjoining tissues are found up to a great distance series of lead fragments coming from the core. In all these cases the damage is generally very great and it is to produce the terrible effects caused to the human body by deformed projectiles that a systematic use has been made of specially prepared bullets (such as dum-dum bullets) which are intended to become deformed and produce "explosive effects" consisting mainly in extreme comminution of bones or in bursting of organs filled with liquids, or of real explosive projectiles that is to say containing an explosive charge which explodes at the moment when the projectile strikes a hard part of the body.* Without studying here the question of the relation existing between the distance at which a wound has been produced, the form and the nature of the projectile and the effects observed (interesting though it may be, and worthy of a detailed description), we simply wish to point out that it is necessary to be extremely reserved in the retrospective diagnosis of the projectile used even after a most complete X-ray examination before stating that a wound was caused by an explosive projectile. "Explosive effects" similar to those shown in published

* See the pamphlet by Dutertre on explosive projectiles (Paris, Maloine, 1916).

radiographs may perfectly well be noticed with ordinary projectiles, as has been demonstrated by experiments.

The radiograph reproduced on Plate II (Fig. 3) shows however a bullet of a special type which seems to have been fired base foremost in order to increase the surface struck and the wound produced.

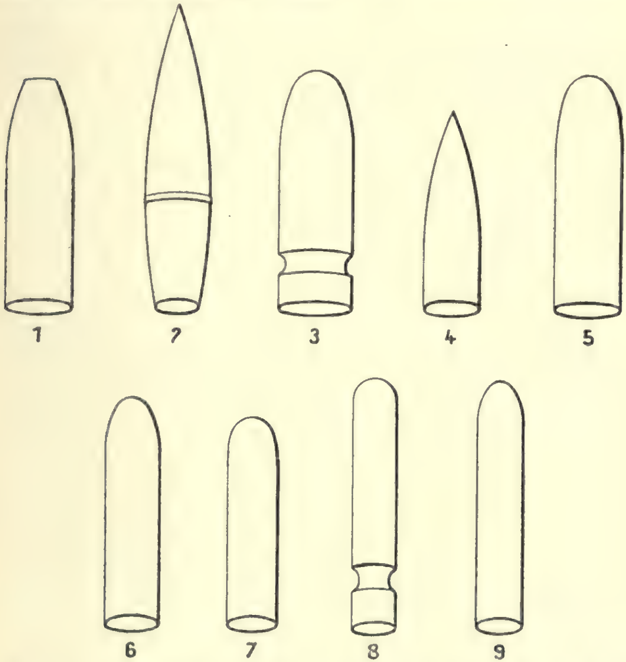



FIG. 100.—Projectiles of the principal rifles used by the allied armies: (1) France, S bullet; (2) France, D bullet; (3) England, rifle model, 1889–91; (4) Russia, rifle model, 1891; (5) Belgium, Mauser model, 1889; (6) Serbia, Mauser model, 1899; (7) Italy, Paravicino-Carcano, 1891; (8) Japan, Brisaka, 1905; (9) Portugal, Mauser, 1904.

We wish to point out that in general and with many reservations as to the correctness of these divisions the course traversed by small projectiles may be divided into three zones:

(1) *Zone of Typical Explosive Effects* when fired point-

blank but which are observed up to a distance of 300 meters and even more;

(2) *The Perforation Zone* the dominant feature of which is a more or less clear perforation of the tissues, and which extends up to 2,000 meters and over;

(3) *Contusion Zone* more or less over 2.200 meters.

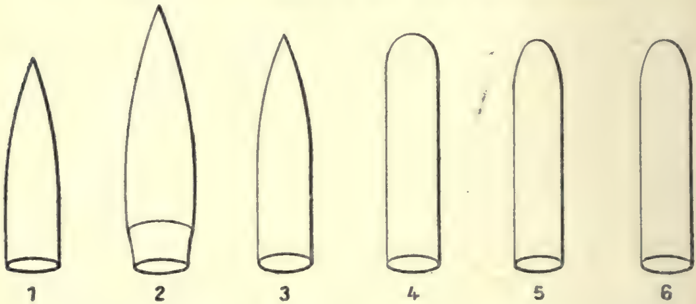



FIG. 101.—Principal projectiles used by the armies of some of the neutral countries: (1) United States of America (M. 1903); (2) Switzerland (M. 1903); (3) Spain, Mauser, 1893; (4) Greece, Männlicher-Schönauer, 1903; (5) Netherlands, Männlicher, 1893; (6) Roumania, Männlicher, 1893.

Although the number of those killed by small projectiles must be proportionately larger than before, the wounded on the other hand have more chances of recovery, and we have been able to notice the mildness of wounds caused by rifle bullets and the tolerance of the tissues of these foreign bodies which are often aseptic. These are points which should not be forgotten when arguing for or against the extraction of a projectile situated in a dangerous place.

The following tables sum up the characteristics of rifle bullets used by the principal belligerent or neutral powers, and supply particulars of their nature and dimensions which may be useful to radiologists and to surgeons in their daily work. It must however not be forgotten that armaments and munitions are being constantly modified in the course of the present war, and that moreover each belligerent often makes use of enemy material captured during the war.

| Name of Country and Weapon. | Core. | Jacket. | Weight (in gr.) | Length (in mm.) | Diameter. (in mm.) |
|---|---|---|---|---|---|
| **I.—ALLIED COUNTRIES** | | | | | |
| FRANCE, Lebel 1886–1893, 8 mm., Bullet S. | Hardened lead | Nickelled copper | 15·0 | 30·3 | 7·72 |
| Bullet D (solid) | All copper | All copper | 12·8 | 39·2 | 8·0 |
| ENGLAND, Lee-Metford and Lee-Enfield, M. 1889–91, cal. 7·7 mm. | Lead with 5 per cent. antimony | Nickelled copper | 14 | 31 | 7·87 |
| BELGIUM, Mauser, M. 1889, cal. 7·65 mm. | Lead with 2 per cent. antimony | Nickelled copper | 14 | 30 | 7·95 |
| ITALY, Paravicino Carcano, M. 1891, cal. 6·5 mm. | Lead with 5 per cent. antimony | Nickelled copper | 10·5 | 29 | 6·75 |
| JAPAN, Arisaka, M. 1905, cal. 6·5 mm. | Soft lead | Nickelled copper | 8 | 32·5 | 6·6 |
| MONTENEGRO | | | | | |
| PORTUGAL, Mauser, M. 1904 cal. 6·5 mm. | Lead with 5 per cent. antimony | Nickelled copper | 10·1 | 32 | 6·7 |
| RUSSIA, Mossin, M. 1891, Bullet S., cal. 7·62 mm. | Lead with 2 per cent antimony | Cast steel covered with nickelled copper | 9·0 | 25·5 | 7·85 |
| SERBIA, Mauser, M. 1899, cal. 7 mm. | Lead with 2 per cent. antimony | Cast steel covered with nickelled copper | 11·2 | 30·8 | 7·25 |
| **II.—PRINCIPAL NEUTRAL COUNTRIES** | | | | | |
| UNITED STATES, M. 1903, cal. 7·62 mm. | Lead with 2 per cent. antimony | Cast steel covered with nickelled copper | 9·7 | 27·8 | 7·85 |
| DENMARK, Krag-Jörgensen, M. 1908, cal. 8 mm. | Soft lead | — | 12·7 | 31·5 | 8·22 |
| SPAIN, Mauser, M. 1893, Bullet S., cal. 7 mm. | Lead with 2 per cent. antimony | — | 10 | 30·8 | 7·20 |
| HOLLAND, Männlicher, M. 1893, cal. 6·5 mm. | Lead with 2 per cent. antimony | — | 10·2 | 30·9 | 6·65 |
| GREECE, Männlicher-Schönauer, M. 1903, cal. 6·4 mm. | Lead with 5 per cent. antimony | — | 10·25 | 31·8 | 6·7 |
| NORWAY, Krag-Jörgensen, M. 1896, cal. 6·5 mm. | Lead with 2 per cent. antimony | — | 10·1 | 32·5 | 6·7 |
| ROUMANIA, Männlicher, M. 1893, cal. 6·5 mm. | Lead with 5 per cent. antimony | — | 10·25 | 31·8 | 5·65 |
| SWEDEN, Mauser, M. 1896, cal. 6.5 mm. | Lead with 5 per cent. antimony | Nickelled copper | 10·1 | 32 | 6·7 |
| SWITZERLAND, Schmidt Rorbin, M. 1890–1903, cal. 7·5 mm. | Lead with 2·5 per cent. antimony | Cast steel and nickelled copper | 11·3 | 34·3 | 7·82 |

1 See p. 132, note 1.

| Name of Country and Weapon. | Core. | Jacket. | Weight (in gr.) | Length (in mm.) | Diameter (in mm.) |
|---|---|---|---|---|---|
| III.—ENEMY COUNTRIES | | | | | |
| GERMANY, M. 1888, Bullet S, cal. 7·9 mm. | Lead with 2·5 per cent. antimony | Cast steel and nickelled copper | 10 | 28·0 | 8·22 |
| AUSTRIA-HUNGARY, Männlicher, M. cal. 8 mm. | — | — | ,, | ,, | ,, |
| BULGARIA, cal. 8 mm. | — | — | ,, | ,, | ,, |
| TURKEY, Mauser, M. 1903, cal. 7·65 mm. | — | — | ,, | 27·5 | 7·92 |

The preceding considerations apply as a whole to the small projectiles of service revolvers and of automatic pistols all of which resemble rifle bullets more or less, but their diminution in size and speed in a general way reduces considerably the zone of explosive action.

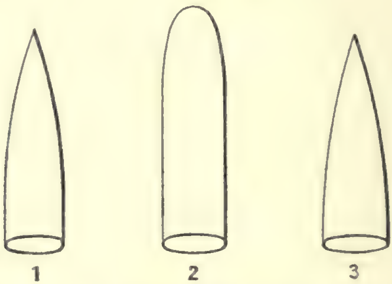



FIG. 102.—The principal rifle bullets used by the enemy armies. (1) German, 1888. (2) Austria-Hungary; Männlicher and also types of German bullets shown in the preceding number; Bulgaria, bullets of the two preceding types. (3) Turkey, Mauser, 1903 (also projectiles of the preceding types used of course with their respective rifles).

As regards projectiles of machine guns which are generally the same as those of rifles, the same ammunition being often used for either arm, there is no distinction whatever between them.

We shall not dwell upon projectiles for practising purposes, as they so rarely produce wounds that they do not offer any practical interest, nor shall we describe projectiles of sporting ammunition or of portable arms for protection as their interest is of a very secondary nature at the present time, and the number of types is too large to enable us to supply precise and sufficiently complete information about them in the scope of this work.

## II. Artillery Projectiles

§ 28.—Still more than the bullets large projectiles have become modified since their first appearance on the battlefield and we could not think of discussing all the old guns and their ammunition, the more so because the number of different types which have been in use is extremely large.

Even now the artillery consists of too many types and calibres for us to be able to describe them. Let us content ourselves by pointing out that under the general name of "gun" there are various types of artillery pieces which are still distinguished according to the trajectory habitually described by their projectiles, under the name of cannon, mortar, howitzer.

The cannon shoots, that is to say throws a projectile the trajectory of which describes a relatively moderate curve, the mortar bombards, that is to say throws by following a trajectory which to start with approaches the vertical a projectile intended to fall behind an obstacle, finally the howitzer shoots and bombards. These distinctions are however rather artificial and depend at present specially upon the gun carriage employed as may be gathered from the constant use during the present war of marine artillery for bombarding at long range.

As regards projectiles which alone interest us here directly it may be said, however paradoxical it may seem, that the more their volume has been increased the less they have acted as large projectiles. They may be distinguished as explosive shells and shrapnel shells and they often combine these two characteristics. But explosive effects do not enter into our subject and moreover they undergo fragmentation into small projectiles in both types.

We are thus dealing with a hollow metal mass of steel or cast iron of a pointed cylindrical shape with the point slightly flattened at the end, the base of which is provided

## PLATE III

Fig. 1.—Radiograph of the right side of the head seen in profile. A rifle bullet of which only the base is missing casts its shadow in the light area of the maxillary sinus. (Teeth fillings should be noticed in this figure as they may be easily taken for projectiles.)

Fig. 2.—The same patient as in the preceding figure. Radiograph of the head, front view. The shadow of the projectile is still seen projected at the level of the right maxillary sinus, and it will be noted that the latter is very clearly less transparent than the left sinus, which is the result of the sinusitis caused by the projectile (verified by operation).

Fig. 3.—Radiograph of the right elbow seen in profile, extero-internal view. Notice should be taken of the periostitic changes and of the disappearance of the joint outlines which is due to the presence of the projectile (bullet encysted).

Fig. 4.—French bullet in contact with the sacrum on a level with the inlet (verified by operation).

N.B.—For the study of these various cases reference should be made to the particulars given in Chapters XI and XIV in which are included the various regions of the body, both from the point of view of the anatomical localisation of the projectile by the X-ray examination (Chapter II) and from the standpoint of the surgical extraction itself (Chapter XIV) undertaken by means of the intermittent control of the screen.

PLATE III

FIG. 1

FIG. 2

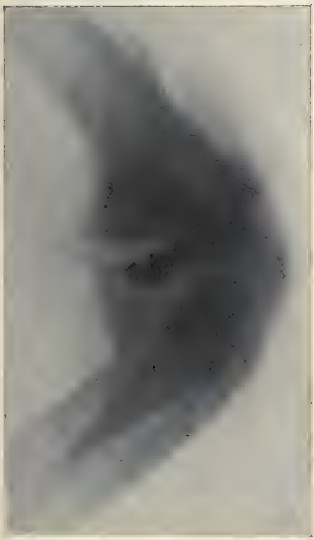


FIG. 3

FIG. 4

with a belt of lead or more generally of copper in order to ensure its fitting into the bore of the gun: the lower end is the base. This constitutes the shell. The truncated anterior part has an orifice in its centre called the eye into which is screwed the fuse, a mechanism by which the explosive charge contained in the interior of the shell, or the exploding powder the combustion of which will cause the projectile to burst, is fired, whilst the charging powder which is placed in the breech at the back of the shell either in a separate linen sack or connected with the shell like a real cartridge is intended solely for the propulsion of the projectile.

The fuse may either act on percussion, that is to say that it explodes from the shock when striking an obstacle, or after having been lighted at the start it detonates the exploding charge after a more or less long interval regulated at will by the gunner. Most of the fuses have a double effect, that is to say they have a percussion mechanism which comes into action in case the shell does not burst from the effect of the time fuse.

All these shells break up more or less irregularly; care has therefore to be taken to ensure that shells intended to reach combatants rather than to destroy their works should burst in a large number of fragments of such a shape that will not make them lose their speed in the air too rapidly and will allow them to retain a sufficient powerful force to kill or put out of action animals and men. Moreover the fragments must be spread over the required area in a suitable manner, that is to say within a certain radius round the bursting point. For this purpose shells have been produced which break up systematically and shells filled with bullets, generally called shrapnel from the name of Colonel Shrapnel who invented them. A shrapnel shell model 1891 of the French short 120 m. gun contains 630 lead bullets of a diameter of 12·8 mm. The bullets used are almost always of lead and spherical (sometimes but rarely polygonal), their weight varies between 8 and 15 grammes and their diameter is between 8 and 14 mm.

Finally, trench war has caused the return of trench engines, round shells and shells of various forms and especially of projectiles thrown by hand, namely grenades.

Consisting especially of a cast-iron case in the official types they may be atypical and improvised from receptacles of various forms and of different kinds (tins, etc.) and may contain all kinds of projectiles.

If we disregard whole pieces or almost whole pieces of a large projectile which are easily recognised such as fuses, bases, etc., which are very exceptional, we find in soldiers wounded by artillery fire either fragments of a shell of cast iron or more often of steel, the usual size of which will vary between a pea and a nut and whose irregular shape does not allow of any definite description or lead bullets either misshapen or not. There may also be found very rarely small fragments of copper coming from the belt and small pieces of aluminium from the fuse.

As regards the nature of the foreign bodies found from grenades and trench engines they generally consist of fragments of cast iron or of steel, but all sorts of material may be discovered. The radiograph reproduced on Plate I (Fig. 3) shows fragments of wire, part of the binding wire of such a missile. Finally trench weapons have altered our radiological ideas by making more and more frequent the enormous number of minute projectiles and even trails of metallic powder. With regard to the size of projectiles found in the wounded we can classify them as follows :

(1) *Dust.*—Metal fragments up to 1 mm. in diameter (Fig. 3, Plate VIII).

(2) *Minute Projectiles.*—Small pieces up to 4 mm. in their longest diameter (smaller than a grain of corn according to the current terminology) ; (Fig. 4, Plate VIII).

(3) *Small Projectiles.*—Fragments between 4 mm. and 1 cm. in diameter (from the size of a grain of corn to that of a large pea) ; (Fig. 4, Plate VIII).

(4) *Medium-sized Projectiles.*—Between 15 mm. and 2 cm. in diameter (from the size of a large pea up to a large haricot) ; (Fig. 96 and Fig. 4, Plate VI).

(5) *Large Projectiles.*—Various bullets and fragments the longest diameter of which is over 2 cm. (over the volume of a haricot) ; (Fig. 6, Plate III).

Although this distinction is artificial it has nevertheless a certain practical interest both from the X-ray and surgical standpoint.

It is evident that the projectiles of the first category cannot be removed. The utmost that could be done would be to take out the whole area of tissue containing a well-localised trail of metallic dust. The projectiles of the second category could only be extracted in quite exceptional cases, and then only with the control of the screen provided it has been possible to mark them, as the tactile sensation given them to the surgeon is often not sufficient to ensure their extraction, even with the most exact marking and with an irreproachable compass localisation. If it is therefore decided to operate absolutely definite indication for operation and appropriate technique are essential. The three last categories alone may be considered as really "surgical." We shall later on discuss this subject further.

As regards the "shape" of the projectiles it is evident that more or less irregular and rough fragments are generally much less tolerated by the tissues, even if they are of a smaller size than smooth projectiles such as "bullets"; it will also be evident that they are more frequently the cause of infection and of early or late septic accidents, owing to latent microbic infection, and that they are as a rule surrounded by dense tissues and are therefore the cause of considerable inconvenience from the purely mechanical standpoint which may call for their extraction. These few points, which we are only able to touch on in passing, will also have to be carefully considered when the question arises of operative interference. We shall not consider here the explosive effects of projectiles or of "indirect" projectiles, and we shall content ourselves by giving a few figures which illustrate sufficiently those various points (see plates not included in the text).

# CHAPTER VII

## GENERAL THEORY OF METHODS OF LOCALISATION

*(Written in collaboration with Mr. A. Dauvillier)*

§ 29.—BEFORE going into the physical problem of the localisation of foreign bodies we must remember the very simple law on which all the methods are based.

We have already seen that if we consider a tube in action X-rays are given off near the centre of the anticathode and from a surface which is always small enough to be regarded as a single point for emission of rays.

We have thus a source of X-rays which is practically a point and may be compared to an intense and single source of light which throws a clear sharp shadow of surrounding objects.

Geometrically a focus like this is a centre of conical projections (see Chapter III). Supposing $C$ to be that centre and $CX$ the axis along which the source of rays travels perpendicular to a linear object $AB$ which is opaque to the radiation of $C$. A surface $P$ being a screen at right angles to $CX$ will act as a plane of projection and we shall perceive on that plane the magnified image $A'B'$ of $AB$ (Fig. 103).

The triangles $CAB$, $CA'B'$ are then similar (Fig. 103) because they have a common vertical angle, and the bases $AB$, $A'B'$ are parallel by definition as being two perpendiculars to the axis. Their sides are therefore proportional and we may write:

$$\frac{AB}{CO} = \frac{A'B'}{CO'} \qquad (1)$$

that is to say, as we have previously seen (see Chapter III), the size of the shadow as projected on the screen is in direct proportion to the dimensions of the object and the distance which separates the surface $P$ from the source $C$ and is inversely proportional to the distance of the object $AB$ from the source.

This consideration enables one to form some deductions which are often useful in the radioscopic examination of foreign bodies.

In practice the distance $CO'$ of the anticathode to the fluorescent screen $P$ may often remain invariable say for examination of the pelvis or thorax. A shrapnel or rifle bullet, the dimensions of which are known to us beforehand, will produce a shadow which will be the larger the deeper

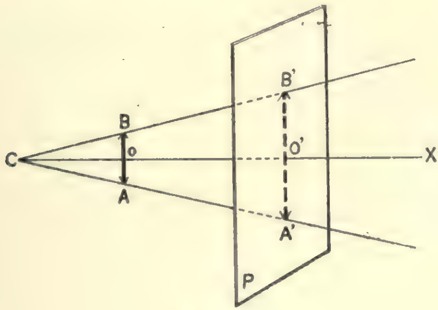



FIG. 103.

its situation (that is to say nearer to the anticathode than the screen). Two examinations one from the back and the other from the front—(the distance from the screen being constant)—will thus supply two shadows of identical dimensions if the foreign body is median, but different dimensions if it is nearer the one than the other, because the smaller shadow will evidently be obtained from the side to which it is nearer. Although this is rather a rough localisation nevertheless it renders in the course of our daily examinations important help by giving immediately an approximate idea of the depth of a projectile and especially in enabling us to choose the method by which a more exact localisation may be undertaken.

Provided we have this method already indicated most proceedings must, and in fact do, rest on the theory of geometrical triangulations.

Let us however point out that the fundamental equation indicated in the preceding page could not be used to determine the situation of a foreign body of an unknown size—which most frequently occurs—because then we can only carry out two direct measurements: one of the distance from the anticathode to the screen $CO'$ and two of the size of the projected shadow (radioscopic or radiographic) $A'B'$—thus we are in the presence of a single equation with two unknown quantities, that is to say of an insoluble problem (but in the case of a shrapnel bullet for instance, the diameter of which is known, we can immediately obtain the result desired).

Therefore the method to be used requires either two sources of X-rays working simultaneously or—and this is the most frequent—the displacement of a single source from one distinct position to another, or else a displacement of $AB$, that is to say a displacement of the object containing the foreign body. These two manipulations will then supply two distinct sets of data which can be expressed in two equations and we thus come back to a problem which is easily solved.

Most of the methods of localisation proposed since the discovery of Röntgen did not include even elementary mathematical considerations. The authors seemed especially to be endeavouring to realise the seat of the foreign body as a material representation in space. Most of these proceedings originated from the following considerations:

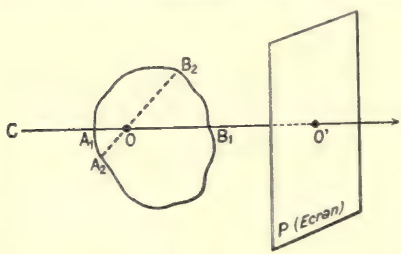



Fig. 104.

Suppose $C$ to be the point of emission of rays, $O$ the foreign body and $O'$ its shadow thrown on the surface $P$ of the screen (Fig. 104), and let the point of entrance and exit of the normal ray on the surface $P$ be $A_1$ and $B_1$, then let us mark those points on the skin by placing in front of and behind the subject and at the proper level an opaque pointed rod and marking thereupon the points of contact with a skin pencil. Let us then proceed to do a second similar operation, after having turned our subject through a certain angle, or after having displaced the source of rays some distance, and we shall then obtain two other points $A_2$ and $B_2$. The four points $A_1$, $B_1$, $A_2$, $B_2$, are such that straight lines joining each pair must cross in the foreign body.

Authors have constructed graphically the quadrilateral figure $A_1$, $B_1$, $A_2$, $B_2$ (by taking with the aid of compasses the distances $A_1$, $B_2$, $B_2$, $B_1$ etc.) or have materialised the curvilinear outline of the foreign body by plotting out the four points. All these proceedings are easily accomplished without any special apparatus and constitute the total of what is called the haphazard method (*le procédé de fortune*).

Another more recent group of proceedings consists in marking on the screen itself and not on the body the position of the shadows for two successive positions of the tube. Only the point of emergence of the normal ray is marked on the skin.

These proceedings are based on the following theory: Supposing $C$ and $C'$ to be two successive positions of the point of emission and $O$ the foreign body and $O_1$ and $O_2$ its shadows (which correspond to the positions $C$ and $C'$) and supposing the screen to be at right angles to one of the axes of projection (since this axis $CO_1$ is the normal ray) and the displacement $CC'$ to have taken place parallel to the surface of the screen, then the two triangles $CC'O$ and $OO_1\,O_2$ are similar and their sides proportional (Fig. 105).

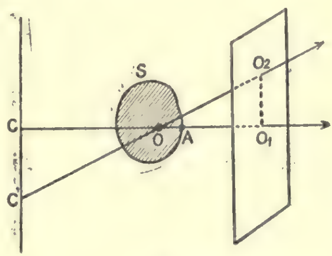


FIG. 105.

We can thus write:

$$\frac{CO}{CC'} = \frac{OO_1}{O_1O_2} \qquad (2)$$

$OO_1$ being the distance of the foreign body from the surface of the screen.

This equation cannot be solved directly because it contains a quantity of $CO$ which we cannot measure and which we must therefore eliminate. Let us point out however that we can write:

$$CO = CO_1 - OO_1$$

but we can measure directly $CO_1$ which is the distance of the anticathode of the tube to the screen and $OO_1$ is but the distance from the screen to the foreign body of which it will suffice to cut off the distance from the screen to the skin, namely $AO_1$, which is directly measurable, in order to obtain the required unknown $OA$ which is depth of the foreign body. We obtain thus:

$$\frac{CO_1 - OO_1}{CC'} = \frac{OO_1}{O_1O_2}$$

We thus obtain a first degree equation with one unknown $OO_1$, all other quantities (that is to say $CC'$ the displacement of the tube—and $O_1O_2$ the displacement of the shadow) being measurable we obtain finally:

$$(CO_1 - OO_1) \times O_1O_2 = OO_1 \times CC'$$

or by developing:

$$CO_1 \times O_1O_2 - OO_1 \times O_1O_2 = OO_1 \times CC'$$

which may be expressed in the form:

$$CO_1 \times C_1O_2 = (OO_1 \times CC') + (OO_1 \times O_1O_2)$$

that is to say:

$$CO_1 \times O_1O_2 = OO_1 \times (CC' + O_1\,O_2)$$

or:

$$OO_1 = \frac{CO_1 \times O_1O_2}{CC' + O_1O_2} \qquad (3)$$

Finally by measuring the distance $AO_1$ which separates the skin from the screen we obtain the depth $OA$.

$$OA = \frac{CO_1 \times O_1O_2}{CC' + O_1O_2} - AO_1$$

If we designate by $h$ the distance from the anticathode to the screen $CO$ and by $d$ the displacement of the tube $CC'$ and by $a$ the displacement of the shadow of the foreign body on the screen $O_1O_2$ and finally by $x$ the distance $OO_1$ then our equation (3) may be written :

$$x = \frac{h\,x\,a}{d+a} = \frac{a}{d+a}\,x\,h \qquad (4)$$

which is a general formula and can easily be remembered.

But that formula may be considerably simplified. In practice the displacement $CC'$ is a constant of approximately 10 cm. If we maintain the distance from anticathode to screen constant, the equation shows that the distance $OO_1$ is only the expression of a single variable quantity, namely the displacement $O_1O_2$. It is therefore possible to trace on the screen a scale which will give by direct reading the distance $OO_1$ ; there will only be one measurement to make that of the distance $AO_1$.

If for technical reasons we wish to leave the distance from anticathode to screen $CO_1$ variable it is possible to simplify the equation (3) by reducing it to two factors $CO_1$, and $\frac{O_1O_2}{CC' + O_1O_2}$; as the second one depends only on $O_1O_2$, it is also possible to trace on the screen a scale graduated in coefficients :

$$\left(\frac{O_1O_2}{CC' + O_1O_2}\right) \text{ or } \frac{a}{a+d}$$

Finally it is also possible to avoid all calculations by using in the latter case a ready-reckoner, or by solving the triangulation by means of rules and a wire. A trigonometric solution of that problem has also been given.

The triangle $OO_1O_2$ being a rectangle (Fig. 105) supplies the solution :

$$OO_1 = O_1O_2 \; tg.\ (OO_2O_1)$$

It is then sufficient to measure $O_1O_2$ and so obtain directly the reading $tg.\ (OO_2O_1)$ in order to get the resolution. Another series of solutions is given by varying the distance $CC'$ in order to construct particular triangles.

Thus by causing a displacement $CC'$ so that the angle

$CC'O$ is equal to 45° then its opposite alternating angle $OO_2O_1$ is also of the same value. The triangle $OO_2O_1$ is then known and $O_1O_2$ gives by preliminary graduation the quantity $OO_1$.

Similarly by making isosceles the triangles $CC'O$ and $OO_2O_1$ so as to have :

$$\widehat{CC'O} = \widehat{COC'}$$

and :

$$\widehat{O_1O_2O} = \widehat{O_1OO_2}$$

the distance $OO_1$ becomes equal to $O_1O_2$, and we have by direct reading the solution we desire.

All these proceedings lead to the same aim with extremely variable degrees of precision. As soon as the material realisation of the triangulation in the space has been effected, the accuracy of the result depends only on the skill of the operator and on the care with which he takes his measurements, and a series of successive determinations alone can indicate the approximation obtained. Should we, on the contrary, start from equation (3) or (4) we can calculate by means of certain experimental data the degree of precision which may be obtained. As an experiment we shall make a calculation by the methods which rest on equation (3).

We have seen that the depth of a point of the foreign body has been given by the relation :

$$OA = \frac{CO_1 \times O_1O_2}{CC' + O_1O_2} - AO_1$$

Let us suppose that the correction $AO_1$ may be measured * with every desirable accuracy which is more or less the case in practice, and that consequently its measurement contains only a negligible mistake.

There remains therefore the term :

$$OO_1 = \frac{CO_1 \times O_1O_2}{CC' + O_1O_2}$$

The differential logarithm of this expression gives the

* In practice we should always endeavour to reduce to a minimum the quantity $AO_1$ which should never be bigger than the quantity $AO$ to be measured.

utmost limit of the mistake which may be made in the result, in the light of possible partial mistakes.

$$\frac{\delta(OO_1)}{OO_1} = \frac{\delta(CO_1)}{(CO_1)} + \frac{\delta\left(\frac{O_1O_2}{CC' + O_1O_2}\right)}{\frac{O_1O_2}{CC' + O_1O_2}}$$

The order of the dimension of the distance anticathode to screen being generally 50 cm. the relative mistake which is habitually made on that measurement is about $\frac{1}{100}$ because it is difficult to appreciate without special apparatus the exact position of the focus on the anticathode. This mistake is therefore not important.

Similarly the mistake made on the displacement (generally automatic) of the tube is slight. On a displacement of 10 cm. a mistake of 1 mm. can be made at the utmost, and we can suppose it to be less.

On the contrary, it is difficult (especially in radioscopy and without special devices) to appreciate with some exactness the distance of two homologous points of two projected shadows. Thus on a value of $O_1O_2$ approaching 1 cm. experience shows that in a large number of radioscopic cases it is possible to make on this length a mistake approaching 2 or 3 mm. Let us suppose it to be at least 2 mm.; we shall have:

$$\frac{\delta(OO_1)}{OO_1} = \frac{1}{100} + \frac{\frac{10}{110} - \frac{8}{107}}{\frac{10}{110}} = \frac{1}{100} + \frac{17{\cdot}8}{100} = 18{\cdot}8 \text{ per cent.}$$

Thus in this very plausible case which is often met with in practice the result will be tainted by an error reaching almost 20 per cent.

Sometimes the objection is made that accuracy is superfluous in a matter of localisation, and that it is sufficient to indicate the depth up to within 1 cm. in order to satisfy the utmost requirements. In fact, the human body is not the stable solid which theory supposes it to be, and sometimes soft parts render accuracy illusory: we must not therefore expect to obtain the exact measurement. However in the example which we have just considered the depth of the foreign body, supposing that the screen touched the skin, was $500 \times \frac{1}{11}$ or 45 mm.; an error of 20 per cent.—this corresponded therefore to 9 mm. more or less, that is to say that the result given could vary between 36 and 54 mm.

Nobody will consider this approximation sufficient, especially in the case when the projectile is situated in the scapular region or in the pelvis. The absolute outside error should in reality not be more than 5 mm., it is therefore necessary to indicate the depths to an average of about 5 per cent.

But there is another cause of error which theory cannot analyse and which seems to have always been neglected. The theory which we have explained here applies to material points such as the point of a bullet or a sufficiently small isolated piece of metal. In those cases where the foreign body is an unaltered shrapnel bullet the preceding equations apply to the centre of the spherical bullet and are correct; but war projectiles have all possible forms and very often most complicated shapes. In the case when we localise a fragment having the form of a piece of wire or of a leaf, it is impossible to recognise two homologous points in the very different shadows projected on the screen—moreover the two projections are not alike.

It is for all these reasons that the physical problem of localisation should only be looked upon with circumspection, and it must be completed by the utmost possible number of physiological considerations and examinations in various positions.

## CHAPTER VIII

### LOCALISATION OF PROJECTILES

§ 30. **General Considerations : Historical Survey.**—Let us suppose that we are dealing with a patient in whom a preliminary examination has revealed the existence of a projectile. The clinical indications seem to indicate removal. Before making a definite decision unless such is indicated in advance by urgent necessity, the surgeon must be informed exactly as to the depth of the projectile under the skin.

We can tell him in most cases, after a well-conducted radioscopic examination, whether the projectile is lodged nearer to the anterior surface or to the posterior, and whether it is intra-osseous or in the soft parts, and in which organ and in which group of muscles it is situated (see Chapter XI) or whether it does or does not move on palpation, and in this case which is the point on the skin at the level of which the maximum movement may be determined. All this information, which we must never omit to supply if we can, and we can do it more often than is generally thought, would by itself enable the surgeon to undertake the extraction in a large number of cases. But even if he dispenses with the screen control it does not exclude (especially in the case of old wounds) lengthy groping about, and if the operator has not this facility, the number of setbacks under these conditions may be relatively high, or else the damage produced may be too considerable. He requires more information. We must give him more precise information as to the depth of the projectile under the skin at the point chosen for the incision.

How are we going to proceed in practice to determine that distance and utilise the general theoretical ideas indicated in the preceding chapter ?

It is not methods of procedure that we shall lack, but the reverse. Since the beginning of the war we have seen the appearance of such a large number of publications describing the methods of localisation that we should be quite embarrassed which method to choose if we were to master each, as our available time would not suffice for such work.

But all these methods are mostly personal variations, very often almost insignificant, of two large methods of procedure, *i.e.* either on the one hand localisations which follow two intersecting axes, or on the other the determination of the depth by estimating the distance of the two shadows of the foreign body produced by a displacement of the tube. These two common methods, the general theory of which we have given in the preceding chapter, have been known and applied almost from the beginning of radiology. By this we mean to say that many amongst the recent publications have only republished, under different names, old and perfectly well-known procedures. These regrettable errors are due to a large extent to the number of radiologists who have suddenly sprung up since the war, and who, without any previous knowledge, thought in good faith they had "discovered" what every professional radiologist has known for a long time. It must however be stated in their favour that the extreme difficulties under existing circumstances which surround bibliographical research partly excuse their ignorance. The same reason makes it impossible for us to give here a complete historical description of this interesting question and forces us to limit ourselves to a short summary.

Finally it must be acknowledged and emphasised that although the theory had been known for a long time and, especially owing to Haret and Hirtz, practical applications have been able to be undertaken, it is nevertheless indisputable that this war, by enabling all radiologists to study an extraordinary number of cases and by imposing upon them the necessity for rapid and suitable solutions, has absolutely transformed the question of localising projectiles and has enabled extraordinary progress to be achieved. Almost every radiologist, whatever the particular method which he has adopted for his personal practice, is to-day a perfect master of this question, and in this respect the war will have brought about, if not a great advance in our theoretical knowledge, at least a considerable extension of the practical applications of it.

*Historical.*—X-rays were discovered in December 1895, and were immediately applied to the search and then to the localisation of projectiles. In March 1896 Buguet and Gascard explained the technique of the first real method. In June of the same year Brissaud and Londe applied the taking of two plates at right angles to the search for an intracranial projectile, an idea which was later on taken up by Mignon. But as errors were frequent mostly because of the difficulties in technique, and because of insufficient understanding of the problem, localisations were only approximate.

In March 1897 Rémy and Contremoulins inaugurated in France the era of instrumental methods, and the latter of these two authors commenced the study of his compass.

In August of the same year Leduc published a work of *The Rapid and Precise Determination of the Position of Bodies seen in the Tissues by means of Radioscopy*, and thus marked the beginning of radioscopic localisations.

In England Mackenzie-Davidson and Hedley started studying in January 1897 and presented in 1898 the first model of their cross-thread localiser, which became classical in the United Kingdom and served as the point of departure for numerous imitations. In 1899 Massiot invented his compass. Guilloz, Londe, Mergier, etc. indicated new methods of technique, and since then publications increased from year to year.

We shall only mention, as deserving special attention, the works of Aubourg, Béclère, Belot, Delherm, Guilleminot, Laquerrière, Albert-Weil, the important publications of Haret and of Tuffier and their methods of localisation for the cranium and finally the multiplication, in the years preceding the war, of compass methods of Miramond, of Laroquette and especially of Hirtz, and the original works of Mazérès.

§ 31. **Radioscopy and Radiography.**—Since the war, as we mentioned before, the number of publications devoted to the localisation of projectiles by means of X-rays has been considerable. But although at the beginning there were hardly any professional radiologists in the armies who together with Haret dared to raise their voices in favour of radioscopic methods (which were defended at the base by the authority of M. Béclère) we have seen gradually a complete change of opinion taking place, as practice showed the necessity of working quickly and the possibility of working well with the screen, and many of those who were the most ardent defenders of exclusive radiography have since adapted their proceedings to radioscopy which continues to gain ground every day.

Without wishing to establish parallels between two methods which, as we have already mentioned (§ 11), must always go together and mutually complete and not exclude each other, we shall only point out that the objections raised against radioscopy may be summed up under four principal headings:

(1) Insufficient accuracy of localisation; (2) impossibility of seeing on the screen certain foreign bodies; (3) Absence of an impartial and permanent record; (4) dangers to the operator.

As regards the latter objection we refer the reader to Chapter IV and, especially, to § 17, as also to the developments given in Chapter XIII. From these it will be seen sufficiently well that with modern materials giving real protection (opaque shield, radiological table protected laterally by opaque screens, opaque gloves and glasses, an opaque and properly movable diaphragm), the dangers which threaten the radiologist during radioscopic localisations are not greater and are rather less than those to which he is exposed during visceral examinations (thorax, stomach, etc.), and no specialist would renounce this. We say that the dangers are less, because the localisations are made especially in recumbent positions in which the path of the rays issuing from the diaphragm rises vertically in front of the observer instead of striking him directly as in upright examinations.

Thus without wishing to consider the danger as absolutely nil we think it must not be exaggerated, because a careful and well-equipped observer is only exposed directly to the action of secondary rays, which is a very small matter in spite of what certain authors may have said.

As regards the accuracy of radioscopic methods, data will be found in the pages of this and of the following chapter, and it will be possible to conclude that, although theoretically certain radiographic proceedings such as the Hirtz compass seem to be capable of a great and almost absolute exactness, nevertheless the human body, not being an unchangeable geometrical solid fixed in an invariable position, leads to the result that there is in practice no difference between these and certain radioscopic proceedings which enable localisations to be made within an error of from 1 to 2 millimeters.

As regards radioscopic visibility, we have examined it sufficiently in detail in § 18, and need not refer to it again, except to remind the reader of our conclusion that with a good technique every projectile which can be removed surgically is visible on the screen and may be localised radioscopically.

Finally, as regards the absence of a permanent record, this is a criticism which may be addressed to those—and we are not of their number—who do not, in every doubtful or difficult case, complete their radioscopic examination by a plate (see what we say in this respect in § 35). Besides, in the question of war projectiles it is not only absolute precision and accuracy which count, as certain authors seem to think. Convenience, rapidity and economy are also very important factors and entirely in favour of radioscopy.

Moreover, we must also take into account the conditions under which the examination is carried out, and at the front within the scope of action of X-ray cars only can radioscopic localisation be carried out in a systematic and regular manner.

Finally—and we shall refer to it again (Chapters XII and XIII)—methods which may be sufficient for recent projectiles, when the wounds are still open, will not be sufficient for old projectiles which have become embedded for some time in healed tissues.

We could not think of describing here, even in an abbreviated manner, all the methods of localisation relatively old, or published since the war, because to do this we should have to double the extent of this work without improving it greatly, as many of these methods only represent insignificant variations of technique. We prefer to describe in a general manner the method of X-ray examinations, and to choose, for purposes of detail, some typical proceedings which appear to us particularly favourable owing to their suitability, exactitude, rapidity or as presenting an interest on account of their originality.

We strongly advise those who start practising X-ray localisation to choose above all a rapid, convenient method with special attention to its general application, and which can be carried out without requiring too complicated apparatus, or at least with a special portable arrangement which could easily be adapted to all current types of apparatus.

By this we wish to say, first of all, that in a general way we advocate radioscopic methods. It must never be forgotten that surgical extraction is as a rule the ultimate motive and the principal aim of localisation which must always be carried out in the operative position, if we wish to avoid frequent and fatal mistakes, due to the change of situation of the projectile on change of position of the patient. This is the reason why methods such as that of Menuet lose part of their value. It also implies the necessity, if we wish to perform perfectly satisfactory work, of constant collaboration between the surgeon and the radiologist and shows us again that it is necessary for the latter to possess a good solid medico-surgical education.

§ 32. **Localisation of a Projectile by the Dimensions of its Shadow.**—We just wish to remind the reader that it is possible to calculate the depth of a projectile, of which we know the true dimensions, according to the magnification of the shadow, which may be easily measured either on the screen or on the plate.

This is a method rarely used, because rifle bullets and shrapnel bullets are projectiles, which more and more constitute a minority of the projectiles to be localised. However, for these projectiles, if they are whole and not deformed, it is in fact possible to calculate quickly the depth either by referring to various tables of magnification or by means of a series of radiographs of the projectile taken in advance and placed at known distances, as has been done for instance quite recently by Pirie (*Arch. of Radiol.*, October 1916, p. 138).

For a shrapnel bullet, which is spherical, the position in space is unimportant. For rifle bullets it must be taken into consideration that only their transverse diameter remains unmodified and may serve as a guide. As regards this we refer the reader to the data given in the tables of Chapter VI for rifle bullets, but we wish to point out that for shrapnel bullets the diameters are sufficiently variable as to render this method, which is so inaccurate and so little to be recommended in a general way, of still less value.

§ 33. **Localisations according to Intersecting Axes.**—We have already seen several times (§ 13 and § 21) how it is possible to find out the situation of a projectile or of some body opaque to X-rays by means of two images taken at right angles to each other, that is to say by means of two examinations, one from the front and the other from the side. But in order that the axes may be quite perpendicular and in order to avoid causes of error, the patient must be fixed and the tube and plate displaced by 90° which is a relatively long distance and sometimes not quite convenient. Moreover, we have no indication yet as to the position of the projectile with reference to the skin, which is a matter of capital importance to the surgeon (the method which consists in making use of two different tubes is not of any greater advantage). In order to succeed we must note the position of the normal ray as seen in each of the two directions and mark on the skin the points of entry and of exit. The marked points obviously give the approximate direction of the projectiles situated at the point of intersection of the two rays.

It is this very simple general method which served as the basis for numerous different technical proceedings pompously called methods, which very often only differ from each other as regards minor considerations in the way of aiming at the projectile or of marking the points on the skin.

The initial proceeding already described, which consists in indicating the points with an opaque rod left in place until a mark with a pencil * is made on the skin, may be replaced by more rapid, elegant, or more precise methods.

* For a better way of marking the skin see what we have said in Chapter IV, § 16.

*The Forceps Method.*—Dr. J. Belot * has used, since the beginning of the war, a method which he has named the "forceps method," the originality of which consists in using a pair of forceps with rings at the ends, whence its name. The forceps are similar to those which are used for taking out plates from reducing baths: the flat ends have been replaced by two metal rings situated opposite each other perpendicularly to the plane of the arms of the forceps. By pressing on the handle of the forceps the arms are opened; on relaxing the hold the arms spring together again. It is thus easy to take hold of a portion of the body between the arms of the pincers and to keep it in place, because the two arms tend by themselves to press the body which they seize.

FIG. 106.—Localisation forceps, by Dr. J. Belot (small model).

FIG. 107.—Localisation forceps by Dr. J. Belot (large model).

The maximum width of the arms must be sufficient for a thigh. In practice Dr. Belot prefers to have two models: one, easy to handle, is used for arms and legs; the other, being larger, is used for the thighs, for the shoulders and the trunk (Figs. 106 and 107).

The following is the method of procedure. The patient is placed on a table and after a quick preliminary screen examination he is fixed in the first position chosen. The diaphragm is partly closed and at the same time the tube

* We have taken this description from the article by J. Belot and H. Fraudet, "Localisation of Projectiles" (*Journal de Radiologie*, t. II. no. 1, Jan.-Feb. 1916, pp. 1–18, with 14 illustrations).

is moved about in its frame or on its stand until the shadow of the projectile to be localised occupies approximately the centre of the illuminated surface. The ring pincers are then taken and the arms opened by pressure, the limb is then taken hold of at a convenient level, and the pincers are gently moved about, without pulling the skin, until the image of the rings covers or surrounds the image of the foreign body. At that moment the hand which holds the pincers stops pressing and the two rings close on the skin. The current is stopped, the light is put on again, the screen is taken away and by means of a skin pencil or of a thermo-cautery, etc., the same mark is made (for instance a cross) in the centre of each ring.

The limb is rotated as far as possible through an angle of about 90° and in this new position a second determination, similar to the first one, is undertaken, but the two marks traced on the skin differ from the former ones, *i.e.* two points are made. Innumerable variations of the same

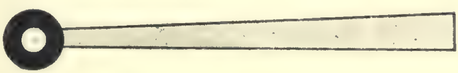


FIG. 108.—Rod provided with a metal ring used for localisation.

process, the principal of which goes back to the discovery of X-rays and seems to have been explained in detail for the first time by Morize * in 1898, have been proposed. Instead of Belot's forceps, which we have just described and the use of which is particularly convenient and rapid, we can also use a small board or some rod (sufficiently long to enable the hand which handles it to be outside the radius of the rays) provided at one of its extremities with a metal ring (Fig. 108).

First of all we place this ring in the first selected position by means of the screen on the skin of the side of the limb which is nearest to the screen, in such a way that the shadow of the foreign body (or a prominent point in that shadow) is projected into the centre of the shadow of the

* Morize, " A New Process for Determining the Position of Foreign Bodies by Radiography " (*Gazette des Hôpitaux*, February 19th, 1898).

ring and the point is then marked. The same manœuvre is then repeated for the side furthest away and the point is then marked (Fig. 109). The limb is then rotated, and the process is recommenced in the new axis selected.

Many English radiologists proceed in this way following Mr. Hernaman Johnson.* By operating simultaneously with two rods or strips of a similar size we come back to the Belot forceps (see Fig. 109). We can also use a rod at the end of which is fixed a buck-shot which is applied to the desired point of the skin, and which is kept motionless until that point has been marked. Finally we can also use for the same purpose the spintermeter rod which is very convenient for exploring under the screen. We thus avoid complicating our apparatus.

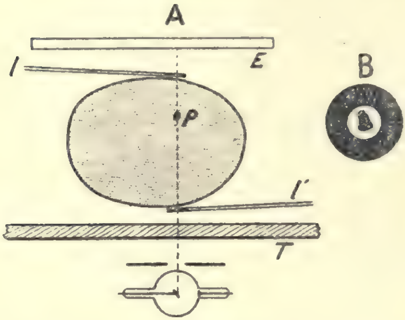



FIG. 109.—Showing how we mark on the skin the points of emergence of a normal ray passing through the projectile by using two rods with rings as shown in Fig. 108. In *B* we see the image which is seen on the screen *A* when these rods have been correctly placed.

Let us also point out as belonging to the same order of ideas and to finish the subject the practical use of two ink-markers which Gallot places simultaneously on the skin, one at the point of entry and the other at the point of exit of the normal ray.

It is also possible to mark the points by placing opaque guiding marks on the skin and by fixing them with some adhesive material, but this manner of proceeding does not in our opinion offer any advantage unless it is a case of taking plates and of making marks by another method.

These few indications seem to us to be sufficient, but we

* F. Hernaman-Johnson, "The Localisation of Bullets and Shell Fragments" (London, Lewis, 1915, broch. in 8vo. Cf. also *Foveau de Courmelles C.R.* 1915, t. 160, p. 97), who has only applied the same method also used by M. Debierne, etc., etc.

do not pretend to have indicated nearly all the old and recent variations of the Morize process.*

The tracing of four marks is generally sufficient to show the situation of a fairly large projectile, provided that the localisers have been placed in quite different directions to each other and as nearly as possible at right angles to each other, because it is evident that if they cross each other at a very acute angle the position is from a practical point of view badly determined. It is also of course necessary to place them perpendicular to the axis of the part of the body examined, in what Belot rightly calls a "right section," because this gives the surgeon the most accurate information.

But if the operator wishes to know the depth of the projectile in relation to the different possible points of incision before making his choice, or if he wishes to visualise the exact situation of a small projectile, we can easily give him satisfaction by perfecting our technique. The radio-profundometer of Réchou, the Menuet appliance, the Debierne method, the Vergely method give us easily the means.

The first of these instruments also plans out the axis of localisation by means of crossed wires (made by Gallot).

*The Menuet Process.*†—The principle of this method is to X-ray in two different positions but in the same part and perpendicular to the general direction of the body or limb in such a way that the normal ray passes through the projectile, then mark on the skin the entry and exit of these normal rays and draw by means of a special "cyrtometer" the outline of the body or limb and plot out the normal

* It is of course evident that when practising radioscopy we must never omit, in all these cases, to look for the point of the skin nearest to the projectile, which in general is very easy, at least in the case of the limbs. By pressing the surface of the body with the spintermeter or with our marking needle (Chapter XIII), we shall find the point at which the projectile is most easily movable. A description of the Coste process will be found in the *Lyon Chirurgical* (August 1916). This author, employing two distinct tubes, takes two plates exactly at right angles, and then establishes, by means of these two plates in a graphical method, the anatomical position of the projectile.

† T. Menuet, "Localisation of Projectiles by means of a Special Marker" (*Acad. médic.*, March 9th, 1915, *Arch. électr. médic.*, March 1916).

rays by metal rods, when the cyrtometer is taken off the patient and readjusted on a horizontal plane.

In order that the cyrtometer should not be twisted during the various manipulations the author has superimposed on each other two belts, one consisting of pieces of wood stuck on linen and the other of steel blades. In order to be able to adjust it and to take it off easily the cyrtometer is divided into two halves joined together by a hinge.

The Debierne method * requires only a very simple geometrical diagram. Suppose we have already marked on the skin of the patient the four points *B*, *B′* and *R*, *R′* which determine the two axes which intersect at the projectile.

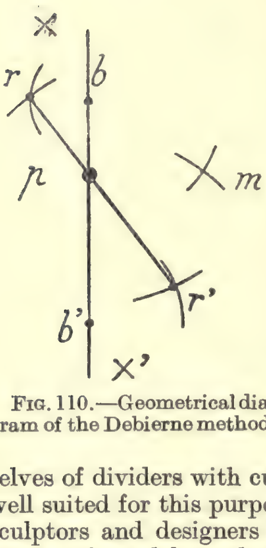


FIG. 110.—Geometrical diagram of the Debierne method.

We cut off the straight line *XX′* (Fig. 110) and trace on a rather large piece of paper (a quarter size is always sufficient), a length *bb′* equal to *BB′* and this length is marked out in blue pencil. In order to measure this distance *BB′* exactly on the body of the patient a pair of compasses with curved points (Fig. 111) and of rather large dimensions should be used. We avail ourselves of dividers with curved points which are particularly well suited for this purpose: these are the dividers used by sculptors and designers in order to take similar measurements of models and mouldings. Otherwise it will be sufficient to fix on ordinary dividers two rods in order to obtain a compass with movable arms which will render the same service. Or else the compasses described later on (§ 34) can be used.

Starting from the point *b* as centre, we trace with the compass an arc of a circle having a radius equal to *B R*, and then starting from *B′* another arc of a circle of a radius equal to *B′ R*. These two arcs meet at the point *r* which

* Debierne, "On the Method of Localising Foreign Bodies by Radioscopy" (*Presse médicale*, March 4th, 1915).

has, in relation to small $b$ and $b'$, the same position as $R$ in relation to $B$ and $B'$.

We obtain the point $r'$ similar to $R'$ in the same manner by tracing from $b$ as centre an arc of a circle with a radius equal to $B\ R'$ and from $b'$ as centre an arc of a circle with a radius equal to $B'\ R'$: the meeting-point of the two arcs gives $r'$. We can also obtain this point, for purposes of verification, by tracing from $r$ an arc of a circle of a radius equal to $R\ R'$ and from $b'$ an arc of a radius equal to $B'\ R'$.

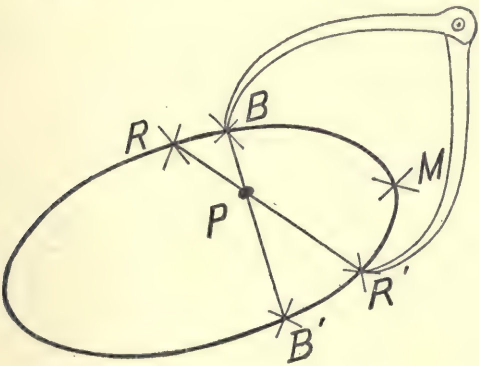



**Fig. 111.—Graphical determination of the seat of a projectile by the Debierne method.**

It is sufficient to join $r\ r'$ (by means of a red pencil) which meets $b\ b'$ at $p$ in order to obtain the position of the projectile and consequently its depth.

This position can also be verified by the tracing of a third axis passing through the point $P$. We can also trace on the same sheet of paper several points indicating the latest aspect determined by the plane passing through the red and blue axes, for instance the point $m$ corresponds to the point $M$ (Fig. 111) which will be the nearest to the projectile or which the surgeon has decided to be the best place for future operation. It is sufficient to mark the point $M$ on the skin of the patient and to describe from the points $b$ and $b'$ as centres two areas of a circle with radii $B\ M$ and $B'\ M$ intersecting at the point $m$.

The sheet on which the preceding geometrical construction has been made may form part of the written report of the case. It constitutes an important document for the surgeon, because it gives him, combined with a radiograph taken in a convenient position, the necessary information for undertaking the successful extraction of the projectile.

*Vergely Method.**—This author has tried to render in a graphic manner the plane on which the projectile is situated, and to visualise that plane in such a way as to determine the depth and direction in which it will be necessary to

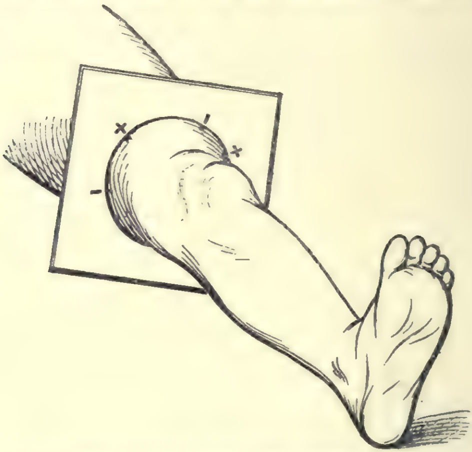


FIG. 112.—Inscribing the marked points on a piece of cut cardboard (Vergely process).

insert a needle or make an incision in order to find the foreign body.

For this purpose, after having marked the skin as previously described with the four marking points, he makes a hole in a piece of cardboard in which can be placed the limb or the part to be examined, which hole should be shaped as accurately as possible to the section of the limb where the marking points have been made. As soon as the card has been cut, it is placed in position and on its edge the exact position of the marked points is inscribed (Fig. 112). After this the cardboard is placed on a sheet

* Vergely, " Method for Accurate Localisation of Projectiles by Radioscopy " (*Presse médicale*, February 18th, 1915).

of paper lying on a table. The two crosses $B$, $B'$ are then joined in a straight line by means of a ruler and then the two points $A$, $A'$ are joined together by a straight line.

The intersection $C$ of these two lines represents the position occupied by the projectile. We therefore can choose the point on the cardboard nearest to that intersection, namely $D$, and from that point $D$ a straight line is drawn which passes through the intersection point $C$ and which is continued on the piece of cardboard itself. The incision will be made at that point and in that direction $D'$ $D$. Moreover, the direction $C$ $D$ represents exactly the depth at which the projectile is lying.

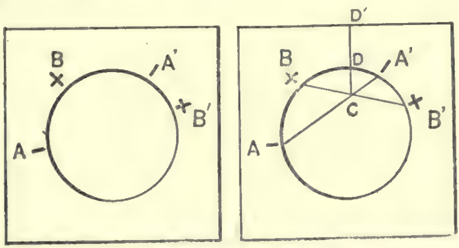



FIG. 113.—Graphical diagram in the Vergely process.

After this we pass on to the third phase in the process which must immediately precede the surgical operation.

The hands of the operator and the limb being rendered surgically aseptic, the distance $C$ $D$ is measured with an aseptic needle and is held with the nail on the needle.

The cardboard is then placed round the limb in such a way that the markings coincide. In order to ensure asepsis the edges of the cardboard may be covered with tincture of iodine. The needle is then inserted at the point $D$ and in the direction $D'$ $D$ until the desired depth has been reached, that is to say where the nail presses on the needle. The needle is left in the soft parts and is used as a guide for the incision until the bistoury has reached the point and it then falls out by itself. This indispensable guide must not be taken out before the projectile has been found. If we wish to make more certain we may, after having inserted the needle, screen the region again to see whether it touches the foreign body.

This precaution, which is only useful for small splinters, can only be used for relatively thin regions, such as the neck or limbs; but the principle of the method may serve even for the trunk, where it will give a useful idea of the depth.

§ 34. **The Compass** *.—In the course of operation, whatever the technique by which the localisation has been effected, the surgeon may need some precise guide, in order to give him at this moment an indication as to the exact site of the projectile and to guide him mechanically by means of a rigid metal pointer to the foreign body, the existence of which has been determined either visually (screen examination), by sound (telephone, La Baume-Pluvinel's telephone probe), or by touch (electro-vibrator).

Instruments, which enable the surgeon to perform this mechanical guiding and which are known under the name of compasses, are now very numerous and were invented some considerable time ago, because in 1899 M. Contremoulins (see p. 153) made a model of them and M. Massiot another model in 1900.

The later models consist of essentially an indicating needle which guides the surgeon as regards direction and depth and which he can regulate in its course, after the depth of the projectile under the skin has been determined and the marking points indicated which enable the apparatus and the accessory pieces supporting the needle to be conveniently arranged.

Some of the instruments allow the guiding to be done only in one invariable fixed direction. These are useless. Others on the contrary offer the great advantage that the foreign body being considered as the centre of a sphere we can materialise it by a metallic arc.

The indicating rod represents the radius of the sphere. It can be displaced both along the arc of the circle and also parallel to itself, so that it always points to the centre of the sphere and will touch it when completely pressed down.

Finally, these compasses have been mostly constructed in order to be adapted for the methods of localisation already described, although with some experience they may

* See art. by M. Béclère (*Paris médicale*, February 5th, 1916, p. 186).

all be used almost without exception, whatever the method adopted, whether radioscopic or radiographic.

Some are therefore constructed for the method of intersecting axes : we shall describe rapidly the most interesting and best known of these varieties. Others have been constructed in order to be applied to the method of displacing the tube : we shall refer to them after describing that method.

*The Belot Compass.*—A description and a diagram of this ingenious instrument used to guide the surgeon in the extraction of projectiles located by the " forceps method " will be found in the *Journal de Radiologie* (1916, No. 1).

*The Debierne Compass* *.—In order to define on the patient himself the direction and depth of the projectile after localising it according to the above-described Debierne method, we can advantageously use a compass which its author had constructed by Messrs. Drault & Raulot-Lapointe. It is nickel-plated and can be sterilised.

At the ends of a metal arc (Fig. 114) are two rods $t$ $t$ bent and terminating at their extremities in a point. They are so arranged as to be freely movable at will and to allow of their ends being superimposed on any given points, such as say $b$ and $b'$ which limit the axis of localisation. An arc $C$ is cut out in the middle to allow of the movement of the piece $G$, which carries a tube in which there is a grooved rod $t'$ terminated at one of its extremities by a point, and

* In order to fix the position of the compass still better the surgeon can add another rod $t'$ beside the rod $t'$ and place it in such a way that its point rests on a point marked on the skin in a convenient position, whilst the extremities of the rods $t$, $t$ are always at the points $B$ and $B'$.

This rod also enables the compass to be used during the operations by placing it on different points from those which have been determined directly by screen examination, and which may at that moment be inaccessible.

For that purpose it is sufficient to arrange the compass on two selected points of the figure constructed in the diagram, and to place the point of the indicating rod $t'$ on a third point of the same figure. Then transfer the compass to the patient in a corresponding position which is determined by the three points coinciding with the corresponding markings and then mark on the patient in a convenient position a fourth point on which is fixed the point of the fourth auxiliary rod $t'$. . . . It is then possible to free the indicating rod ; it may be displaced on the arc $c$, still remaining in the direction of the projectile.

at the other by a milled button which enables it to be moved about in following the ray. It will be understood,

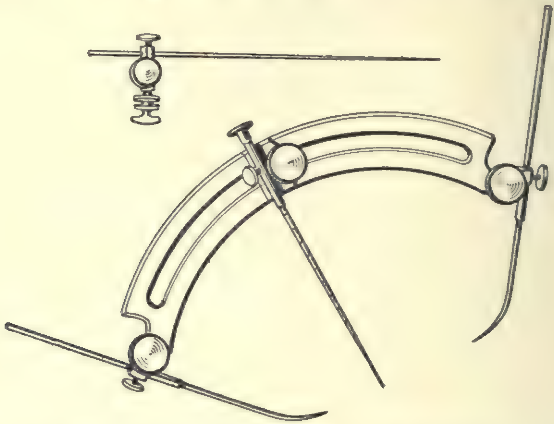


FIG. 114.—The Debierne Compass (Drault & Roulot-Lapointe, manufacturers).

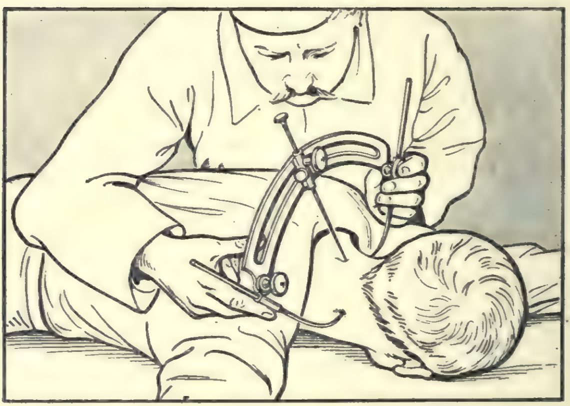


FIG. 115.—The adjusting of the Debierne compass on a wounded man.

by looking at the figure, that as soon as the extremities of the needles *t* and *t* coincide with the two points *d* and *d′*

of the localisation axis, the extremity $p$ of the movable rod will always lead to the projectile, whatever the position of that rod in relation to the arc $C$.

In order to use the compass after completing the graphical construction (Fig. 111) the position of the rod $t'$ of the compass is so regulated on the drawing that the point of the compass coincides with the point $p$, thus showing the site of the projectile; then the position of the rods $t$ $t$ is regulated so that their points fall, say, on the points $b$ $b'$ which are the extremities of the blue axis.

If the compass is now placed on the patient in such a manner that the points of the rods $t$ $t$ coincide with the blue points $B$ $B'$ marked on the skin, the amount by which the

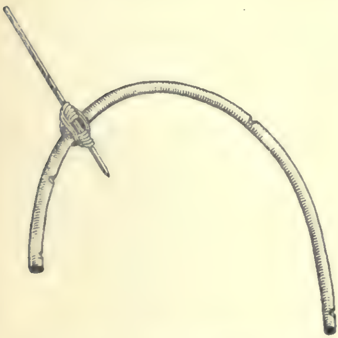


Fig. 116.—The Cadenat apparatus which represents the simplest form of a compass.

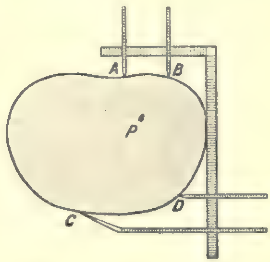



Fig. 117.—Diagram of the localisation arrangement of the Saïssi compass (compare Fig. 120), which effects the localisation by two intersecting axes.

point of the rod $t'$ is displaced in order to touch the skin will indicate, by direct reading of the number of the divisions on the rod, the depth of the projectile in a direction which will be that of the rod itself.

It is therefore possible to choose the orientation of the corresponding rod at the most favourable point for operation (Fig. 115).

The "sector-guide" of Grandgérard has the same number of rods as the Debierne compass, but the three rods which form a tripod are grouped at one of the extremities of the arc.

Moreover, the indicator rod has at its upper extremity a small detachable spirit level.*

*The F. M. Cádenat Apparatus.*†—This author has described a rough-and-ready "compass" which can be easily made anywhere with a thick and thin wire and a knitting needle (Fig. 116). But it seems that all the units which may have to extract projectiles offering any difficulties are already fitted up pretty well at the present time so as not to have to make use of improvised appliances.

*The Saïssi Compass.*‡—The diagram 117 shows the theory of the apparatus. The diagram 118 and the figures 119

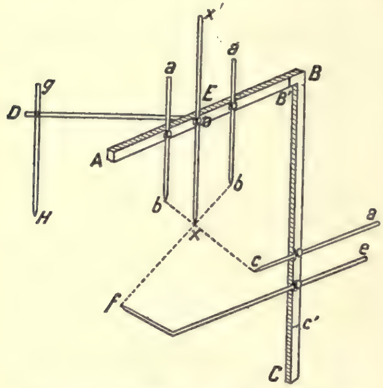



Fig. 118.—Diagram of the method of regulation of the indicator rod $xx'$ of the handle $g$ (see Fig. 120) of the Saïssi compass.

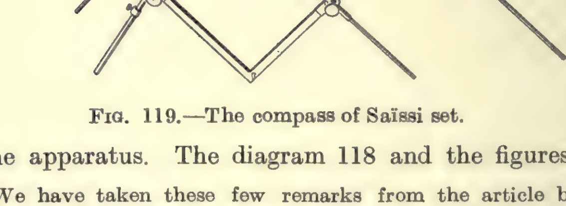


Fig. 119.—The compass of Saïssi set.

* We have taken these few remarks from the article by M. Béclère already mentioned, as we have not before us that instrument constructed by Messrs. Malaquin & Dutertre.

† F. M. Cadenat, " A Simple Apparatus for Localising Foreign Bodies" (*Presse médicale*, February 14th, 1916, p. 67).

‡ See Albert-Weil, "Localisation des projectiles" (*Paris médicale*, February 5th, 1916, p. 130).

and 120 indicate the demonstration by crossed threads of the situation of the projectile and the regulation of the indicator rod *xx*. It is also necessary to have the handle *gh* which enables a third cutaneous marking point to be obtained, the other two being supplied by the extremities of the rods *bb*. Finally Fig. 121 shows us the "surgical" part of the instrument placed into position for operation.

However convenient and sufficient the principle of

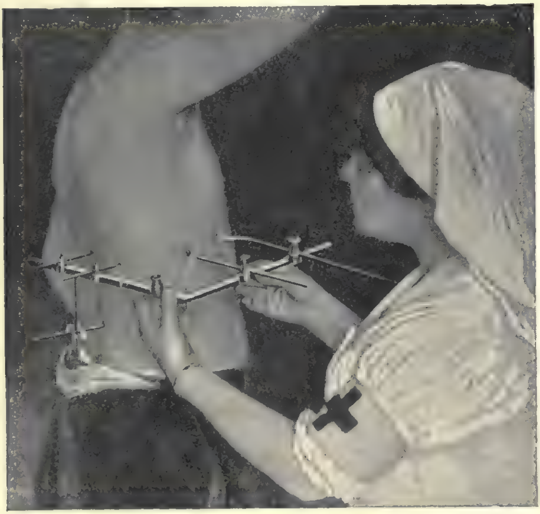


Fig. 120.—The arranging and regulation of the Saïssi compass on the patient. (Plate by Dr. Henry Béclère.)

marking by two intersecting axes may be in a large number of cases and especially for the limbs and however useful the guiding appliances based on the use of these processes may be, we must not disregard their serious defects. In fact they cannot be applied or are not sufficiently accurate (owing to the insufficient spreading of the axes) in all thick parts, that is to say in a large number of the most important cases. They cannot therefore claim to be generally applicable. We therefore formally advise the plan of abandoning them in favour of techniques which we are now going to explain and all of which depend so to say on localisation by displacement of the tube.

*Bibliography.*—We could not possibly give complete bibliographical references with regard to localisation processes relating to Chapters VIII and IX. We shall content

FIG. 121.—The use of the surgical part of the Saïssi compass. Verification before the operation. (Plate by Dr. Henry Béclère.)

ourselves by referring the reader to the excellent articles by Lebon (*Progrès médical*, 1915); Charlier (*Journal de Radiologie*, 1915); Albert-Weil (*Paris médical*, 1914—1916), from which we ourselves have taken numerous extracts, and to the collection of the *Journal de Radiologie*, the analyses of which will supply useful and ample reading.

## CHAPTER IX

### LOCALISATION OF PROJECTILES (*continued*)

### METHOD OF THE DOUBLE IMAGE

**§ 35. Generalities on Localisation by the Double Image.**— The localisation processes derived from this method, which has already been explained from the theoretical standpoint in Chapter VII, give the whole of the qualities required for rendering its application really general.

What is it that we require of them? Firstly a series of primary conditions: (1) It should be possible to effect the localisation in the operation position according to any direction indicated by the surgeon. (2) We must be able to apply it to every projectile the dimensions of which permit of its removal in the region under consideration. (3) It must possess an accuracy which should be sufficiently practical, that is to say in our opinion the error should not exceed 10 per cent. But it is absolutely useless to expect an absolute theoretical precision when —in view of the fact that the human body is not a rigid and motionless solid—in practice there occur variations which often reach—and sometimes exceed—10 per cent. and which thus deprive the localisation of its strict value (see also Chapter XIII).

Moreover present circumstances give a primary importance to two conditions which in time of peace are of secondary value: First, rapidity of application, and secondly the simplicity of the process. We may also mention, as interesting though secondary considerations even at present, the economy and the small elaboration of material together with the security of the radiologist; these are all points discussed elsewhere and on which we shall not insist here.

All these considerations make us always prefer (see

§ 31) radioscopic processes to radiographic processes, both when it is a question of the double-image method or of the intersecting-axes method. We shall also see that they may be applied as well to the regulation of compasses—especially of Hirtz's—and their value will therefore be felt more and more, whilst the plates will supply us with all the important information which they can give us, if we take either the recognised front and side views or two stereoscopic plates. (See Chapter X.)

Screen localisation methods based on the process of the double image constitute by far the most numerous group. Since the war they have multiplied enormously. We shall consider them first and study the radiographic processes afterwards. There is however no fundamental difference between the two. Whether the measurement of the distance between the two shadows is indicated on the surface of a fluorescent screen or on the gelatine of a plate, the method remains the same. We shall describe later on the Hirtz compass and some other localising instruments.

We think that the information given in this chapter will be sufficient to enable any attentive reader to understand the theoretical principle of each process, and to select from the methods recommended by us the one which best suits his personal requirements. But these descriptions are given to prepare him for practical work, which is indispensable, and to facilitate it but not replace it. We have therefore given only brief and superficial descriptions of apparatus always dry and difficult to understand. The described instrument is not before us, so we have described as fully as possible the points which could be applied to the majority of methods and which are of general interest. Although we have tried to give a complete list of the different methods, we have described fully only those which appear to us to be really interesting and we have not tried to give in detail the smaller instrumental changes which have appeared since the war.

We only hope that the present impossibility of making serious bibliographical research has not caused us to make many important omissions, and we wish to apologise in advance for those we may have made.

It will be noted that we have discussed the localising methods used by our English colleagues and by those of other allied nations to a very small extent. We ask them to believe that this is not due to our ignorance of their processes or to want of appreciation of their value, but simply because our space is limited and this work is addressed especially to Frenchmen and we thought it would be preferable to describe for our readers appliances which they would probably have at their disposal than others not so well known to them, however excellent they might be.

Finally we must strongly advise beginners to practise for a long time, after having made a choice of a method, at first on fictitious foreign bodies and then to verify the correctness of their localisation, before commencing to put them into practice on wounded men. They should always be careful to see to what extent the information given has been correct, by being present as often as possible at operations even if they have not the opportunity of collaborating constantly with surgeons in their extractions as we would advise them to do. Seeing that the extraction of projectiles involves an operation of some importance, neither beginners nor old practitioners should ever neglect to verify the depth found either by an examination of plates, front and side views, or by the process indicated later on. Owing to the value of experience we think that it is better to keep to a method which may perhaps not be so perfect, but with the working of which we are perfectly well acquainted, than to keep changing the method employed. Finally it must never be forgotten that the determination of the depth must be accompanied in every possible case by a complete X-ray and clinical examination (see Chapters V and XI).

We also wish to mention that from now onward we shall only consider in this chapter the recumbent posture as the position for localisation. We shall therefore not mention it again.

## 1. Radioscopic Methods

In France it is to Haret that the credit is due for the real revival of these methods as well as for the idea of the first simple and general technique. Almost all the numerous perfections introduced since the war in the employment of the double image under various forms by so many authors are derived from it.

In order to co-ordinate to a certain extent the enumeration of the processes which are based on this method, we shall at first consider those which depend on a comparison of shadows given by the projectile and by an external foreign body the situation of which can be directly appreciable and which use in general the displacement of the shadow but without measuring its displacement. Then we shall describe the processes based on the classical equation (p. 147) and finally we shall consider some special solutions.

We wish moreover to point out that it is possible to use also the displacement of the shadows in order to return to the method of two straight lines which intersect. Let us place (Fig. 122) radioscopically two metallic indices $A$ and $B$ on the two opposite faces of the part of the examined body in such a way that their two shadows and the shadow of the projectile become merged on the screen.

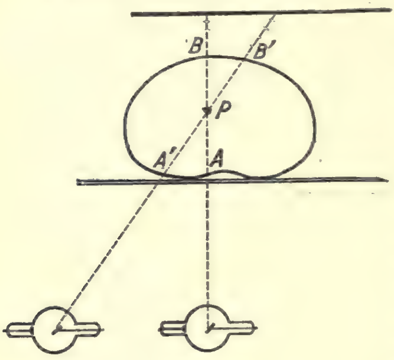



FIG. 122.

Let us displace the tube on one side or on the other side, and let us recommence to place our two marks—either $A'$ or $B'$—in such a way that they superpose their shadows again over the shadow of the projectile. We shall thus have marked four points which when joined intersect at the level of the projectile $P$, and we thus come back again to the process of two axes. On the other hand, if we mark $BB'$ by $a$, $A'\ A$ by $b$ and the thickness—which can be easily measured directly—of the wounded part by $h$, we obtain the distances $BP$ or $AP$ by the classical formula $\frac{ha}{a + c}$ and $\frac{hc}{a + e}$ whilst $BP + AP = AB = h$ which gives us a verification and brings us back under a somewhat modified form to the method of displacement of shadows.

§ 36. **Radioscopic Processes using the Displacement of the Shadow without measuring it.**—It is evident that, for the same displacement of the source of rays, the shadow of an opaque body on the screen will move away from its first position the more, the nearer the body is to the source, that is to say the deeper it is. If we have an opaque body external to the body and if we use it as a term of comparison it will supply us with an easy means to estimate indirectly the depth of the retained projectile which we are trying to find. It is, in general, on this

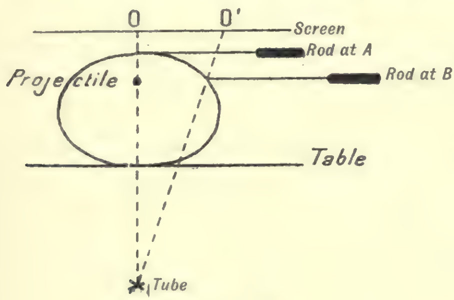



Fig. 123.

elementary method of ascertaining that the following processes and other similar ones, which we do not consider necessary to describe, are based.

*Knife Process.** — Popularised in France by M. Béclère this process is essentially a localising process. It consists of two stages. In the first one we determine usually by means of the point of the spintermeter (position of the rod at *A* of Fig. 123) the point of exit on the skin of the normal ray passing through the projectile, that is to say *O*. In the second period we leave the extremity of the rod on the place marked and move the tube.

The image of the projectile on the fluorescent screen

* Also called the process of the metallic rod (see Charlier, *Journ. de Rad.*, 1915, p. 580).

becomes displaced. The image of the rod which is nearer to the screen is displaced much less. But if it is gradually lowered along the body of the patient it will be displaced more and more as it is moved away from the screen. By either lowering or raising the rod gradually along the body we shall find that at a certain moment the amount of their displacement coincides. (Position at *B* of the rod on Fig. 123.)

At this moment the foreign body and the extremity of the metal rod are in the same horizontal plane, and the track of that plane can be marked on the skin. We shall thus have an indication of the depth we require. It is said that an English radiologist who employed this method placed a coin in a thick book and by using a knife as a rod (whence the name of this process) inserted at each attempt the blade exactly between the two sheets of the book which contained the coin.

In spite of its apparent exactitude this is only a rapid method of approximation or a makeshift process if no special instruments are at hand.

*Le Faguays Process.**—He uses the knife process but by his method it is possible to measure the depth instead of simply guessing it. The apparatus (Fig. 124A) consists of a vertical rod *c* fixed on a base, on which slide two cursors through each of which passes a wooden ruler which may be displaced horizontally, the rods and rulers being graduated in millimeters. The upper ruler *F* is terminated at one of its extremities by a metal ring, the lower one *H* is a lead point (Fig. 124).

The marker is placed near the wounded, the two horizontal rulers being perpendicular to the large axis of the region to be examined.

At first we determine the normal ray passing through the projectile and the extremity *F* of the upper ruler is placed on the skin in such a way that the shadow of the projectile is centred in the metallic ring and the ruler which determines the point *A* is fixed (Fig. 124C).

Thereupon the diaphragm is opened and the lower ruler is placed at such a height that *H* touches the skin and that the shadows of *H* and of the projectile face each

* Le Faguays, "Note sur un appareil de localisation de projectiles" (*Journ. de Rad.*, 1915, p. 711).

other. By displacing the tube perpendicularly to the direction of the rulers the former process is used in order to adapt the position of *H* to the same depth as the projectile. This distance is read off on the rod *C* (Fig. 124C).

A

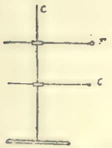


FIG. 124A.

B

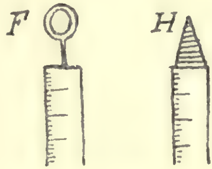



FIG. 124B.

C

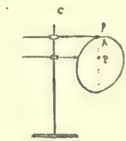


FIG. 124C.

This process evidently shares all the defects of the preceding one.

*Process and Apparatus of Morin and Le Maréchal.**—The patient being placed in position for operation the situation of a point *O* of the projectile (Fig. 125) will be defined by the normal ray *ION* passing through that point and through the distance *IO* from that point to the surface of the table. Let us suppose a spherical surface which has its centre in the projectile supposed to be reduced to the point *O*. Any line *MO* at right angle to that surface will pass through the projectile. These data are used by means of the apparatus represented schematically on Fig. 126.

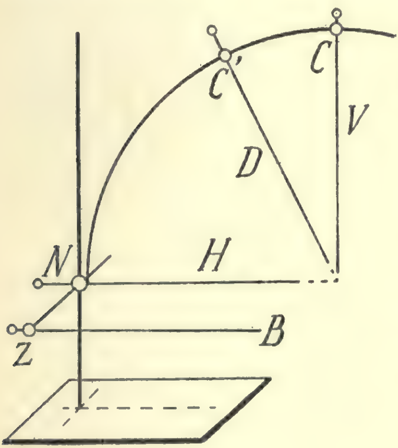



FIG. 125.

* Le Maréchal et Morin, "A New Apparatus to Localise Projectiles in the Wounded" (*Journ. de Rad.*, 1916, p. 102).

On a graduated vertical column there can be moved a slide *N* carrying several parts which are also mobile: (1) A horizontal rod *H*. (2) An arc which is a little more than a quadrant of a circle attached by one extremity to a ring which can turn round *H*. The arc in its rotating movements describes a spherical surface with the centre *O*. (3) A horizontal scale carrying at one end a socket in which there slides another horizontal rod the pointer *B*.

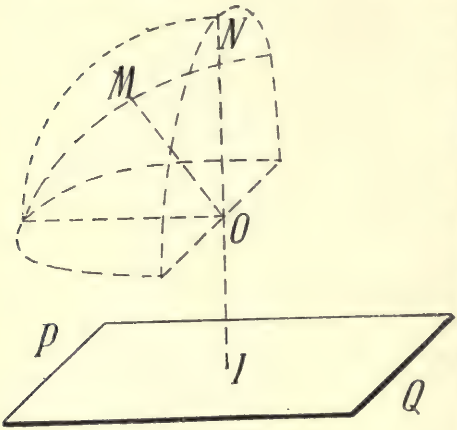



FIG. 126.

On the other hand the mobile arc carries two slides *C*, *C′* which glide on it and themselves carry other rods *V*, *D*, at right angles to the arch and situated on its plane. At the end of their course the rods *H*, *V*, *D* touch at the centre of the arc *O* and *D* (the directing rod is always directed towards the centre).

The supporting column may have another slide carrying a horizontal fluorescent screen on the surface of which are engraved in black, on the under surface, lines parallel to *H* and to the long axis of the screen (Fig. 127). The attachment is made in such a way that the vertical plane determined by *H* cuts the surface in an eccentric line (base line)

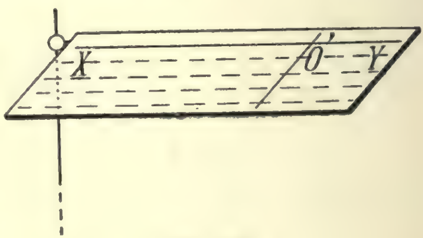



FIG. 127.

whilst another line perpendicular to the former ones cuts the base line at the projection $O'$ of the centre of the arc on the screen (principal point).

In order to effect the localisation the rods $V$, $D$ are withdrawn and the arc is inclined in order not to interfere with the working of the screen which is fitted on the supporting column. The projectile is found and centred. Thereupon the principal point $O'$ of the screen is also brought into the central ray. The centre of the arc is now situated on the vertical of the projectile, and we recognise the straight line $ION$ of the Diagram 125. Moreover the shadow of $H$ is formed on the same base line as that of the projectile.

In order to find the level of the latter the tube is displaced perpendicularly to the direction $H$. The shadows move in an inverse direction which indicates the one in which it is necessary to move the slide in order to bring the shadow of $H$ on the same base line as that of the projectile, that is to say to place the rod $H$ at the level required. When this is done the centre of the arc passes through the projectile itself and the localisation is made.

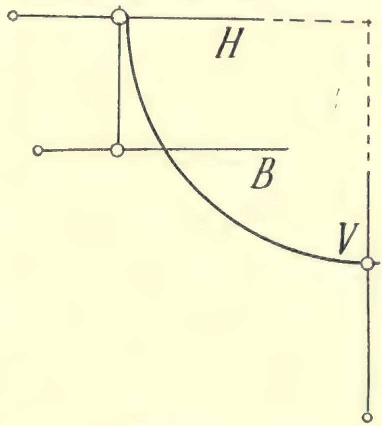



FIG. 128.

In order to find again later on the position of the projectile we make on the skin of the patient three marks, the positions of which are determined by the compass, the screen is taken away, $V$ is replaced, the arc is brought back into the vertical plane. The rods $V$ and $H$ (which if prolonged would meet at the projectile) are pushed down to the surface of the skin and their points of contact $RV$ and $RH$ with the skin are marked, and finally with the rod $B$ we mark the third cutaneous marking point $RB$ chosen at random.

To obtain a permanent record of this curve, the height of the nut on the supporting column should be noted, the arc is lowered on the rod *B* so as to place *VHB* on the same plane and a piece of paper is placed underneath and on it is traced a sketch similar to that of Fig. 128.

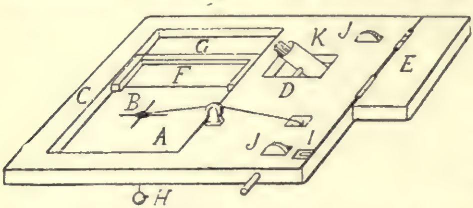



Fig. 129.—The pierced screen of Hirtz and Gallot (Gallot & Co., constructors).

The pierced screen of Hirtz and Gallot (Gallot & Co., manufacturers) can be recommended for its simplicity and ease of working. It is fixed (Fig. 129) by means of a piece *E* to which it is joined by hinges which enable it to be held in the screen carrying clamp of any X-ray table and to be moved in three directions at right angles. The apparatus has the following accessories: A mobile wire *F* stretched on a holder *G* which moves in an opening in the frame of the screen. A thin thread wound on a rod forming a windlass worked by two milled discs *J* and *J′* passes through the hole *B* and terminates in a small leaden ball *H*. Usually this ball is held in a clamp *I*. Finally in *K* a receptacle on a pivot contains small pieces of thin wood (matches). The bottom is provided with a plug soaked in thick ink.

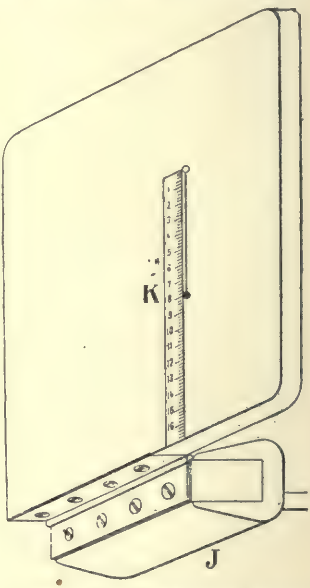



Fig. 130.—The pierced screen of Hirtz and Gallot fixed into the rod supporting the screen and lifted in order to effect the measurement of the length of the thread which gives the depth of the projectile.

In order to use this screen we must at first make certain that the tube is centred absolutely correctly, and that the pencil of rays which it emits when the diaphragm is almost entirely closed is quite vertical.* Then the patient is placed on the table in the required position.

(*a*) The screen is then placed by moving its supporting arm at a small distance above the region containing the projectile.

(*b*) The shadow of the projectile is then made to coincide with the middle of the luminous spot of 3 to 4 cm. in dia-

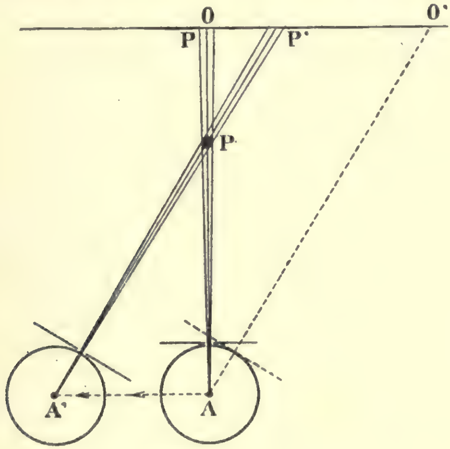



Fig. 131.

meter produced by the vertical pencil of rays by moving the tube.

(*c*) The screen is now displaced in its frame until the black spot produced by the hole is brought into coincidence with the middle of the shadow of the projectile or with an outstanding point of its outline. The two crossed black lines greatly facilitate the centring.

(*d*) Next the current going through the tube is cut off; one of the wooden rods contained in the receptacle contain-

* See Laquerrière, Sluys and de Rolland on the importance of centring the tube in this process (*Journal de Radiologie*, 1916, p. 174).

ing the thick ink is passed vertically through the hole in the screen until it touches the skin. The path of the normal ray will thus be marked where it emerges from the skin.

Fig. 131 enables one to understand the principle of this process.

The tube $A$ projects vertically at $O$ on the hole in the screen $E$ the shadow of the projectile $P$. The rotation of the tube deviates the luminous pencil to $O'$. It is brought back to $O''$ by sliding the tube to $A'$ until it passes again through the projectile $P$.

As soon as the patient has been removed the ball on the thread descends through the hole $O$ until the image reaches $O''$ (the position of which is determined by the mobile wire $F$). The ball will then be exactly at the point $P$, that is to say at the very same place which was occupied in space by the projectile.

§ 37. **Radioscopic Processes including the Measurement of the Displacement of the Shadow.**—The processes which we are going to study now and which form by far the most numerous and the most important include in their technique the measurement of the distance between the shadows produced in two successive positions of the tube according to the classical formula of depth $x = \frac{ha}{a + d}$.

In view of the importance of this procedure we shall give in detail the general method of applying it, enabling it to be used by any radiologist who has nothing else but an X-ray couch with a mobile tube under it and a screen which can be fixed above it at a desired height.

Suppose (Fig. 132) $S$ to be the patient placed on the couch $T$ in position for operation, $P$ the retained projectile the depth of which we wish to discover.

We shall begin by placing our tube accurately centred previously in such a way that the projectile is in the normal ray and we shall mark on the skin the points of entry $B$ and of exit $A$ of that normal ray. Suppose $O$ to be the position of the focus of the anticathode.

Then we mark on the lead glass which covers the screen $E$ some point $C$ which can be easily found again of the shadow of the projectile, say the point if it is a bullet (we should avoid taking the centre because of possible errors in determining it exactly and of mistakes this may cause in the estimation of the depth).

Let us now displace our anticathode from $O$ to $O'$ (Fig. 133) and let us measure the distance $OO'$ and presume that $OO'$ equals say 11 cm. The shadow of the bullet will be displaced. Suppose $D$ to be the new position of its point. Let us measure $CD$ which will equal say 2·3 cm.

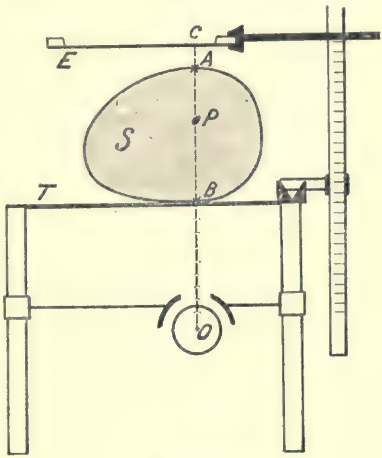



FIG. 132.

Let us measure the distance $OC$ from the anticathode to the screen, say 64 cm. the depth of the foreign body will be supplied to us by the classical formula from which we shall only have to subtract the distance $AC$ (say 3·1 cm.) from the screen to the skin (Fig. 132) with which the screen cannot always be in contact. We shall thus have:

$$X = OC \times \frac{CD}{CD + OO'} - AC$$

that is to say in the example chosen:

$$X = 64 \times \frac{2 \cdot 3}{2 \cdot 3 + 11} - 3 \cdot 1 = 11 \cdot 7 - 3 \cdot 1 = 8 \cdot 6 \text{ cm.}$$

and our foreign body will be at a distance of 8·6 cm. or 86 mm. above the point $A$. We have presumed the distance $AP$ to be smaller than $BP$ and we have made the localising mark on the side from which it is at the least depth which is logical and customary. Let us suppose that it is a thoracic projectile which is thus localised from the front. Let our patient now turn over and place himself on his abdomen and let us determine the depth again, this time from the back. We shall thus obtain the depth *BP*, say 13·2 cm. We have thus determined *AP* and *BP*. We only need to add these two quantities in order to obtain the length *AB* (here 8·6 + 13·2 = 21·8 cm.). But we are also able to *measure directly* this length very easily by means of callipers (or by means of any similar appliance easily improvised). This is an excellent and valuable control of the correctness of our localisation and we should always use it whenever the projectile is deep or is situated in a difficult region. It is

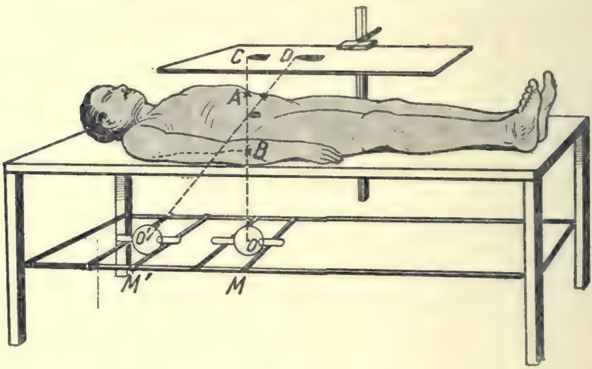



FIG. 133.

evident that we cannot expect an absolute similarity in the figures for *AB* found by these two methods, but that difference should be within reasonable limits otherwise we should repeat our localisation which for some reason or other is too inaccurate.

This procedure may certainly be used in the way we have just described. But it is very slow and there are many causes of error. We will therefore discuss, by adding our practical experience to the theoretical considerations described in Chapter VII, the various measurements to be made and try to find any possible simplifications of the technique.

1. *Distance from Anticathode to Screen.*—The distance from the anticathode to the surface of the table is measured once for all directly; say it is 33 cm., thereupon we place

a centimeter scale on the support carrying the tube in such a way that the figure 33 is on a level with the top of the couch. When the support is raised we can read off the distance of the anticathode to the screen on the scale. It is evident that we shall take it for granted that the focus is situated at the centre of the anticathode, and that we shall consider that it coincides with the centre of the sphere of the tube. As this hypothesis is never realised absolutely exactly there will be some slight error which can be ignored in practice because to obtain greater accuracy would introduce unnecessary complications. This measurement should however be verified each time that a new tube is used. We can see at once the considerable simplification of calculations which will result from adopting a constant distance from the anticathode to the screen, say 50 or 60 cm. It becomes a simple matter if we also adopt (see later) a constant displacement of the tube to prepare scales which give the depth of the projectile by direct reading of the displacement of its shadow, or to construct isobathymetric curves which answer the same purpose.

Numerous authors have adopted this process of which we give later on an example by describing the Allaire apparatus. But in spite of its great apparent suitability we must not advocate its use in general, because the distance left between the table and the screen is not sufficient and often interferes with the examination of large patients, or else serious mistakes are caused owing to the large distance separating the screen from the skin during localisation on thin parts such as the hand.

2. *Displacement of the Tube.*—It depends on the suitability of apparatus at our disposal whether this displacement is made in the same direction or at right angles to the long axis of the X-ray couch. Here too an important simplification of calculations will be obtained if we adopt for the displacement a constant distance in every case, say 10 cm. The advantage of this is not attended by any inconvenience so we shall not hesitate to make use of it and we shall adopt in common with the majority of workers this distance of 10 cm. |

It is extremely useful and almost indispensable if we wish to be able to effect this displacement rapidly in the darkness of the X-ray room, without groping and without the possibility of a mistake, to add to the apparatus a special stop device enabling us to change the tube automatically from its first to its second position which is then fixed to avoid any error from an accidental movement. All manufacturers now produce similar appliances to be fixed to their couches but a simple block of wood will suit the purpose.

In order to avoid all calculation it is possible to materialise the data of the problem, as has been so ingeniously and very simply done by Haret.

*The Haret Process* *.—The tube is displaced at a fixed distance from the upper surface of the couch. The vertical gliding rod which supports the screen is graduated in centimeters in such a way that when the screen is fixed for an examination we read directly in millimeters the exact distance $AB$ which separates the focus of the anti-cathode from the screen (Fig. 134). An angle block has been prepared in order to allow the displacement of the tube by 10 cm. in darkness.

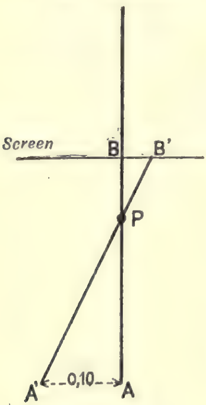



Fig. 134.

In order to localise we place the screen in contact with the skin on the region under examination, we allow the normal ray to pass through the projectile, we obtain on the screen a shadow which we mark with a grease pencil, and this is the point $B$. We then displace the tube along the slide by a distance $AA'$ (which we have settled is to be 10 cm.) and the projectile gives us a second image $B'$ which we also mark on the screen. We can measure the distance $BB'$ of the two images of the projectile on the screen. The focus of the anticathode in its two displacements and the two images of the projectile are on the same plane as the projectile.

To obtain the depth of the foreign body all that is necessary is to construct in space the two triangles $BPB'$

* Haret and Schlesinger, " A Very Simple Apparatus for Localising Foreign Bodies " (*Presse médicale*, December 24th, p. 746).

and $APA'$ which have two sides $BP$ and $PA$ in a straight line.

The sides $BB'$ and $AA'$ are perpendicular to the straight line $AB$, and we know by simple reading the distances $BB'$ and $AA'$. If we join the points $A'B'$ by a string we shall obtain on the line $BA$ a point $P$, the summit of the two triangles which is the exact point where the projectile

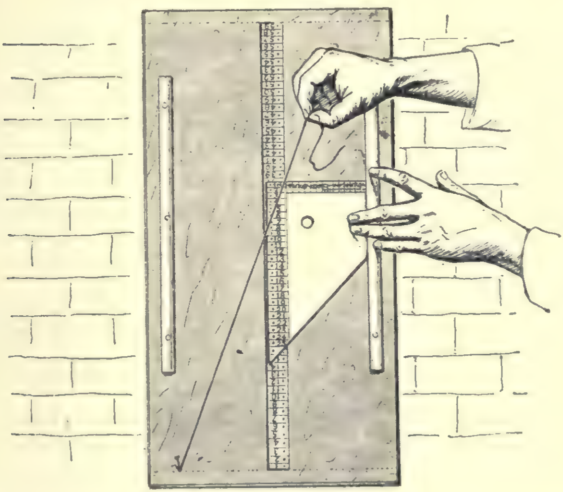


FIG. 135.—The Haret Apparatus (Gallot & Co., manufacturers).

is situated, the distance $BP$ which we read easily is the distance from the projectile to the skin.

The following appliance is constructed in order to render the process practical: A dressmaker's measuring tape is pasted on a small board (say the cover of a coil), one side only, say the left side, being taken into consideration (Figs. 135 and 136) in order to apply it to the line $AB$ and at $A'$ a thin thread is placed. A set square is then taken and the two sides of the right angle are graduated in centimeters. The finding of the position of the projectile will be very simple. For a thickness $AB$ we place the top of the square angle of the square at the point $B$ corresponding to the number of centimeters indicated by the support of the screen. On the side $BB'$ we take the figure of the variation of the shadow of the projectile. If we join $A'B'$ with the thread this thread cuts the line $AB$ at a point $P$ so that $PB$ is the distance from the projectile to the skin.

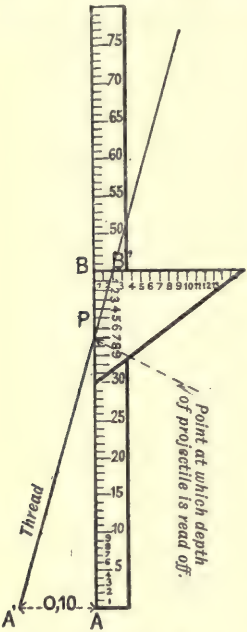



FIG. 136.—The Haret appliance.

Should we for any reason whatever not be able to place the screen in direct contact with the skin we carry out the same procedure but we must measure the distance between the screen and the point on the skin where the normal ray emerges. All we need then do is to subtract that distance from the figure given.

*The Jaugeas Process.**—A technique very similar to the preceding one has been simultaneously described by Jaugeas.

*The Allaire Radioscopic Marker.*—This marker consists of a rectangular frame opaque to the X-rays of 0·03 m. in thickness at a certain point of which there is a rectangular space of 0·12 m. in length by 0·06 m. in width divided into four parts by two crossed metal plates. A metal graduation is placed at the upper part which covers the two rectangular spaces. The vertical plate forms the zero of the graduation and the divisions increase progressively to the right and to the left of that plate. The graduation has been established by practice and calculation for a distance of 50 cm. from the anticathode to the screen and for a displacement of the tube by 10 cm.

If we wish to make use of that appliance, it is placed at a distance of 47 cm. from the anticathode. The screen will

* Jaugeas, *Presse médicale*, 1914, p. 743.

thus be at 50 cm. from the anticathode, as the thickness of the marker is 3 cm.

From a rapid examination with a fluorescent screen we determine the depth at which the foreign body is situated

FIG. 137.

and the tube is adjusted to its level. The screen is placed upon the localiser and the tube is displaced in such a way that the metallic plate appears on the screen only in the shape of a line. The normal ray passes through the inter-

FIG. 138.

section point of these lines. In order to obtain these lines precisely the tube must be displaced successively from right to left and from front to back. Care must, moreover, be taken when the patient is lying on the table that the shadow of the foreign body is placed in the opening made in the scale, coinciding with the horizontal of the vertical plate (Fig. 137). The tube is then displaced by 10 cm. say to the left. The shadow of the foreign body is displaced to the right and runs through a larger or smaller number of divisions corresponding to its depth. (Fig. 138). Each division passed represents a depth of 2 cm. from the foreign body to the skin. If the division is passed incompletely its value is represented as follows: half represent 1 cm., quarter 0·5 cm. If for instance the shadow has passed two divisions and a half the projectile is at 2·5 cm. from the skin.

*The Londe Process.*—To determine the distance at which the foreign body is situated from the plate without calculation and by simple compass measurement this author since 1898 has been using a wooden triangle. On the perpendicular dropped from the summit of that triangle there are fixed metallic rods of unequal length and separated from one another by a distance of 1 cm.

The patient is taken away from the radioscopic table, the triangle is placed in a vertical plane which passes through the foreign body, the tube is then displaced. The iron rods will throw their shadow on the screen, it is sufficient to read the division which corresponds to the localising mask left in place of the shadow of the projectile in order to know its depth. If for instance the two images of the foreign body are situated between the fourth and fifth rod, and if the rods are at a distance of 1 cm. its depth is about 4·5 cm.

This very simple process does away with a somewhat delicate measurement, namely the measurement of the distance from the tube to the plate.

§ 38. **Mazérès's Rule and its Simplification of the Calculation—Diaphragm Effect—The Skiameter—The Bathymeter.**—Let us point out that the classical equation $x = \frac{h + a}{a + d}$ may, if we adopt for the displacement $d$ of the tube a constant distance, say 10 cm., be expressed in the form $x = Kh$.

We calculate for the various successive entire values of

$K$ expressed in hundredths, the corresponding value of $a$:

$$a = \frac{100K}{1-K}$$

These values of $a$, expressed in millimeters, are placed on the ruler, starting from a common point, and they are numbered with a corresponding value of $K$. We have thus realised a scale which measures directly, in coefficients of $K$ any length $a$.

This is the rule invented by Mazérès (Fig. 139) and its application to the localisation of projectiles is most advantageous because it enables a considerable simplification of our calculation even if we leave the distance of the anticathode to screen variable which we recommend. If we measure the displacement of the shadows on the divisions of the rule, the depth of the projectile will be obtained

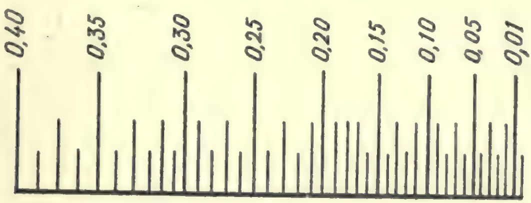



FIG. 139.—The Mazérès rule (we may of course increase the scale for any desired length).

by simple multiplication of the figure on the rule by the distance of the anticathode to the screen. It is only necessary to deduct from it the distance screen to skin and we shall only have had to do a direct reading (anticathode to screen) on a graduated scale and a simple measurement (screen to skin).

But even if we employ the rule as a ready reckoner which reduces all calculations to a single operation—a very simple subtraction—the method is capable of two serious objections which however may apply to all radioscopic proceedings which we have so far described.

First of all there is the relative inaccuracy of the measurement of the displacement of the shadow. The marks made in pencil, or with a stylographic pen, etc., on the plate of the screen lack precision, they are too thick or indistinct, etc., and may produce errors of reading which, when added up, may easily reach 2–3 mm. and sometimes more. And we have seen (p. 149) what a serious effect these errors have on the final results.

It was therefore necessary to find a process for measuring the displacement of the shadows which would enable us to avoid these errors. Messrs. Viallet and Dauvillier have successively solved this problem by effecting this measurement by the method of adaptation of optical shadows, the precision of which is well known. Moreover the observer is freed from any causes of error resulting from the graphical marking of the screen.

On the other hand when the tube is displaced if it is a question of finding a very small projectile situated in a thick region or in a fat subject the projectile, very visible when the diaphragm is closed as far as possible, can sometimes be seen only with difficulty when owing to the 10 cm. displacement it is necessary to open the diaphragm to follow its shadow. It may happen that under these conditions it becomes quite invisible. The localisation therefore becomes a matter of guess-work and the displacement of the image is measured incorrectly or else is not measured at all. These cases have induced certain surgeons, and even certain radiologists, to state that it is impossible to devise a general method for screen localisation whereas the failure is due to inadequate and faulty technique. We have already said, and we repeat it, that if the diaphragm is properly handled any projectile which can be extracted surgically is visible. All that we have to do is to apply the diaphragm-effect at all stages of localisation. We shall now see how Messrs. Viallet and Dauvillier on the one hand and M. Dessane on the other hand have solved this problem.

*The Skiameter of Viallet and Dauvillier.*—This apparatus (Fig. 140) which is perhaps the most precise of those founded on radioscopy was devised and produced by its inventors in the last months of 1914. It is specially suited for the outfit of the X-ray lorries, Gallot type.

Its essential parts are: (1) A rule with a stop device fixed on the horizontal bar of the tube carrier to effect automatically the displacement of 10 centimeters (Fig.

141). (2) An elliptical lead cylinder having at its upper part a small fluorescent screen and provided with a network formed of two plates of lead crossing at right angles which cut out the embarrassing effect of the secondary rays and at the same time allow a direct sight of the prominent points of the shadows. (3) A square section tube having

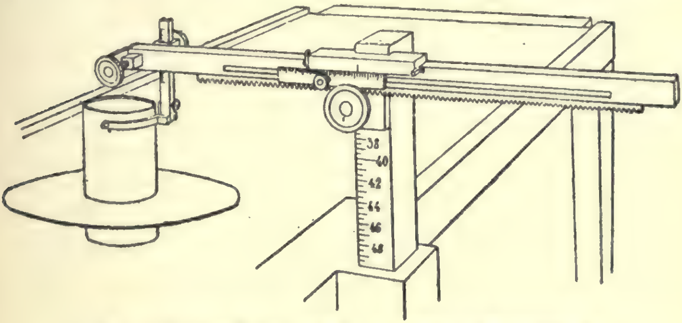



Fig. 140.—The Viallet and Dauvillier skiameter.

a double rule of Mazérès type; on its extremity is fitted the oval cylinder provided with its small screen. (4) Finally a wooden upright, carrying a centimeter scale giving by direct reading the distance anticathode to screen, supports the whole.

To start with, the localisation includes as usual the centring of the projectile in the line of the normal ray and the determination of the point of exit of that ray on the skin (called by Viallet the marking of the projectile on the surface) and which is carried out with any ordinary screen. The cylinder of the skiameter is then placed directly above the marked point and if possible it is placed in contact with the skin (position *A* of the tube, Fig. 142).

Fig. 141.—The stop device of the skiameter. It allows a displacement of five centimeters on each side of the normal ray.

The tube is then displaced by 5 cm. to the right, which can be carried out automatically with the stop device (position $A'$, Fig. 142), the opening of the diaphragm is increased and the shadow of the projectile will be seen on the small screen. By means of the regulating screw the first "sighting" is made by making an outstanding point of the shadow of the projectile coincide with the transverse line of the network in the cylinder. The Mazérès ruler is moved by lifting the stop which kept it fixed and the tube is displaced by 10 cm. towards the left (this is effected

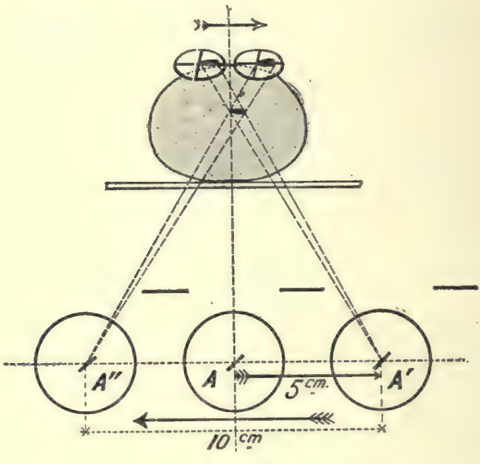



FIG. 142.

automatically owing to the stop device) (position $A''$, Fig. 142).

Then we make the second "sighting" by making the same point of the shadow coincide with the same line in the cylinder, by means of the rack on the support, the Mazérès ruler will be displaced and in order to find the desired depth it will be sufficient to multiply the coefficient obtained on the ruler by the distance anticathode to screen (read off from the upright) or else to consult a previously established ready reckoner which indicates that product. As the height of the cylinder is 100 mm. the result obtained should be reduced by 100. Should it not have been possible to establish contact between the cylinder and the skin, this distance after being measured should also be deducted.*

This process combines great precision with great rapidity and, owing to the use of the diaphragm-effect supplied by the cylinder and owing also to the displacement from one position to the other of the normal ray enables us to obtain an excellent view of even the smallest projectiles. Moreover it possesses as we have already said the advantage of measuring the displacement of the shadows by optical means.

*The Localiser-Guide* by Gudin † (Fig. 143), constructed by Drault & Raulot-Lapointe, has adapted the excellent principles of the skiameter to an apparatus giving the exact site of the projectile in space by attaching to it a mechanical guiding instrument, a compass. It also gives localising marks.

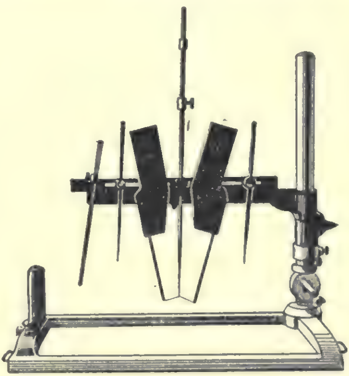


FIG. 143.—Localiser-guide by Gudin (Drault & Raulot-Lapointe, manufacturers).

*The Radio-Bathymeter* of Dessane seems to us to add to the advantages of the skiameter (precision, omission of calculations by the use of the Mazérès ruler and of ready reckoners, perfect visibility, etc.) a still greater facility of working and a certain simplification of apparatus, the screen used being 18 × 24 and lending itself, consequently, to a complete exploration of the patient without having to change

* It will be noticed that had the tube been guided by the vertical upright supporting the skiameter, thus making the distance anticathode to screen constant whilst avoiding the inconveniences mentioned above, a Mazérès ruler could be constructed which would immediately supply the depth of the projectile by direct reading. But this process which resembles very closely that of Barret described later on, unfortunately requires a complicated and little-known apparatus.

† Gudin, *Bul. Acad. Méd.*, October 17th, 1916, p. 294.

the apparatus. It is quite possible with a little skill to adapt our screen to make a rudimentary but working model of it ourselves and at small expense.

Finally, it facilitates perhaps more than any other apparatus the reading of the distance screen to skin which is often so difficult. It is very rapid, it supplies in even inexperienced hands exact and certain results and, in difficult cases, perfect visibility. This is the method adopted by one of us for all localisations carried out in the Central Service of Radiology of the ninth region at Tours.

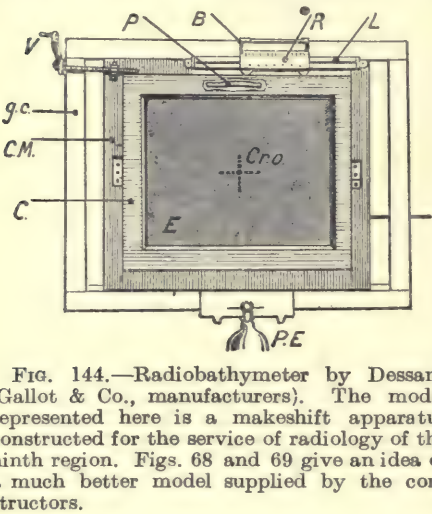



FIG. 144.—Radiobathymeter by Dessane (Gallot & Co., manufacturers). The model represented here is a makeshift apparatus constructed for the service of radiology of the ninth region. Figs. 68 and 69 give an idea of a much better model supplied by the constructors.

The bathymeter (Fig. 144) consists essentially of a screen 18 × 24 (*E*) fitted on a frame *CM* which is itself mobile by sliding in the interior of a second frame *gc*. The screen *AC* is fixed by hinges to the frame *CM* and can be lifted like a lid of a box, leaving thus absolutely free access to the underlying region (Fig. 145). The displacement of the mobile frame *CM* in the interior of the large frame *gc* and in its long diameter is produced by a simple screw rod *V* the rotation of which, either in one or in another direction, controls the direction to the right or to the left of these displacements. A Mazérès ruler *R* is moved with it. Its registering is mobilised when the stop *B* is lowered enabling thus the coefficient to be read (Fig. 148).

In the centre of the under surface of the screen *E* there is pasted an opaque cross-bar and on this surface a ready-reckoner has been fixed by which calculations are avoided.

These columns of figures will be seen in Fig. 145. A horizontal piece *PH* (Fig. 146*A*) which is placed in the mobile frame (Fig. 145) when the screen is lifted and carries a carefully centred orifice, enabling us to reproduce the normal ray by inserting in this orifice the rod represented in *B* on Fig. 146.

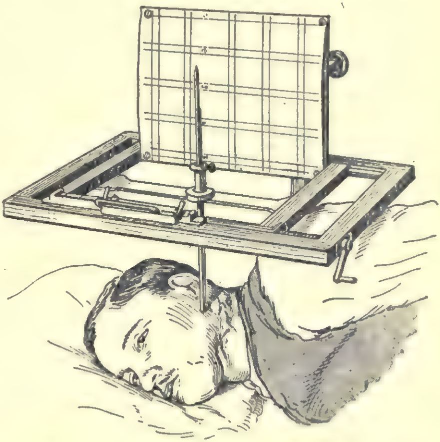


FIG. 145.—The Dessane bathymeter. The screen is lifted, we see on its under surface the columns of figures of the ready-reckoner (p. 232). The horizontal piece has been placed in position and the rod (Fig. 146 *B*) measures the distance screen to skin.

A stop device similar to the one shown for the skiameter but used for measuring the displacements of the tube made in the long axis of the couch completes the apparatus. To carry out the localisation, the apparatus is placed in the screen carrier (Fig. 147) and its horizontality verified; then the patient is placed in the required position. The procedure adopted is as follows: The centre—or any prominent point—of the shadow of the projectile and the centre of the opaque cross-bar are placed in the normal ray. The current is cut off, the screen is lifted and after placing into position the horizontal piece the exit of the nor-

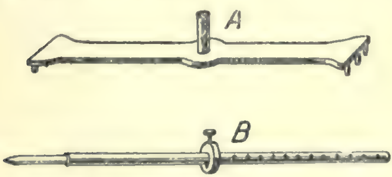



FIG. 146.—The horizontal piece *A* enables the rod *B* to be centred and the point of exit of the normal ray to be marked, and then by simply removing the rod *B* to obtain the distance screen to skin by direct reading very accurately (Fig. 145).

mal ray is marked with a pencil carried by one end of the rod *T* inserted in the orifice *O*.

This rod is replaced and by letting its other extremity descend until it touches the skin (without depressing it), which contact is made of course at the point of exit of the normal ray, we estimate directly at the level of the ring *B* the distance screen to skin, the rod *T* being graduated in mm. This is the operation shown in Fig. 145.

The horizontal piece is taken away, the screen is lowered again, the current is put on again, and the tube is displaced by 5 cm. to the right (which is effected automatically

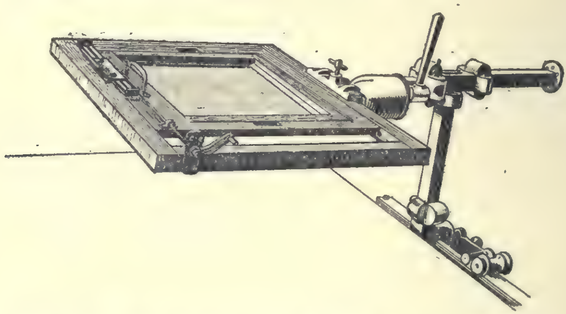


FIG. 147.—The bathymeter fixed to the screen carrier and ready to carry out a localisation.

owing to the stop device). The diaphragm is slightly opened and the opaque cross is placed in such a way that one of its limbs which is perpendicular to the direction of the displacement of the mobile frame (that is to say perpendicular to the long axis of the couch) is situated slightly to the left of a prominent point of the shadow of the projectile. Then by manipulating the screw rod *V* we make these two shadows coincide, thus reproducing the first "sighting."

The tube is next displaced by 10 cm. to the left, the stop (Fig. 148) is lowered and by turning (always in the same direction) the threaded rod *V* the contact (destroyed by the displacement of the tube) is re-established between the limb of the cross and the prominent point of the shadow. The operation is then terminated. The screen is then lifted in order to have the ready-reckoner before our eyes (p. 232) the coefficient found on the Mazérès ruler is noted, say 13 (Fig. 148 *B*), the distance anticathode to screen on the

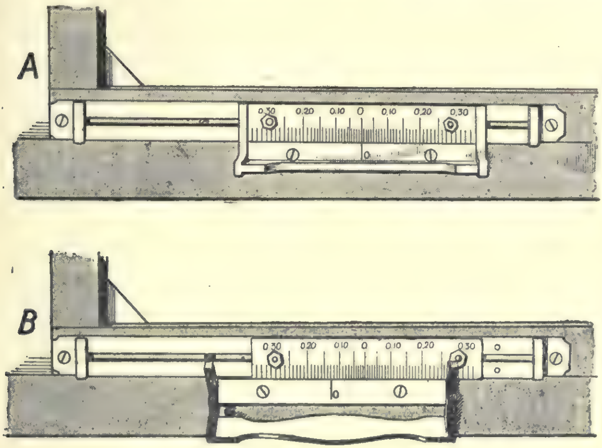



FIG. 148.—Details of the Mazérès ruler. At *A* the ruler glides on the frame, at *B* it remains stationary and the scale is only displaced over it when the stop is lifted.

vertical upright of the screen-carrier is taken note of (say 62 cm.), the ready-reckoner is consulted and we find the figure 80·6. It is sufficient to deduct from it the distance

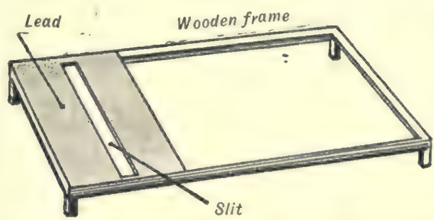



FIG. 149.—The diaphragm-slit of the bathymeter.

screen to skin read on the graduated rod, say 37 mm., in order to have the depth of the projectile in millimeters which would be here 53·6 mm. and we shall consider it to be 54.

If we find ourselves in the presence of projectiles which for some reason are difficult to see and which it is difficult or impossible to follow during the second displacement of the tube, we simply place on the tube carrier the apparatus of Fig. 149 by placing the open part of the frame above the diaphragm. As soon as the projectile has been found and centred, it is placed in such a position that the lead plate is situated above the diaphragm and that the projectile is framed in the slit of that plate. In this slit the shadow of the projectile is displaced with the displacement of the tube and the diaphragm effect thus produced allows perfect visibility.

The bathymeter which we have described and shown here is a relatively simple model which may be constructed almost everywhere. A considerably perfected model has been constructed by Messrs. Gallot (Figs. 68 and 69 give an idea of it) and is particularly suitable to be adapted on the radio-surgical couch of Ledoux-Lebard of which it constitutes an indispensable complement.

§ 39. **Particular Cases of Triangulation.**—The measurements, readings or calculations which have to be made in these various procedures which we have just described are not very complicated and only a small amount of training is required to apply them with confidence.

They may still however be the cause of errors for careless operators. Many inventors have therefore tried to eliminate them by estimating the determination of the depth by a single direct reading or a single measurement on the screen. We have already shown when describing the Allaire marker or the skiameter possible solutions of this problem, and we have also discussed the criticisms to which they are subject, and the reasons why they may not be considered suitable for general adoption in spite of their merits.

Some inventors have devised instruments capable of effecting all the necessary movements automatically.

In this connection we have seen a very ingenious apparatus invented by M. Biton at Cholet which is however too complex and overloaded for it to come into general use.

Others such as Messrs. Desplats and Paucot have constructed graphs with curves of equal depth. Mr. Quichard has invented another radioscopic apparatus for direct reading (manufacturer, Rupalley), etc.

More interesting are however, to our mind, the attempts made by some to make use of particular cases of relations of identical triangles and thus to arrive at simplified formulæ or to introduce angular data according to the pattern of M. Guilleminot * in his radiogoniometer.

*The Roussel Process* (Figs. 149–150), (*Report of the XIth Region, February* 1916).—Suppose a tube is placed under the table. Let us place above the opening of the tube carrier upon the ordinary diaphragm (Fig. 150) a lead plate pierced by two orifices of about 1 cm. in diameter each, one $A$ placed in the course of the normal ray to the plane of the table $T$, the other $B$ made in such a way that the distance $AB$ from its centre to the centre of the first one is in a simple relation, in preference $\frac{1}{2}$ or $\frac{1}{3}$, with the distance which separates the centre of $A$ from the focus $F$ of the anticathode.

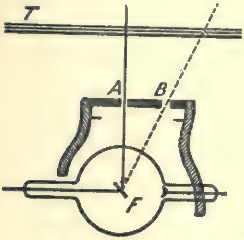



FIG. 150.

If, for instance, $AB = \frac{1}{2}\, AF$ we can write:

$$Tan\ AFB = \tfrac{1}{2}$$

and the angle which has this property is the angle 26° 33′ 50″.

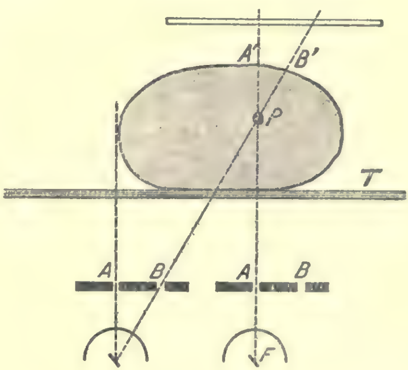



FIG. 151.

Let us suppose that the patient is placed on the couch, let us examine him, let us first roughly centre the projectile $P$

* Guilleminot, *Traité de radiographie et de radioscopie clinique de précision* (Paris, 1900).

with the ordinary diaphragm and then centre it in the orifice $A$ of our lead plate, and mark the exit $A'$ of the normal ray on the skin. Let us now displace the tube until the shadow of the projectile appears again on the screen, being shown by the rays now traversing the orifice $B$. Suppose $B'$ is the projection on the skin (Fig. 151).

The triangle $A'PB'$ is a rectangle (because we can always obtain $A'B'$ on a horizontal), its sides are parallel to those of the triangle $FAB$, these triangles are therefore equal and we have:

$$\frac{A'B'}{A'P} = \frac{AB}{AF} = \frac{1}{2} \text{ whence } A'P = 2A'B'$$

*The Strohl* and Mary Mercier Processes.*—These authors have also recourse to particular cases of triangulation.

*The Pierre Process.*—Already indicated in detail in his remarkable article on localisation processes which appeared in May 1915, by Mr. Lebon † who says it was shown to him by Messrs. Gallot and Rivier, without knowing its real author, this process has been taken up again by Mr. Pierre ‡ from whom we take its description.

Let us consider a tube which may be displaced along a horizontal scale and may be turned round an axis also horizontal and perpendicular to the preceding scale; this tube is provided with a metal rod the direction of which passes through the centre of the small central plane mirror. In the displacement of the tube the centre of this mirror describes a horizontal line parallel to the scale. The part in which the foreign body is situated lying on the radioscopic screen, let us suppose that we have caused the vertical plane which contains the line on which the centre of the anticathode is displaced to pass through the foreign body $M$ and let us take this plane as the plane of the figure. By means of a plumb-bob we place the metal rod in a vertical position; for any position of the tube we have on the screen: (1) a shadow of the rod situated vertically above it, (2) a shadow of the foreign body $M$. By displacing the scale in a convenient direction, these two shadows will be brought to coincide in a single point $m$ and this

* Strohl, *Journal de Radiologie*, 1916, p. 173.

† *Progrès médical*, May 1915.

‡ *Académie de Médecine*, October 26th, 1915, *Bulletin*, p. 472.

point will be marked in pencil on the screen: the foreign body is situated on the vertical passing through that point.

The tube is then brought behind and is turned round its axis so that the metallic rod forms an angle of 45° with the horizontal and consequently also an angle of 45° with the vertical.

We shall still have on the screen two shadows: (1) the shadow of the rod reduced to a point; (2) the shadow of the foreign body. By displacing the tube in a convenient direction we shall make these shadows coincide at *s*, a point which we shall also mark on the screen (Fig. 152).

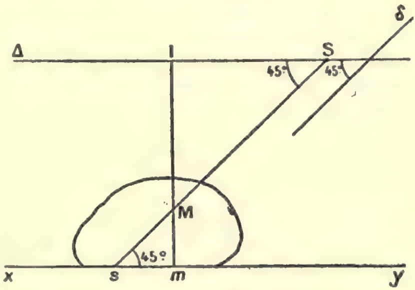



FIG. 152.

We shall observe that owing to the equality of the angles at *M* and at *s*, *Mms* is an isosceles triangle and that consequently the sides *Mm* and *ms* are equal. By measuring the distance of the two points, *m* and *s*, marked on the screen, we shall obtain the length of the line *Mm*, that is to say the distance of the foreign body to the screen. The foreign body is therefore on the vertical which passes through *m* and above that point at a distance equal to *ms*, the length measured directly on the screen.

In practice it would be interesting to place the screen on the part which contains the foreign body and the tube above, which simply amounts to reversing the procedure.

§ 40. **The Barret and Andrault Process.**—This apparatus deserves special mention owing to its ingenuity and because it has the very rare distinction amongst these methods which are founded on the double-image idea that it is not based on the properties of similar triangles.

Let us suppose that we have a tube which in addition to its ordinary displacements in a plane parallel to that of the table, can also be raised (or lowered) vertically under the table and the screen is attached to the tube, that is to say that it can be raised or lowered at the same time as the tube and that an upright graduated in millimeters enables us to read directly the value of these vertical displacements.

Suppose $T$ to be the plane of the table, $P$ the retained projectile. We centre it as usual on the normal ray. Suppose $A_1$ to be the position of the anticathode of the tube, $E_1$ the position of the fluorescent screen at the moment when the centring is effected. We place on the skin of the subject at the emergence of the normal ray a mark $R$ which may be a metallic fragment which is attached by some adhesive or a rod, say the point of the spintermeter (the shadow of which is produced at $p'$ at the same time as that of the projectile).

Let us displace now the tube by any desired quantity, in the same plane parallel to that of the table. Suppose A to be its new position. The shadow of the projectile will be produced at $p''$ and we shall mark it on the screen. The shadow of the cutaneous marking will be shown in $n$.

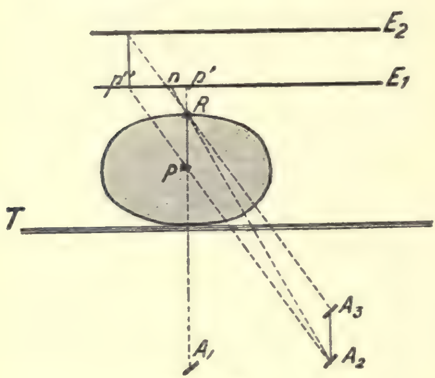



Fig. 153.

Let us now lift the tube and together with it the screen until the shadow of the marking again coincides with the point ($p''$) marked on the screen. The anticathode will be at $A_3$, the screen at $E_2$.

The figure shows us that the distance $A_2A_3$ measured by direct reading on the upright gives us the depth of the projectile (parallels included between parallels). Here we have no calculations, only a single mark to be made on the screen any displacement of the tube, no measuring of the distance screen to skin. It is therefore regrettable that this method so attractive at first sight needs a special and rather costly installation and one difficult to make under conditions which ensure a constant rigid parallelism of the plane of the screen and of the plane of displacement of the tube which is an essential condition for a correct result.

## Radiographic Processes

All the processes which we have so far described and based on the displacement of the tube were exclusively radioscopic. It will however be readily understood that the same principles can, as already indicated, be applied without any changes to the determination of the depth by radiographic means. In the latter case we shall measure the distance between the two shadows of the projectile on plates and not on the screen. On the whole this is only a simple difference in the technique. If various complications and an additional expenditure of time and money result therefrom, we are compensated by a greater precision—at least theoretically—and we possess a fixed and permanent image, which may be undertaken by anybody, and consequently free from the character of subjectivity of the radioscopic observation and of the personal factor which goes with it. It seems therefore that especially for the regulation of the compass, radiographic processes are the best, and up to the present this has been and still is the unanimous opinion of the greater number of radiologists and especially of surgeons.

However, we have said (§ 35) why we prefer good radioscopic processes the advantage of which are considerable especially in war time. They also allow the regulation and the use of compasses—such as the excellent instrument of Hirtz—with the advantage of rapidity, simplicity and economy, and at the same time of correctness, which have caused them to be immediately adopted for that use by most of those who have tried them, and we strongly advise their use by all radiologists.

Moreover, the majority of radiographic processes—for instance the Hirtz—presume a previous radioscopic examination, even if not a complete radioscopic localisation. They are not free from the dangers of radioscopy, slight though they be for those who take adequate precautions (see § 17), of which they retain all the inconveniences without profiting from its advantages. Therefore, in our opinion, radiographic methods can only justify their existence in two cases: (1) If the surgeon has no confidence in his radiologist and wishes to undertake himself the regulation of the compass, without having the time or the wish to carry out all the preliminary manipulations. He is given a plate according to which he regulates his instrument, but what confidence can he then have in the accuracy of the preliminary operations? (2) The radiologist is not a physician, he ignores radioscopy and is afraid to use it on account of its numerous sources of error, whilst he has learned the manœuvres of a radiographic process which enables him to supply a mechanical localising instrument to a surgeon who cannot or does not wish to practise the extraction of projectiles by means of the intermittent control of the screen, and even in the latter case the manipulator—as he does not deserve the name of a radiologist—would have to use preferably processes which include two separate plates enabling him to carry out a stereoscopic examination (see Chapter X).

*The Buguet and Gascard Process.**—These authors were amongst the first to apply to radiography as well as to radioscopy the classical formula which we have described on pp. 146–7.

Instead of measuring the displacement $a$ on the screen they note it on the plate.

*The Mackenzie-Davidson and Hedley Process.*†—These authors seem to have been the first ones to materialise by an intersection of threads the situation of the projectile in space by using for the localisation two radiographic impressions made on the same plate.

Fig. 154 shows a July 1900 model of their apparatus. It is interesting to compare it to the apparatus of Marion-Danion shown later on. Their method, excellent at that period, has been in constant use since.

* Buguet et Gascard, C.R. Acad. des Sciences, 1896, "The Séchehaye Method" (*Bulletin médical de la Suisse romande*, 1898) is also a variation of the same principle.

† Mackenzie-Davidson, "A Method of Precise Localisation and Measurement by Means of the Röntgen Rays" (*Lancet*, October 1898).

*The Mergier Process* is based on the same principle as the preceding one, except that the shadows are recorded on two different plates.

*The Contremoulins and Rémy Process.*—Also basing themselves on the same idea but criticising the lack of precision of their predecessors these authors have elaborated an extraordinarily laborious and complicated method which certainly gives exact results in theory, but meets in practice with practically the same difficulties and with the same causes of physiological inaccuracy as the others. It is used only by its authors who had the merit of being amongst the first ones to complete the proper localisation by mechanical localising instrument, guiding the surgeon to the projectile by a compass which formerly rendered real services.

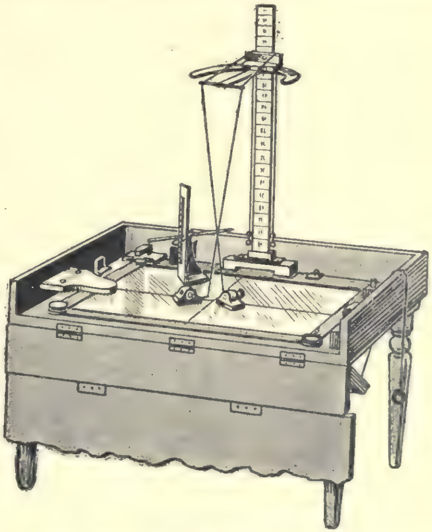


FIG. 154.—The Mackenzie-Davidson and Hedley Process.

*Colardeau Process.**—This author has revived and perfected an old process.

Let us mark on the skin of the patient near the point where a previous screen examination has shown us the projectile, a small cross $O$. Let us call it the "original marking" and let us imagine three rectangular axes passing through it. The axis of $x$ will be parallel to the transverse diameter of the patient, the axis $y$ to the long axis of his body and the axis $z$ perpendicular to the preceding ones will traverse the patient. We shall determine the co-ordinates $XYZ$ of the projectile in relation to this

* *Arch. Electr. Médic.*, March 1915, and *Presse médicale*, 1915.

system of axes. The two co-ordinates $XY$ indicated starting from $O$ on the surface of the body will indicate where the surgeon should make an incision in order to find the projectile at the depth $Z$. The two radiographs taken as follows will enable us to make these calculations.

A cassette similar to one which is used for stereoscopic radiographs, but on the upper face of which there is let into the wood an intersection of opaque metal wires, is placed under the region examined and it is made sure, by means of a plumb-bob, that the centre of the anticathode which has been placed 50 cm. above the plate (slid into the cassette) falls at the intersection point of the wires, *i.e.* the centre of the plate. Finally we place the region to be radiographed, which has already been examined with the screen, in such a way that the projectile is situated more or less in the centre of the plate. On the point of intersection we place an adhesive metal index on the skin of the patient, this giving us the point of the axis $z$. The other one is determined by the plumb-bob and at the level of the second point we mark with a dermographic pencil a small cross, the two branches of which follow the directions $xx'yy'$ of the two opaque wires of the cassette. The centre of this small cross will be the origin $O$ of our three rectangular axes.

We displace then the tube (which was centred at $O'$) parallel to the direction $XX'$, by a quantity $d$ in such a way that it is at $A_1$ and we take a plate in which the image of our projectile $P$ is at $P_1$. Thereupon, after changing the plate without moving the patient, we displace the tube from $2d = 64$ mm. to $A_2$ position symmetrical to $A_1$ in relation to the initial position $O'$ and we take a second plate on which the image of the projectile will be $P_2$.

The shadow of the intersection of wires traces on these plates (Fig. 156) the axis $xx'yy'$ and we shall measure directly, with a double-decimeter the distance $x_1$ from $P_1$ to the axes $yy'$ on the plate $C_1$, the distance $x_2$ from $P_2$ to $yy'$ on the plate $C_2$, the distance $y$ from $P_1$ or from $P_2$ to the axes $xx'$ on one or the other plate (this distance is evidently the same on the two plates). The depth $Z'$ of the projectile (starting from the plate) is then easily calculated. In fact, the two similar triangles of a common summit $P$ (Fig. 155) give:

$$\frac{Z'}{D-Z'}=\frac{x_2-x_1}{2\delta} \text{ whence } Z'=\frac{D\,(x_2-x_1)}{(x_2-x_1)+2\delta}$$

that is to say with the adopted numerical values expressed in millimeters:

$$Z'=\frac{500\,(x_2-x_1)}{(x_2-x_1)+64}$$

If we wish to have the depth $Z$ calculated from the point marked by the plumb-bob on the skin, it is sufficient to

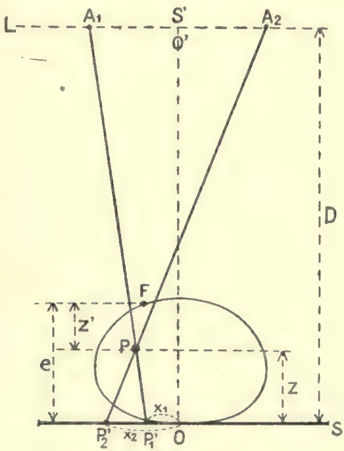



FIG. 155.

measure the thickness $e$ of the member between the two markings and to deduct $Z'$ from $e$: $Z = e - Z'$.

If we wish to have the two other co-ordinates $X$ and $Y$, let us note that the two triangles $O'QP$ and $O'OM$ give:

$$\frac{X}{(x_1+x_2)}=\frac{D-2'}{D} \text{ whence } X=\frac{D-Z'}{D}\;\frac{(x_1+x_2)}{2}=\frac{(500-Z')\,(x_1+x)}{1{,}000}$$

The value of $2'$ being like that of $X$ is immediately deducted from that expression.

We shall have $Y$ in function of $y$ by the same formula:

$$\frac{Y}{y}=\frac{D-Z'}{D} \text{ whence } = Y\frac{(D-Z')}{D}\,y=\frac{(500-2)}{500}\,y$$

In practice we shall of course make use of ready-reckoners.

*The Bertin Sans and Leenhardt Process.*—We can only mention in passing this process, called the process of graduated crosses, as well as the excellent process by Henrard (of Brussels), the ingenious appliances of Mazérès, of Miramond de la Roquette, etc.

*The Belot Method.*—Particularly interesting though

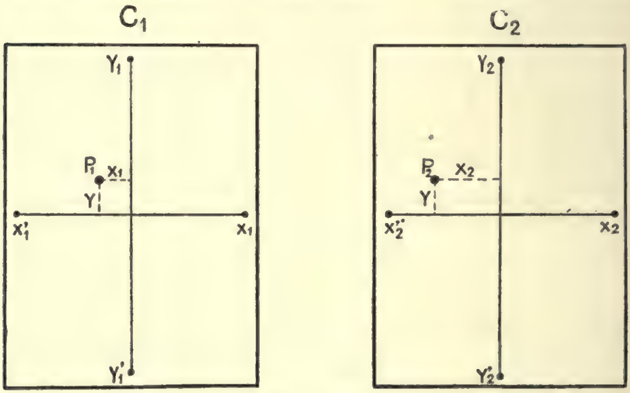
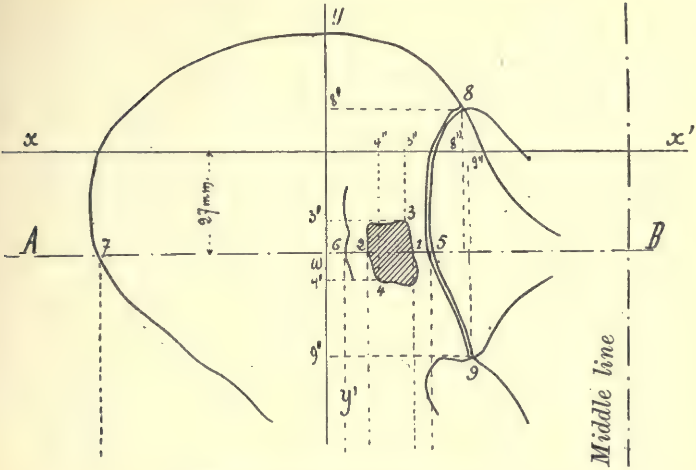



FIG. 156.

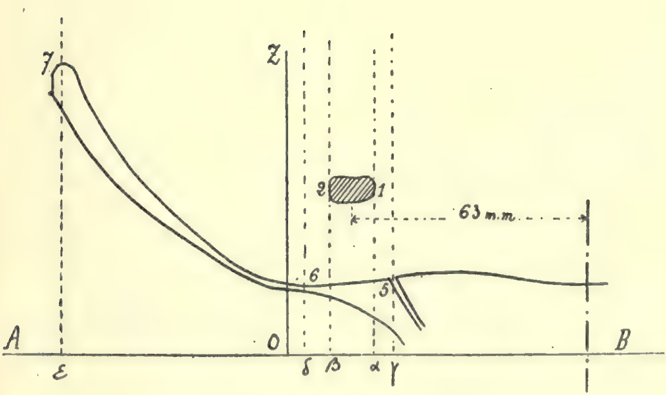
rather complex it indicates a localisation not as is the case with most other methods, in relation to a point on the skin always variable and capable of being depressed but in relation to the bones. This is at the same time an excellent method of anatomical localisation.

It is particularly valuable in certain difficult cases, for instance for projectiles of the sacro-iliac regions or of the iliac fossa, if we wish to know whether they are in front or behind the bone or included in its thickness. It is known that in these cases we may sometimes find ourselves in serious doubt as to the position of the projectile even if we know the exact distance which separates it from the skin.

Fig. 157 shows the instructions supplied say for a shell




*Right iliac fossa (internal)*
*Anterior view*




*Section at level of A B*

FIG. 157.—The Belot Method.

splinter of the right iliac fossa and shows the precise numerical and anatomical details which it is possible to obtain by determining successively the co-ordinates of the various chosen points of the projectile and of the skeleton bones on the diagram. For details of the calculations and for the ready-reckoners we refer the reader to the original article by Belot and Fraudet (*Journal de Radiologie*, 1916, pp. 1–18) as owing to lack of space we cannot, unfortunately, give here all the instructions relating to it or reproduce the ready-reckoners drawn out by the authors.

Process adapted to the regulation of a compass. A certain number of processes based on the method of the double image are essentially intended to be used in combination with some "mechanical guiding" instrument for the surgeon which we have already studied in relation to their modalities which are adapted to the method of intersecting axes (see § 34). The same general considerations may always be applied here. We are going to consider in detail their prototype, the Hirtz compass.

§ 41. **The Hirtz Compass.***—The Hirtz "localising compass" was invented in 1907 and is certainly to-day one of the best known as well as one of the best amongst appliances of a similar kind. The following are the considerations on which it is based (Fig. 158).

Let $R$ be a sensitive plate: to its envelope is attached an index $V'$ on which is centred with a plumb-bob the anticathode of the tube $V$. The region containing the projectile $P$ is placed over the plate.

On the three points $A$, $B$, $C$, conveniently chosen on the skin, there are fixed metal markers. This focus of the tube is successively displaced from $F$ to $F'$ and from each of these points a radiograph is made on the same

* The following works should be consulted on this compass: E. J. Hirtz, "L'examen radiologique des blessés et la recherche des projectiles" (*Achives de Médecine et de Pharmacie militaires*, 1916). Morin et H. Béclère, "Simplification de la construction graphique dans la localisation des projectiles par la méthode du compas de Hirtz" (*Journ. de Rad.* 1916, p. 31). A. Charlier, "Nouveau procédé radiographique pour régler le compas de Hirtz" (*Journ. de Rad.* 1916, p. 43). R. Chaperon et J. Vanderhaeghen, "Contrôleur pour le réglage et localisateur de Hirtz" (*Journ. de Rad.* 1916, p. 46). J. de Poliakoff, "Quelques modifications à la technique de la localisation des corps étrangers à l'aide du compas de Hirtz" (*Achives de Bergonié*, avril 1916, p. 97).

plate *R*. Thus each of the four opaque bodies *P*, *A*, *B*, *C*, will give a double image on the sensitive layer. Knowing the distances *VV′*, *FF′* and those which separate each of the double images we can deduce from this the data for a precise localisation by graphical and numerical means. These data will enable us to regulate the compass so that its "sound" will lead the operator to the foreign body.

This is how we shall proceed practically. Having pre-

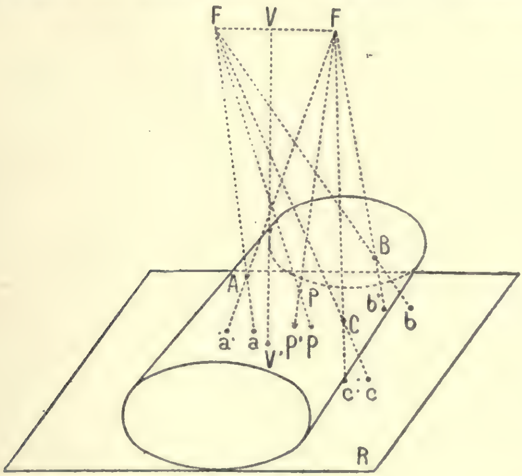



FIG. 158.

viously discovered the foreign body by a radiograph or screen examination and having settled on the surgical route of access after estimating its situation or its depth by a rapid process, we shall proceed as follows:

(*a*) Place on the table a plate of a convenient size enclosed in a paper envelope or in a cassette. The size 18 × 24 or 24 × 30 cm. will generally be sufficient if we use the Blondin tracing board.

(*b*) Fix in the middle of the envelope of the plate or of the cassette a small lead index (say of a triangular form).

(*c*) Centre the anticathode of the tube vertically over this index with the plumb-bob.

(*d*) Place the patient on the table without displacing the plate or the tube in such a way that the point indicating the normal ray and passing through the projectile is directed less to the middle of the plate. The patient must be placed in the position for operation. (The centring stand of Charlier will be very useful for those doing this easily and correctly.)

(*e*) Select and mark three points on the skin. The triangle formed by them circumscribes the track of the normal ray. These points must not be either too near to each other, because in that case they would be much too near to the incision during the operation, or too far, because their image would then project outside the limits of the plate.*

(*f*) The tube is then placed at the desired height, say 60 cm. in every case. It is better to adopt a fixed distance to avoid error. Marks or stereoscopic wedges are placed on the horizontal tube carrier arm at 3 cm. from each side of the position of the tube.

(*g*) Two radiographs are taken on the same plate from two points of the space 6 cm. apart, determined by the markings of the horizontal arm just mentioned.

(*h*) After developing we notice on the plate a simple image for the triangular index, foot of the vertical, and of two conjugated images for the projectile and for each of the three marked balls.

(*i*) Mark the three cutaneous points (tattooing).

*Interpretation of the Plate. Drawing the Graph.*—(*a*) When the plate is dry mark with an ink spot the centres of the triangular index, the images of the marking balls and those of the foreign body.

* The tracing boards of Blondin greatly facilitate this placing in position on the plate. They consist of a series of frames traced on a rigid sheet of a transparent substance. The sheet is placed in contact with the skin, the borders kept parallel with those of the plate and the centre of the frames marked by a cross is brought directly under the plumb-bob denoting the vertical line from the anticathode. Those of the frames are chosen (they are made for varying heights differing by 5 cm. above the plate) which correspond to the thickness of the region.

It is then easy to make the localising marks on the skin. Under these conditions we are sure that the maximum sensitive surface will be used whilst the triangle formed by the markings will have the largest possible extent. On each marking point rests the lead ball which terminates the leg of the uprights supplied with each compass.

(*b*) Spread on the plate a sheet of transparent paper and copy the different points appearing on it. We obtain thus (Fig. 159) the points $O$ (index), $pp'$ (projectile), $aa'$, $bb'$, $cc'$ (markings).

(*c*) Draw through the point $O$ a parallel to the directions $aa'$, $bb'$, $cc'$, and mark $F$ and $F'$ at 3 cm. on each side of $O$. $F$ and $F'$ represent the horizontal projection of the anticathode in its two successive positions.

Join up in each group of the conjugated images the right image to the left focus and *vice versa* (for instance $b$ to $F'$ and $b'$ to $F$). The intersections of these lines give the points 1, 2, 3 for the markings and $P$ for the projectile, which are the horizontal projections we are trying to find.

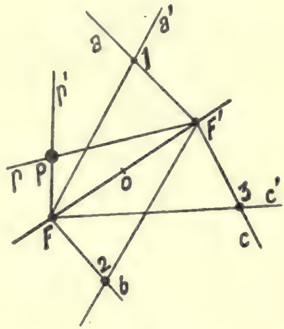


FIG. 159.

(*d*) Originally the method included the execution of another diagram giving the vertical projections of the different points in which we are interested (Fig. 160).

It is more convenient to use the simplified method described both by Henry Béclère and Morin and by Charlier which suppresses this second diagram. This method is as follows: Measure with a graduated ruler the distances $pp'$, $aa'$, $bb'$, $cc'$, which correspond to the distances between the conjugated images, and read off on a numerical table, previously made out and supplied by the manufacturer opposite the corresponding numbers the heights of the different points $P$, 1, 2, 3 above the horizontal plane (plane of the plate).

There is in existence a table calculated for the height of the anticathode of 60 cm. and another one for a height of 50 cm. It may also be replaced by a small graduated ruler supplied by the manufacturer which gives by direct reading the height of a point in terms of the distance between these two images.

(*e*) Deduct (algebraically) the number which expresses the height of *P* (projectile) successively from those which correspond to the heights of the points 1, 2, 3 (markings). The differences are noted: they are those which will be used for the regulating of the compass for the depth.

*The Compass and its Regulation.*—The compass shown in Fig. 151 consists of three branches 1, 2, 3 turning round a common axis *O* in which is held by friction a rod *S* or a localising sound having fixed stop *r*. On each branch there glides a cursor traversed perpendicularly to the plane of the three branches by a rod on which is traced, starting from zero, a double graduation in millimeters. The cursors and their rods can be fixed in any position by binding screws. A thumb-nut placed at the lower part of the axis of the compass enable the branches to be fixed in a good position.

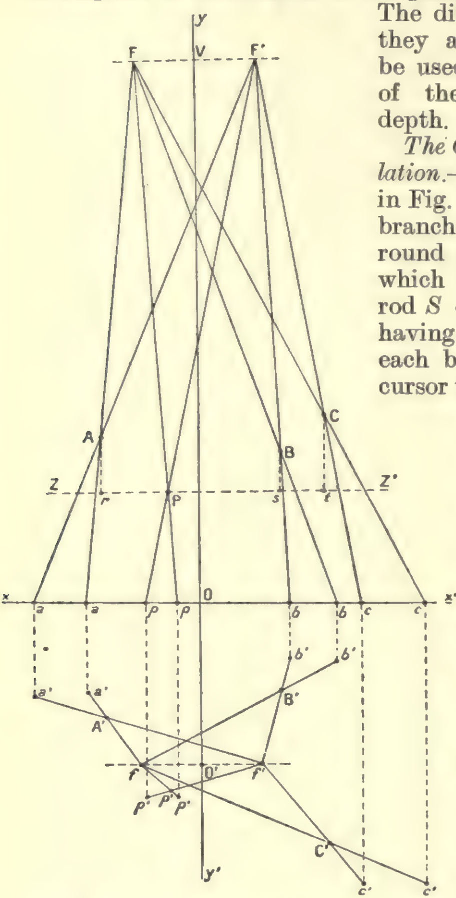



FIG. 160.—The Hirtz diagram, according to the first not simplified method.

Round the axis of the compass there also turns an arc *d* on which also slides a cursor pierced by a hole in which the sound is held by friction. When the sound is in the central position it traverses the cursor of the arc and also the axis of the compass. If the cursor is displaced on the arc the sound will take an inclined position $S'$.

*Regulation of the Compass.*—(*a*) Place the sound in a median position; bring the zero of each graduated rod flush with the upper surface of the corresponding cursor; unscrew the thumb-nut which frees the branches.

**Depth Scale by MM. MORIN and Henri BÉCLÈRE.**

| Distance from centre of radiation...... 600 m/m.<br>Lateral displacement ........................ 60 m/m. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Shift | Depth | Shift | Depth | Shift | Depth | Shift | Depth | Shift | Depth |
| m/m | m/m | m/m | m/m | m/m | m/m | m/m | m/m | m/m | m/m |
| 1 | 10 | 11 | 93 | 21 | 155,5 | 31 | 204,5 | 41 | 243,5 |
| 1,5 | 14,5 | 11,5 | 96,5 | 21,5 | 158,5 | 31,5 | 206,5 | 41,5 | 245,5 |
| 2 | 19,5 | 12 | 100 | 22 | 161 | 32 | 208,5 | 42 | 247 |
| 2,5 | 24 | 12,5 | 103,5 | 22,5 | 163,5 | 32,5 | 211 | 42,5 | 249 |
| 3 | 28,5 | 13 | 107 | 23 | 166,5 | 33 | 213 | 43 | 250,5 |
| 3,5 | 33 | 13,5 | 110 | 23,5 | 169 | 33,5 | 215 | 43,5 | 252 |
| 4 | 37,5 | 14 | 113,5 | 24 | 171,5 | 34 | 217 | 44 | 254 |
| 4,5 | 42 | 14,5 | 117 | 24,5 | 174 | 34,5 | 219 | 44,5 | 255,5 |
| 5 | 46 | 15 | 120 | 25 | 176,5 | 35 | 221 | 45 | 257 |
| 5,5 | 50,5 | 15,5 | 123 | 25,5 | 179 | 35,5 | 223 | 45,5 | 258,5 |
| 6 | 54,5 | 16 | 126,5 | 26 | 181,5 | 36 | 225 | 46 | 260,5 |
| 6,5 | 58,5 | 16,5 | 129,5 | 26,5 | 184 | 36,5 | 227 | 46,5 | 262 |
| 7 | 62,5 | 17 | 132,5 | 27 | 186 | 37 | 229 | 47 | 263,5 |
| 7,5 | 66,5 | 17,5 | 135,5 | 27,5 | 188,5 | 37,5 | 230,5 | 47,5 | 265 |
| 8 | 70,5 | 18 | 138,5 | 28 | 191 | 38 | 232,5 | 48 | 266,5 |
| 8,5 | 74,5 | 18,5 | 141,5 | 28,5 | 193 | 38,5 | 234,5 | 48,5 | 268 |
| 9 | 78,5 | 19 | 144,5 | 29 | 195,5 | 39 | 236,5 | 49 | 269,5 |
| 9,5 | 82 | 19,5 | 147 | 29,5 | 198 | 39,5 | 238 | 49,5 | 271 |
| 10 | 85,5 | 20 | 150 | 30 | 200 | 40 | 240 | 50 | 272,5 |
| 10,5 | 89,5 | 20,5 | 153 | 30,5 | 202 | 40,5 | 242 | | |

(*b*) Place the graph traced on transparent paper on a small drawing-board. Place the point of the localising sound-line on the horizontal projection $P$ (Fig. 159) of the foreign body, then bring the extremities of each of the rods on the points 1, 2, 3; projections of the three marking balls; fix the binding screws of the cursors and the thumb-nut. In order to facilitate this regulating it would be convenient to use the special drawing pins invented by Chaperon. They are fixed on the points $P$, 1, 2, 3 and present notches which immediately stop the different rods of the compass in the correct position.

(*c*) In order to regulate the depth the three rods of the compass should be respectively shortened or lengthened by the number of millimeters found to represent the difference between the height of each mark and the height of the projectile above the plate. The compass is then ready for the operation which is given in Chapter XIII.

The patient is brought into the operating theatre and placed on the table in the position in which he has been radiographed. This condition is not absolutely imperative; because what we are trying to obtain is the concordance of the markings traced on the skin of the wounded with the extremities of the three rods of the compass. As soon as this condition has been brought about, the localisation is correct and the localising sound lowered touches the skin at a point *i* (Figs. 161 and 162). The distance which separates the stop *r* from the upper surface of the cursor *o* indicates the depth of the foreign body. It will be necessary for the sound to penetrate the tissues to that depth so that its point may come into contact with the object we are looking for.

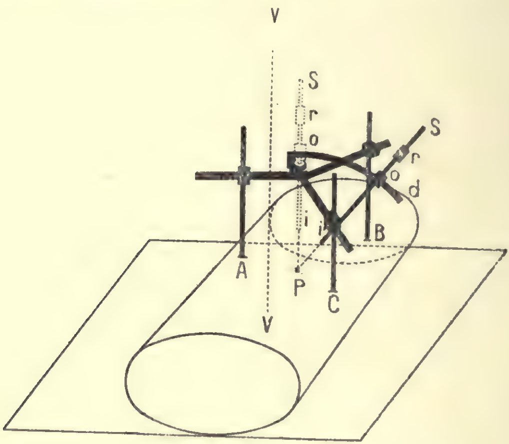



FIG. 161.

If for any reason the incision cannot be made at the point *i*, the sound is placed in a convenient oblique position by letting the cursor slide on the arc (Fig. 162). As this arc itself turns round the axis of the compass we can easily see that the sound can take instantaneously an infinity of different positions, without having to make a new regulation. Still in all these positions its point will find the projectile because its length determined by the fixed abutment *r* is such that it represents exactly a ray of the circumference from which the arc has been taken.

The Compass includes two arcs, a short one (Fig. 163) and a long one (Fig. 162) which enable the sound to be deviated up to 90° from its vertical position of regulation.

The use of the arc has this essential peculiarity, an

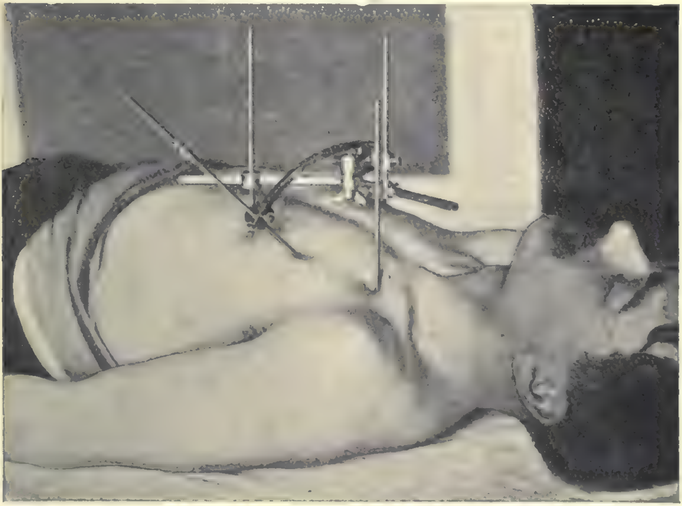


Fig. 162.—The Hirtz compass placed into position before the operation by utilising the large arc. (Plate by Dr. Henri Béclère.)

original characteristic of the Hirtz compass, in that it enables us to carry out the guiding on the lateral regions of the trunk, also to deviate from localisations made in an antero-posterior direction or inversely, and to leave the patient in a lying position.*

Used in its new and simplified form the localisation by the Hirtz method requires at an average from 30 to

* If we wish to use the compass with a tube placed under the table we use a special board called centring board.

40 minutes * and this time is greatly shortened if it is possible to undertake a series of localisations.

Nevertheless, we consider that this time taken is too long to enable this method to be generally adopted in its radiographic form in war radiology. Moreover, the plate obtained cannot generally be used from the radiodiagnostic standpoint.

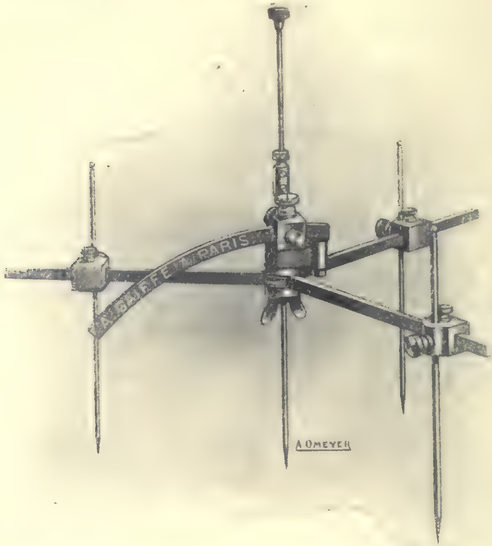


FIG. 163.—The Hirtz compass and its little arc.

We therefore much prefer radioscopic localisations by means of any of the rapid processes already described, and the taking of a simple plate for diagnostic purposes only, if it is a difficult case. If however it is absolutely desired to have a radiographic localisation, we should use a process of two separated images, say one of those which supply stereoscopic images like the Richard processes, Paris, etc. (see Chapter X). The compass should be regulated according to these plates. Although it does not offer us the most perfect method of extraction (see Chapters XII,

* *Arch. Electr. Méd.*, March 1915, p. 110.

XIII, XIV) it is at least in our opinion, and in view of the absence of the possibility of using the intermittent control of the screen under good conditions, one of the best mechanical guiding instruments.

It seems to us moreover by far more practical to undertake its regulating exclusively by radioscopic means. The simplest form after having marked the three cutaneous marking points consists in measuring directly their distance from the plane of the table by means of a compass and in marking the projectile radioscopically. It is then easy to regulate the compass. This regulating gives then a precision within a few millimeters which in practice does not differ from the results obtained by the radiographic process in view of the multiple causes of error which always intervene and prevent that absolute precision which is theoretically possible.

M. Hirtz has however himself described a process of regulating his compass radioscopically by means of his ingenious appliance of the pierced screen. The patient lies still in the position for operation, the projectile is localised, thereupon the extremity of the localising sound *S* of the compass is brought to the point *O* the exit of the normal ray marked previously at the moment of localisation (Fig. 164). The three points of the compass are placed on points *A*, *B*, *C* chosen, circumscribing *O* and in such a way that the direction of the sound *S* is practically vertical. The apparatus is thereupon mobilised by loosening the screw, until the spirit level of the sound shows that it is vertical and coincides consequently with

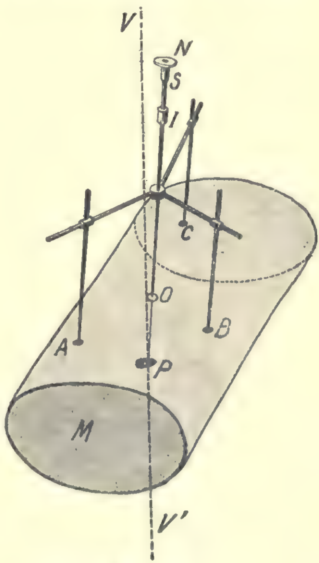


FIG. 164.

the normal ray. The screw is then made fast and the points $A$, $B$, $C$ are definitely marked on the skin. As the depth of the projectile is known from the screen examination, the index $I$ carried by the sound $S$ is moved away from the centre $B$ by a quantity $DI$ equal to that depth, the regulating is then effected and the operation may be undertaken.

This process gives only the guidance for the vertical. In order to be able to use the arc it will be sufficient to shorten the length of each of the surrounding rods by a distance equal to the depth of the projectile.

Mr. Aimé uses the pierced screen in a somewhat different way by determining radioscopically the height of the ball-markers above the table and by regulating the compass on them as usual. He has introduced some slight modifications in the pierced screen of Hirtz-Gallot which still more facilitate its use for this regulation. Let us point out that the skiameter and bathymeter can be used perfectly well to regulate the Hirtz compass, a process which in our opinion will more and more supplant the radiographic method, in view of its suitability. We would therefore advise those who have to make use of that compass to have recourse to it.

After these detailed descriptions we can review the other appliances very rapidly.

*The Marion-Danion Marker.**—This instrument really consists of two parts; one part is a localising apparatus (proper) of the cross-wire type, of which the Mackenzie-Davidson type apparatus represents a practical and well-known form, reproduced almost identically by Messrs. Marion-Danion (compare Figs. 154 and 165); the other part is a " compass " added to this apparatus.

The marker gives the position of the projectile in relation to two marking points on the skin. It is regulated by means of two radiographs made on the same plate by materialising in space by two threads the two rays which supply the two projections of the projectile in the course

* See Marion, *The Localisation of Foreign Bodies with the Marion-Danion Localiser* (Paris, Marétheux, 1915); Marion, *Chirurgie de guerre* (Paris, Maloine, 1916); Weber, *Thèse de Paris* (1915); Charlier, " Le repéreur Marion-Danion " (*Journal de Radiologie*, 1915, p. 774).

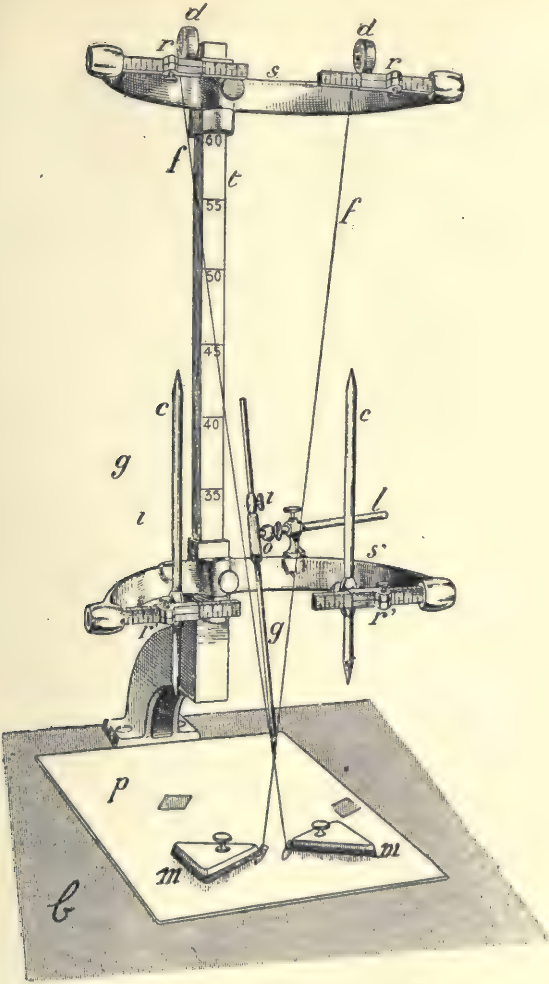



FIG. 165.—The Marion-Danion marker.

of two successive radiographs. It is then sufficient to bring the extremity of the indicating rod to the intersection

15

point of the two threads to enable the compass to be utilised.

This apparatus which can give excellent results when used by a good surgeon is very attractive owing to the facility with which its regulating can be understood. Its use is perhaps a little easier and less meticulous than that of Hirtz, but although it shares the other inconveniences of the latter it does not give the same facilities for operation (it has only two marking points and does not possess the large curved branch). It is cumbrous and expensive and does not seem to have come into general use. A similar simplified and much less expensive apparatus has been devised by Jallot.

*The Aubourg Operation Indicator* * (Gallot, manufacturer). —Being anxious to place at the disposal of radiologists an instrument which would enable them to ensure, whatever the radioscopic localisation method used, that the surgeon has a guiding rod during the operation, Aubourg designed at the beginning of the war an apparatus which materialises the path of the normal ray.

But as the surgeon wishes sometimes to have another way of access, this first apparatus has been modified with the collaboration of A. Lavialle, permitting the use of any route. It is possible with the aid of this instrument to introduce a curette or forceps into the wound and to obtain contact with the projectile. Figs. 166 and 167 give an idea as to the manner in which it is used.

In this respect we may point out that some authors have advocated, especially in England, the use of "operation indicators" regulated at the very moment of the operation carried out on the X-ray table, and which can be again regulated by radioscopic control during the operation. A somewhat similar appliance has been introduced in the ninth region by Mr. Maillard.

Owing to lack of space and to the fact that we have not or only insufficiently experimented with them we shall only mention other appliances such as those of Messrs. Loro, Buffon and Ozil, of Mr. Luzoir, of Mr. Masson (d'Oran), etc.

§ 42. **Localisation by means of a Tube with a Double Anticathode.**—It is evident that instead of using the two

* Lavialle, "Description technique de l'indicateur opératoire d'Aubourg" (*Journal de Radiologie*, 1916, p. 40).

shadows supplied by a displacement of the tube for

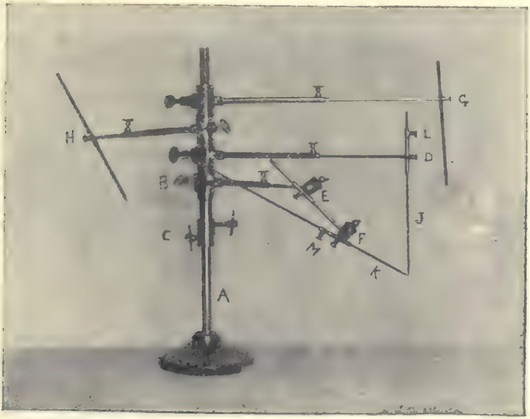



FIG. 166.—The Aubourg operation indicator with all its pieces for using either a vertical or oblique route of access.

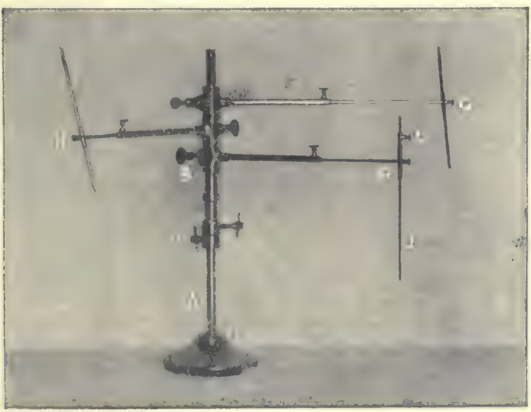


FIG. 167.—The Aubourg operation indicator with the pieces for using a vertical route of access only. (The pieces for the oblique access have been taken away.)

localising, it would be possible to make use of two different radiation sources from two different tubes.

*The Mergier Process* *.—This author seems to have been the first one to describe in 1898 this method. He used two Crookes tubes, the anticathodes of which were placed at a known distance from a fluorescent screen provided with an intersection of metal wires and worked by always using either radioscopically or radiographically the classical equation (p. 147).

The diagram in Fig. 168 which reproduces his apparatus from a figure which appeared in April 1898 in the journal *La Nature* is at first sight rather bewildering to those radiologists who did not go through those heroic times of radiology and they will have some difficulty in recognising the tubes. Mergier also invented a small ruler which made it possible after a very simple materialisation of the path of the rays to read the depth of the projectile directly, and avoid all calculation.

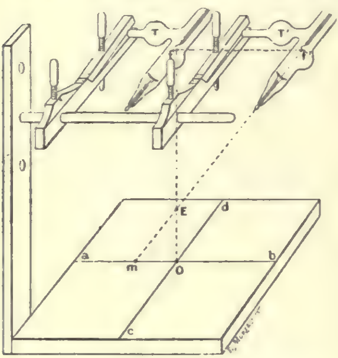



FIG. 168.—The Mergier appliance with two tubes.

In 1899 Warluz and Jollant † also used two distinct tubes and have since added to their method the use of a special compass.

These various authors made their two tubes work only in turn. Later on other experimenters had the idea, in order to take the radiographs with a double pose, to let them start working simultaneously, so that the operation was shortened.

But the difficulties of exciting and regulating a second tube, whether included or not in the same circuit, did not make it possible to solve this problem in a practical way,

* "Mergier in Clerc," *La Nature*, April 30th, 1898.

† Warluz and Jollant, "Recherche des corps étrangers et des points visibles intéressants à l'intérieur des corps perméables aux rayons X Assoc. franc. pour l'Avance des Sciences" (Congrès de Boulogne-sur-Mer, 1899).

and led the experimenters to the conception of a single tube containing two foci : the tube with a double anticathode. Introduced at first in France by Guilloz (Fig. 169), this new type was soon imitated in Germany and an instrument which is now used by our enemies for the determination of the depth of projectiles has been based on its use. This instrument is based on the following considerations. The distance from the two sources (generally the displacement of the tube, here the distance between the two anticathodes) being invariable and known (say 6 cm.) the distance anticathode—screen (or plate) also being invariable and known (say 60

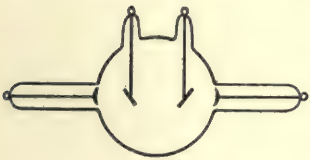


FIG. 169.—Tube with a double anticathode by Guilloz.

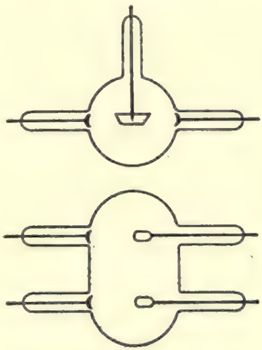


FIG. 170.—Two types of tubes with double anticathode.

cm.) it is, as we have seen, extremely easy to know the distance from the screen—or from the plate—to the projectile by a simple measurement of the distance between the two images. It is therefore easy to design an instrument of a type of a compass with a double opening, constructed say (Fig. 171) in such a way that by measuring between the points $A$ and $B$ the distance between the two homologous points of the two shadows of the projectile we can read in front of the index $I$ carried by the branch $BD$, on a graduation inscribed on an arc of the circle $EH$ carried by the branch $AC$, directly in millimeters, the distance from the projectile to the plate (or to the screen).

In spite of its undeniable convenience the use of tubes with a double anticathode has not become popular in view of the difficulties of their construction, of the usual asymmetry in the working of the two anticathodes and of their rapid heating.

This abandonment of a type of tube which lent itself to multiple and interesting applications, not only from the standpoint of localising projectiles, but also from the radio-stereoscopic standpoint, has induced one of us with Dauvillier to interest M. Pilon in this direction. Fig. 172 shows this remarkable tube with a double anticathode, water cooled, which he was able to construct and we shall explain later on how we have applied it to the localisation and extraction of projectiles.

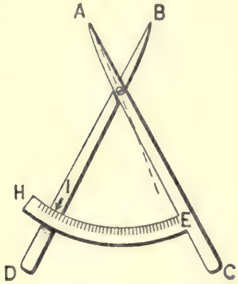



FIG. 171.

§ 43. **Practical Conclusions.**—In order to make our choice with advantage from the rather numerous methods already described by us or mentioned in this and in the preceding chapter, and from the large number which we had to omit either through lack of space or of sufficient documents to be quite familiar with them, it is necessary to consider carefully the object aimed at, the material at our disposal and especially the process of extraction which will be adopted.

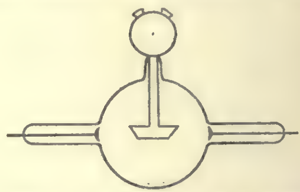


FIG. 172.—Diagram of a tube with double anticathode by Ledoux-Lebard and Dauvillier (Pilon, manufacturer).

Localisation by the method of two axes which intersect has the advantage of being simple, economical and rapid, but very often it lacks precision, and consequently cannot be used in a general way. This can only be used for projectiles of limbs which are to be removed by means of the intermittent control of the screen, or in cases of emergency in certain front line units. We think that it is infinitely preferable to choose, amongst the radioscopic methods based on the displacement of the tube, one of those which are really applicable to all possible cases and which moreover offer, as compared with radiographic processes, considerable advantages of convenience, rapidity and of quite sufficient precision, and in all cases to use the same method of localisation. But according to the region, to the difficulty or to the peculiarity of the case the operator should provide himself with all the necessary information by taking one or more plates, and by using all the necessary complementary examinations. These plates will supply data which will be clearer and more useful than localisation plates by double exposure, which generally have no diagnostic value.

The Haret method which is very simple and which may be applied in all cases and does not necessitate any complicated calculation is greatly to be recommended. The same applies to the process of the pierced screen by Hirtz-Gallot, which is simple, rapid and may be used anywhere (except on board a ship). These processes require only a minimum of special material. Among those which demand a costlier outfit though very slightly more complicated we personally give the preference to the Viallet-Dauvillier method modified by Dessane (Radiobathymeter), as constantly used by one of us in the service at Tours. It is simple, rapid and precise and can be used for all projectiles which can be removed surgically.

With these methods the surgeon who undertakes the extraction aided by the intermittent control of the screen and guided by a professional physician-radiologist is sure to obtain good results. They will also enable the radiologists to regulate their apparatus simply and rapidly when they are working for surgeons who are not in possession of this resource through not having the appropriate apparatus or who use it only as a check, but work with a compass, or finally for those who persist in their method of working and use a mechanical guiding instrument exclusively.

Finally to those who wish to remain absolutely true to radiography alone either from habit or from a fear of cutaneous accidents (a fear which is only justifiable when the radiologist already suffers from marked chronic affection of the skin), or from lack of anatomical and medico-surgical knowledge which does not enable them to use radioscopy without misleading the surgeon, we recommend

GIVING THE DEPTH, THE DISTANCE ANTICATHODE TO SCREEN

DISTANCES ANTICATHODE — SCREEN

COEFFICIENTS

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 38 | 3,8 | 7,6 | 11,4 | 15,2 | 19,0 | 22,8 | 26.6 | 30.4 | 34.2 | 38.0 | 41.8 | 45.6 | 49.4 | 53,2 | 57 | 60.8 |
| 39 | 3.9 | 7,8 | 11,7 | 15.6 | 19,5 | 23.4 | 27.3 | 31,2 | 35.1 | 39.0 | 42.9 | 46,8 | 50.7 | 54.6 | 58,5 | 62,4 |
| 40 | 4,0 | 8.0 | 12,0 | 16.0 | 20,0 | 24.0 | 28.0 | 32,0 | 36.0 | 40.0 | 44,0 | 48.0 | 52,0 | 56,0 | 60 | 64 |
| 41 | 4,1 | 8,2 | 12,3 | 16.4 | 20.5 | 24,6 | 28,7 | 32,8 | 36,9 | 41,0 | 45,1 | 49,2 | 53,3 | 57.3 | 61,5 | 65,6 |
| 42 | 4,2 | 8,4 | 12,6 | 16,8 | 21,0 | 25.2 | 29,4 | 33,6 | 37,8 | 42,0 | 46,2 | 50.4 | 54,6 | 58.7 | 63 | 67.2 |
| 43 | 4.3 | 8,6 | 12,9 | 17,2 | 21.5 | 25,8 | 30,1 | 34,4 | 38,7 | 43,0 | 47.3 | 51,6 | 55,9 | 60.2 | 64.5 | 68,8 |
| 44 | 4,4 | 8.8 | 13.2 | 17.6 | 22,0 | 26,4 | 30.8 | 35.2 | 39.6 | 44,0 | 48,4 | 52,8 | 57.2 | 61.6 | 66 | 70,4 |
| 45 | 4.5 | 9,0 | 13,5 | 18,0 | 22,5 | 27.0 | 31,5 | 36,0 | 40,5 | 45.0 | 49,5 | 54,0 | 58.5 | 63.0 | 67,5 | 72 |
| 46 | 4,6 | 9,2 | 13,8 | 18,4 | 23,0 | 27,6 | 32,2 | 36.8 | 41,4 | 46.0 | 50.6 | 55.2 | 59,8 | 64,4 | 69 | 73.6 |
| 47 | 4,7 | 9,4 | 14,1 | 18.8 | 23,5 | 28,2 | 32,9 | 37,6 | 42,3 | 47,0 | 51,7 | 56,4 | 61,1 | 65,8 | 70.5 | 75,2 |
| 48 | 4,8 | 9,6 | 14,4 | 19.2 | 24,0 | 28,8 | 33,6 | 38,4 | 43,2 | 48.0 | 52,8 | 57,6 | 62.4 | 67,2 | 72 | 76,9 |
| 49 | 4,9 | 9,8 | 14,7 | 19,6 | 24.5 | 29,4 | 34.3 | 39,2 | 44,1 | 49.0 | 53,9 | 58,8 | 63.7 | 68.6 | 73.5 | 78.4 |
| 50 | 5,0 | 10,0 | 15,0 | 20,0 | 25,0 | 30,0 | 35,0 | 40,0 | 45,0 | 50.0 | 55,0 | 60.0 | 65,0 | 70,0 | 75 | 80 |
| 51 | 5,1 | 10,2 | 15,3 | 20,4 | 25,5 | 30.6 | 35.7 | 40.8 | 45,9 | 51,0 | 56.1 | 61.2 | 66.3 | 71,4 | 76,5 | 81,6 |
| 52 | 5,2 | 10.4 | 15,6 | 20.8 | 26,0 | 31,2 | 36,4 | 41,6 | 46.8 | 52,0 | 57.2 | 62,4 | 67,7 | 72,8 | 78 | 83,2 |
| 53 | 5,3 | 10,6 | 15,9 | 21.2 | 26.5 | 31,8 | 37,1 | 42,4 | 47.7 | 53,0 | 58,3 | 63,6 | 63,9 | 74,2 | 79.5 | 84.8 |
| 54 | 5.4 | 10.8 | 16.2 | 21,6 | 27,0 | 32.4 | 37.8 | 43,2 | 48.6 | 54,0 | 59,4 | 64.8 | 70.2 | 75,6 | 81 | 86,4 |
| 55 | 5,5 | 11,0 | 16,5 | 22,0 | 27.5 | 33,0 | 38,5 | 44,0 | 49,5 | 55.0 | 60.5 | 65.0 | 71,5 | 77,0 | 82,5 | 88 |
| 56 | 5,6 | 11 2 | 16.8 | 22,4 | 28.0 | 33 6 | 39,2 | 44,8 | 50,4 | 56,0 | 61,6 | 67,2 | 72.8 | 78,4 | 84 | 89,6 |
| 57 | 5,7 | 11,4 | 17,1 | 22,8 | 28,5 | 34,2 | 39.9 | 45,6 | 51,3 | 57.0 | 62.7 | 68.4 | 74,1 | 79.8 | 85.5 | 91.2 |
| 58 | 5,8 | 11,6 | 17,4 | 23,2 | 29,0 | 34,8 | 40,6 | 46,4 | 52,2 | 58,0 | 63,8 | 69,6 | 75,4 | 81,2 | 87 | 92,8 |
| 59 | 5,9 | 11,8 | 17,7 | 23,6 | 29.5 | 35,4 | 41,3 | 47,2 | 53,1 | 59,0 | 64,9 | 70.8 | 76.7 | 82,6 | 88.5 | 94,4 |
| 60 | 6,0 | 12,0 | 18,0 | 24,0 | 30,0 | 36,0 | 42,0 | 48,0 | 54,0 | 60,0 | 66,0 | 72,0 | 78,0 | 84.0 | 90 | 96 |
| 61 | 6,1 | 12,2 | 18.3 | 24,4 | 30,5 | 36,6 | 42.7 | 48,8 | 54,9 | 61,0 | 67,1 | 73.2 | 79,3 | 85.4 | 91,5 | 97.6 |
| 62 | 6,2 | 12,4 | 18,6 | 24,8 | 31,0 | 37.2 | 43,4 | 49,6 | 55,8 | 62,0 | 68.2 | 74.4 | 80.6 | 86.8 | 93 | 99 2 |
| 63 | 6,3 | 12,6 | 18,9 | 25,2 | 31.5 | 37,8 | 44,1 | 50.4 | 56,7 | 63,0 | 69,3 | 75,6 | 81.9 | 88.2 | 94,5 | 101 |
| 64 | 6,4 | 12,8 | 19,2 | 25,6 | 32,0 | 38,4 | 44.8 | 51,2 | 57,7 | 64,0 | 70.4 | 76,8 | 83,2 | 89,6 | 96 | 102,5 |
| 65 | 6.5 | 13,0 | 19,5 | 26,0 | 32,5 | 39,0 | 45.5 | 52,0 | 58,5 | 65,0 | 71,5 | 78,0 | 84,5 | 91,0 | 97,5 | 104 |
| 66 | 6,6 | 13,2 | 19,8 | 28 4 | 33,0 | 39,6 | 46.2 | 52.8 | 59,4 | 66.0 | 72,6 | 79,2 | 85,8 | 92,4 | 99 | 105,5 |

This table, primarily intended for use with the skiameter, can also be used with the image, including the radioscopic

AND THE COEFFICIENT OF MAZÉRÈS SCALE BEING KNOWN.

COEFFICIENTS

| | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 38 | 64.5 | 68.5 | 72 | 76 | 80 | 83,5 | 87,5 | 91 | 95 | 99 | 102,5 | 106 | 110 | 114 | 118 | 121.5 | 125.5 |
| 39 | 66.2 | 70.2 | 74 | 78 | 82 | 85,7 | 89,5 | 94 | 97.5 | 101,5 | 105 | 109 | 113 | 117 | 121 | 124.5 | 129 |
| 40 | 68 | 72 | 76 | 80 | 84 | 88 | 92 | 96 | 100 | 104 | 108 | 112 | 116 | 120 | 124 | 128 | 132 |
| 41 | 69.7 | 74 | 78 | 82 | 86 | 90 | 94 | 98,5 | 102.5 | 106,5 | 110,5 | 115 | 119 | 123 | 127 | 131 | 135 |
| 42 | 71.4 | 75,5 | 80 | 84 | 88 | 92 | 96,5 | 101 | 105 | 109 | 113 | 117,5 | 122 | 126 | 130 | 134 | 138,5 |
| 43 | 73,1 | 77,5 | 81.5 | 86 | 90.2 | 94.5 | 99 | 103 | 107.5 | 112 | 116 | 120 | 125 | 129 | 133 | 137,5 | 142 |
| 44 | 74,8 | 79,2 | 83,5 | 88 | 92.5 | 97 | 101 | 105,5 | 110 | 114 | 119 | 123 | 127.5 | 132 | 136 | 140.5 | 145 |
| 45 | 76.5 | 81 | 85,5 | 90 | 94.5 | 99 | 103.5 | 108 | 112.5 | 117 | 121,5 | 126 | 130,5 | 135 | 139.5 | 144 | 148,5 |
| 46 | 78.2 | 83 | 87,5 | 92 | 96.5 | 101 | 106 | 110 | 115 | 120 | 124 | 129 | 133,5 | 138 | 142,5 | 147 | 152 |
| 47 | 80 | 84.5 | 89 | 94 | 98.7 | 103,5 | 108 | 113 | 117,5 | 122 | 127 | 131,5 | 136.5 | 141 | 145,5 | 150 | 155 |
| 48 | 81.5 | 86.5 | 91 | 96 | 100.6 | 105,5 | 110 | 115 | 120 | 125 | 129,5 | 134,5 | 139 | 144 | 149 | 153.5 | 158,5 |
| 49 | 83,2 | 88,2 | 93 | 98 | 103 | 108 | 112,5 | 118 | 122,5 | 127 | 132 | 137 | 142 | 147 | 152 | 157 | 162 |
| 50 | 85 | 90 | 95 | 100 | 105 | 110 | 115 | 120 | 125 | 130 | 135 | 140 | 145 | 150 | 155 | 160 | 165 |
| 51 | 86.7 | 92 | 97 | 102 | 107 | 112 | 117 | 122,5 | 127 | 132,5 | 137,5 | 143 | 148 | 153 | 158 | 163 | 168 |
| 52 | 88,3 | 93,5 | 99 | 104 | 109 | 114,5 | 119,5 | 125 | 130 | 135 | 140 | 145,5 | 151 | 156 | 161 | 166 | 172 |
| 53 | 90 | 95,5 | 100,5 | 106 | 111 | 116.5 | 122 | 127 | 132,5 | 138 | 143 | 148 | 154 | 159 | 164 | 169.5 | 175 |
| 54 | 91,8 | 97 | 102.5 | 108 | 113 | 119 | 124 | 130 | 135 | 140 | 146 | 151 | 156,5 | 162 | 167 | 172,5 | 178 |
| 55 | 93,5 | 99 | 104.5 | 110 | 115 | 121 | 126,5 | 132 | 137,5 | 143 | 148,5 | 154 | 159.5 | 165 | 170.5 | 176 | 181,5 |
| 56 | 95,2 | 101 | 106,5 | 112 | 117,5 | 123 | 129 | 134,5 | 140 | 145.5 | 151 | 157 | 162,5 | 168 | 173,5 | 179 | 185 |
| 57 | 97 | 102,5 | 108 | 114 | 119.5 | 125,5 | 131 | 137 | 142,5 | 148 | 154 | 160 | 165.5 | 171 | 177 | 182 | 188 |
| 58 | 98,5 | 104.5 | 110 | 116 | 122 | 127.5 | 133.5 | 139 | 145 | 151 | 156.5 | 162,5 | 168 | 174 | 180 | 185,5 | 191.5 |
| 59 | 100,5 | 106 | 112 | 118 | 124 | 130 | 136 | 142 | 147,5 | 153,5 | 159 | 165 | 171 | 177 | 183 | 188,5 | 195 |
| 60 | 102 | 108 | 114 | 120 | 126 | 132 | 138 | 144 | 150 | 156 | 162 | 168 | 174 | 180 | 186 | 192 | 198 |
| 61 | 103,6 | 110 | 116 | 122 | 128 | 134 | 140 | 146 | 152,5 | 158,5 | 164,5 | 171 | 177 | 183 | 189 | 195 | 201 |
| 62 | 105.5 | 111,5 | 118 | 124 | 130 | 136 | 142.5 | 149 | 155 | 161 | 167 | 173,5 | 180 | 186 | 192 | 198 | 205 |
| 63 | 107 | 113.5 | 120 | 126 | 132 | 138.5 | 145 | 151 | 157,5 | 164 | 170 | 176 | 183 | 189 | 195 | 201 | 208 |
| 64 | 109 | 115 | 121,5 | 128 | 134 | 141 | 147 | 154 | 160 | 166.5 | 173 | 179 | 185,5 | 192 | 198 | 204 | 211 |
| 65 | 110.5 | 117 | 123.5 | 130 | 136.5 | 143 | 149.5 | 156 | 162.5 | 169 | 175 | 182 | 188,5 | 195 | 202 | 208 | 214 |
| 66 | 112 | 119 | 125,5 | 132 | 138.5 | 145 | 152 | 158.5 | 165 | 172 | 178 | 185 | 191.5 | 198 | 204 | 211 | 218 |

bathymeter and for all radioscopic procedures depending on the displacement of the regulation of the compass.

any of the methods with exposures on two different plates (see Chapter X).

As a mechanical guiding instrument we recommend preferably the Hirtz compass without however wishing to in any way detract from the merits of other instruments.

Finally for especially difficult cases in which the localisation of the projectile in relation to the bone may be difficult and plays an important part in the choice of the way of access as well as in the success, rapidity and facility of operations the Belot method should be used.

It must not be forgotten however that the best method is always the one which we know best.

After making the localisation of a projectile we must note the results obtained as well as the position of the patient when it was done. Special forms are very useful for this purpose. Those used by us are of a different colour (blue) from the ordinary radiographic forms (white); at the top they have a frame containing general indications similar to those reproduced in the form on p. 126, and at the bottom the particulars given on p. 234, taken partially from the form made out by Viallet in the fourth region.

We reproduce on the previous page the Dauvillier ready-reckoner which is useful for all processes of localisation which use the method of the double image, and especially for radioscopic methods as well as the skiameter and bathymeter.

## RADIOLOGICAL LOCALISATION FORMS

A shrapnel bullet
A rifle bullet
A shell fragment (approximate dimensions:)
is lodged in the soft / osseous parts under the right / left surface of:

A point has been marked on the skin. The projectile is situated at millimeters below that point.

The position of the wounded during the radioscopic localisation:
Ventral
Dorsal
Left lateral.

The decubitus was right lateral.
Indication of accessory positions:
Particular remarks:
Result of Operation: Operated upon at
by Mr.

Of course this form may be easily modified as desired according to the process used.

## CHAPTER X

### RADIO-STEREOSCOPY

§44. It is only natural that the idea should be entertained of applying to radiography the very attractive advantages of stereoscopy. Messrs. Imbert & Bertin Sans (of Montpellier) appear to have been the first to make practical application of this principle in March 1896, whilst Messrs. Marie & Ribaut endeavoured to determine geometrically the rules of accurate radio-stereoscopy in accordance with the data established by Cazes in a series of highly interesting memoirs. They have shown how they thought it possible to measure distances by means of stereoscopic radiography and have published the description of a stereometer.

Since their time nearly every radiologist interested in this branch of the science has added something to the technique and has proclaimed its advantages. We need only mention the works of Messrs. Aubourg & Galezoski and of M. Béclère in France and also those of Sir James Mackenzie-Davidson in England. In spite of the justifiable enthusiasm felt by every radiologist for the incomparable beauty of stereoscopic reproductions, it does not appear that the art has been developed in this country to the extent it deserves. At a time when in the United States it was being applied almost systematically to every radiographic examination, the art of stereoscopy was still during the period before the war in its infancy in France; since then however, it has not escaped being rediscovered by a certain number of neophytes, who, without the knowledge of previous research and of the theoretical and practical objections to which it is susceptible, desired to apply it indiscriminately to the localisation of all foreign bodies.

We cannot think of explaining here, however briefly, the theory of stereoscopic vision, and we must refer those who desire to study the subject to the works already mentioned. We will content ourselves with pointing out that the essential principle of binocular vision is that of the perception of relief experienced when each eye receives an image (and a different image) of the same object. The appreciation of relief and of distances between objects depends upon the psychical interpretation of two different luminous impressions based upon education and habit.

Generally speaking, the problem of stereoscopic photography and radiography lies chiefly in obtaining two images of the object, or set of objects, which are to be reproduced in relief, each image corresponding to that of one eye. If arrangements are made, so that the image corresponding to the right eye is clearly seen by that eye, and the image corresponding to the left eye by the other eye, then the sensation experienced is that of appreciation of relief in those persons who possess stereoscopic vision, and although

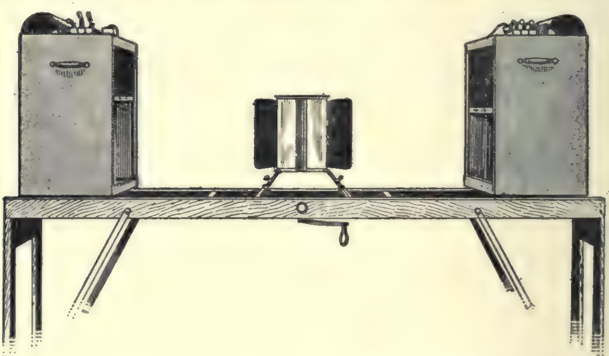


FIG. 173.—Wheatstone Stereoscope.

the two images are dissimilar and not capable of being superimposed one on the other, they will still give the impression of one single object.

Inventors have therefore devoted themselves to the exact reproduction of these retinal images.

In order to obtain these images photographers use two cameras coupled together and provided with identical lenses, the main axes of which are parallel; the distance between the two lenses corresponds in general to the mean distance between the eyes, that is to say 7 centimeters. By using one camera only, which can be moved to a distance of 7 centimeters in a horizontal line perpendicular to its main axis, one would evidently obtain the same result.

A similar process is observed in stereoscopic radiography, but, instead of a lens, in this case a tube is employed. By moving this tube to the right and to the left in succession two images, *i.e.* radiographs, are obtained, viz. a right and left image.

However, this displacement of the tube the distance required and the changing of the plate, which must be executed without causing the slightest movement of the portion radiographed (the change being always perpendicular to its main axis), is a delicate operation which takes the operator some time to effect. It has therefore been proposed to construct foot levers to displace the tube automatically after the first exposure and also to arrange frames provided with an automatic release and with a changing device which will simultaneously substitute the second negative for the first. Americans, especially Lester Leonard Case and Pfahler, have been able to obtain by these technical means marvellous stereoscopic radiographs of the viscera, the two exposures and all details of which have been carried out within a total period of one to two seconds at the most.

With the object of simplifying this work and doing away with the necessity of displacement of the tube and replacing it by a change of connections, use has also been made of double anticathodal tubes, which we have already mentioned in the previous chapter. However, their use has, so far, not become general on account of certain technical difficulties attending their construction.

In order to examine the two negatives obtained, so as to give the impression of relief, they should be viewed either by means of the Wheatstone stereoscope (Fig. 173), or the stereoscope by M. Hirtz (Fig. 174); or, if time is no object, reductions can be made, which can then be simply examined by means of one of the small hand stereoscopes described as "Mexican." These are highly to be recommended, as they are not only easy to operate but are also very inexpensive.

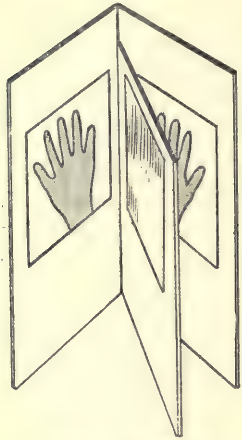


Fig. 174.—Hirtz Stereoscope.

In some cases stereoscopes of the type introduced by the Canadian radiologist Pirie are employed. In appearance and size they resemble pocket binoculars, and permit of a direct examination of two stereoscopic radiographs placed next to each other on the same plane (Fig. 175). A French model of that instrument, the *Mattey stereo-telescope*, was presented by Aubourg to the Radiological Society.

In all these cases the contrast is obtained just as if the eye were substituted for the tube, the right eye in the position of the right tube and the left eye in the position of the left tube respectively. This contrast is called *direct* or *orthoscopic*. If the respective position of the negatives be changed, and the negatives taken in the left position of the tube be observed with the right eye, and the right negative with the left eye, then we obtain the impression that the object has been reversed in relation to the observer, the relief being described as *reversed* or *pseudoscopic*. For instance, if it is a question of a stereoscopic radiograph of the hand, the palmar surface facing the observer, we shall see it from its dorsal aspect on reversing the position of the negatives. This pseudoscopic examination may have a certain interest, particularly in the search for foreign bodies; and, if it be easy to effect it by means of this simple transposition of the radiographs in the case of

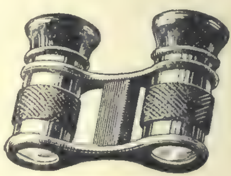


Fig. 175.—Pirie Stereoscope.

separate negatives, it is none the less easy when taking the two images on the same plate or paper, the one image being consequently superimposed upon the other. In this connection Messrs. J. Richard & Colardeau have invented an ingenious stereoscopic device (Fig. 176) which permits the examination of radiographs at will, either with ordinary relief or with pseudoscopic relief, by simply changing the eyepieces used.

There is no need to insist upon the fact that the whole interest of stereoscopic radiography lies in the search for

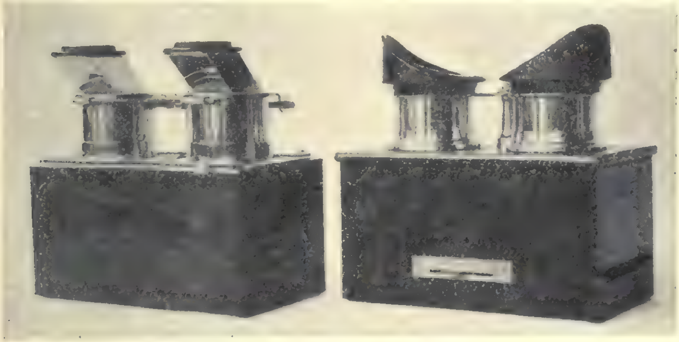


FIG. 176.—Orthoscopic and pseudoscopic stereoscopes by Richard and Colardeau giving the impression of contrast by direct examination of the negatives without reduction (the pseudoscopic apparatus is on the left).

and extraction of projectiles. An examination of stereoscopic negatives shows at once, for instance, whether the projectile lies in front of, behind or within the neck of the femur, giving at the same time an admirable view of the concomitant bony lesions, fractures, loss of substance or osteo-periostitic proliferations, etc. This enables one to obtain most important data, and it is frequently possible to obtain a topographical localisation of the projectile so that it can be treated with success surgically. For this reason stereoscopic radiography represents a useful addition to those various methods of localising projectiles which have already been spoken of, as well as to radioscopic examinations for anatomical localisation which are dealt with in the next chapter. In certain examinations of the skull, face, shoulder or hip—if a perfect representation is required—it may prove to be almost indispensable to ascertain the exact position of the projectile in relation to the bony image before doing anything else. In every case the images obtained are distinguished by their plastic effect, and by the facility with which they enable one to form an image in space.

Not content with these results, which are sufficiently remarkable in themselves, the most enthusiastic experts have for some time past asserted that they can employ this method for the most varied and precise measurements, and that they can apply this *stereometry* to determine the position and depth of projectiles.

In order to achieve this result the first essential factor is to obtain images yielding an absolutely true reproduction of the actual state of affairs. For this purpose Messrs. Marie & Ribaut, taking as their basis Caze's studies on the geometry of lenses coupled together, have formulated rules enabling them to establish a method which they term the *precision method*.

We shall only make mention here of their classic formula according to which, in order to obtain exact results, it is necessary to formulate the following equation by which—

$$\triangle \text{ max.} = \frac{D\,(D\,P)}{50\,P}$$

in which $\triangle$ is the maximum distance between the two foci, (in this case the two positions of the focus of the anticathode), $P$ the maximum thickness of the object to be radiographed, and $D$ the distance between the tube and the object.

It may be mentioned that this point of view has not been endorsed by all authors, M. Destot in particular having made some very adverse and apparently not unreasonable criticisms; and, without availing themselves of the formula already mentioned, most radiologists are content to adopt in all cases a fixed distance between the two positions of the tube, viz.: 6 centimeters, 6·5 cm., or 7 cm., and they are perfectly satisfied with this method of procedure.

Whatever position may be adopted with regard to this question, which we cannot now discuss at greater length, Messrs. Marie & Ribaut have continued and extended their studies, and were the first to describe a *stereometer* for radiological purposes. But the few works devoted to this art of mensuration had been quite forgotten until research work, in connection with war projectiles, gave it a fresh interest and caused more numerous investigations to be carried out in that direction. Under the name of "Tauleigne-Mazo's *radiostereometer* a new apparatus has been introduced, the technical construction of which has been simplified, in as much as it makes an ingenious use of the net system —first applied by M. Béclère to the stereoscopic measurement of depth.

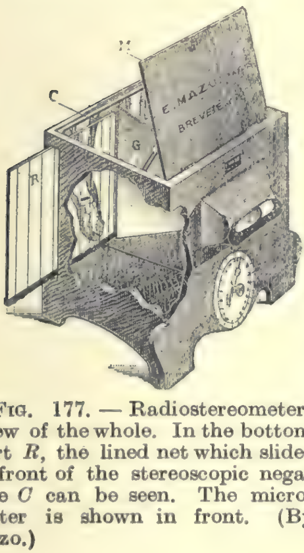



FIG. 177. — Radiostereometer. View of the whole. In the bottom part *R*, the lined net which slides in front of the stereoscopic negative *C* can be seen. The micrometer is shown in front. (By Mazo.)

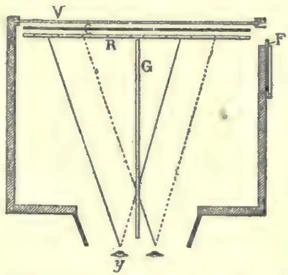



FIG. 178.—Horizontal section of the radiostereometer. *V* is a ground glass; *C* the negative; *R* the lined net; *G* the double-faced glass; *y* shows the place for eyes. It will be observed that according to whether the observer looks to the left (complete lines) or to the right (dotted lines) the impression of orthoscopic or pseudoscopic relief will be obtained, according as the image observed by each eye happens to be the direct image or the image seen in the glass of the corresponding negative. (By Mazo.)

The stereoscopic images are taken under exactly the same conditions as regards adjustment of the tube and the distance between the two foci (4 centimeters between the two successive positions of the anticathode) and they are taken on the same negative. The latter is placed in the apparatus shown in Fig. 177. The sketch 178 shows a sectional elevation thereof, and enables one to understand the respective arrangement of the negative *C*, of the glass *R* (bearing a net of parallel vertical lines), and of the double mirrors so that the observer, according as to whether he looks to the right or to the left, will have the impression of true, or pseudoscopic relief.

Once the sensation of contrast has been obtained the displacement of the lined net, and the reading of the micrometer, indicate the depth of the projectile.

The firm of Jules Richard has constructed an "instantaneous metrical gauge" which shows, by direct reading, the depth of a projectile from the stereoradiographic negative, and we consider it to be one of the best apparatus of its kind now in existence.

This apparatus consists of a rectangular frame, for receiving the negative, which is kept in position by means of clamps. Slides and guides permit of the displacement of pointers which are fixed at two symmetrical places on each of the images formed by the projectile. By the simultaneous adjustment of the graduated scales the reading shows the depth of the projectile in millimeters.

Another apparatus by the same constructor, the stereothesimeter by Messrs. Paris & Richard (Fig. 179), permits of the determination not only of the exact depth of any chosen point on a stereoscopic negative, but also of defining its length and breadth; that is to say of ascertaining without calculation the three co-ordinates of that point. A "stereoradiographic scale," Chauvelon-Richard system, has also been introduced by the same firm.

It must, however, be pointed out that on the whole there is no longer any question of stereoscopy in the strict sense of the word, as far as these various processes are concerned. Two negatives are used which are obtained by displacing the tube, exactly in the same way as by the radiographic process of the double image, dealt with in the preceding chapter. It is found that these negatives also possess the property of being stereoscopic, but we no longer have any need to resort to that property to determine the depth of the projectile.

In consequence of the fact that a sufficiently large number of persons, estimated by various authors at 10% or 20% do not possess stereoscopic vision, we are inevitably compelled to adopt this course, and to abandon in the strict sense of the word stereoscopic localisation, when trying to obtain the great advantage of possessing images which give an impression of contrast (when localising by the double-image radiographic methods). For a method of this kind this is a latent defect which needs to be remedied. Considering, furthermore, that the normal sense of vision brings also the psychic faculties into play, stereoscopic vision possesses a subjective side, which it is difficult to reconcile with the requirements of a method of

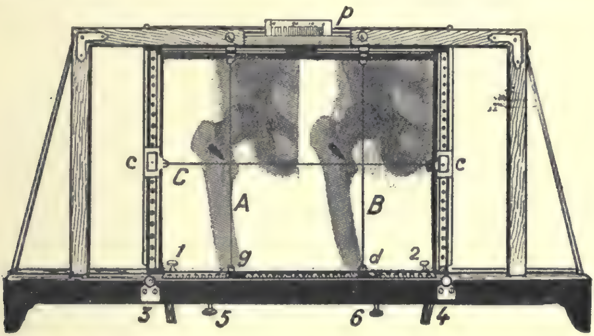



FIG. 179.—View of the Paris-Richard "stereothesimeter."

measurement which must essentially be objective. In fact, comparison of the readings of the depth of a projectile, by means of a real radio-stereometric apparatus such for instance as that by Tauleignemazo, obtained by different observers, very rarely gives figures which agree in a satisfactory manner.

Every radiologist should therefore know and utilise stereoscopic radiography in all cases where it seems advisable, because the information provided will frequently be of just as great value to him as to the surgeon when desirous of *locating anatomically* (in relation to the skeleton) the position of a projectile; or for completing and determining the data given by two rectangular radiographs, or above all it is of still greater value for this purpose in certain regions, and more especially in the region of the head, the shoulder and the pelvis. On the other hand, stereo-radiometry properly so-called does not appear to deserve recommendation, at least as far as the general method for the localisation of projectiles is concerned.

But all those who persevere in the use of radiographic localisation methods, by the double-image process, will be more and more inclined to replace the single double-exposure negative by two stereoscopic images taken on the same plate. In this way they can the more easily succeed in arranging their pointers, and they will have negatives which can be used both from the radio-diagnostic and anatomical localisation point of view.

Stereoscopic radioscopy belongs to the future. We shall only devote a few lines to explaining its principles by reason of its great interest which is at present more theoretical than practical.

After having applied the principles of stereoscopy to radiographic images, endeavours were soon made to extend them also to radioscopic images. If two sources of X-rays at a slight distance apart (6 to 10 centimeters) be utilised as foci for illuminating the fluorescent screen, and if the shadows projected upon that screen by a body placed between it and the X-ray sources (by arranging a system of shutters so as alternately to shut off in turn one eye and one source) be examined in this manner, the object will apparently be viewed in relief. If one eye and the source of the rays at the *opposite* side be simultaneously uncovered, then the impression obtained is that of true relief; whilst, if one eye and the source at the same side be uncovered at the same time, then it will be noticed that the impression is one of pseudoscopic relief.

Messrs. Roullies & Lacroix, followed by Guilloz, and especially Villard, have invented extremely ingenious devices for the utilisation of this method, but they are still too complicated and more especially require too delicate adjustment to enable them to be of any practical value.

The cross-wire method when applied to stereoscopic radioscopy has not had any greater success, and this very attractive method has so far not been allowed to emerge from the sphere of the laboratory nor is one able to obtain contrast effects on the screen for any other than very simple and transparent objects and such parts of the body as the hand and forearm.

It is therefore not surprising that its application to the study of projectiles has not yet been the subject of any work during the course of this war ; at least not so far as we are aware.

However, having studied the works previously published on that subject, it occurred to one of us and to A. Dauvillier * that it might be interesting to apply the special facilities presented by the double anticathodal tube to ascertain the relative depths of two objects, such as for instance a projectile and the end of a pair of forceps, in order to obtain *radioscopic* data as to depth which would be of some use to the surgeon in connection with his work. In fact, it is known (see Chapters XIII and XIV) that, in order to effect extraction of foreign bodies by means of intermittent control of the screen, the surgeon must be able to operate by following the direction of the normal ray. When he cannot look for the projectile by searching directly downwards in this way, following the true direction of a straight line perpendicular to the plane of the table, he loses the elements of *absolute security* and rapidity offered by that method. On approaching the projectile obliquely, it may happen that the instrument is either above or below, thus necessitating a great waste of time in groping about for the object, and he may even be obliged to abandon extraction altogether when operating in a difficult and dangerous part, owing to not having an exact idea as to the position of the projectile in relation to the route by which it entered. Even if the tube be moved about in order to observe the relative displacements of the shadows of the projectile on the one hand, and the end of the forceps for instance on the other, and thus to determine their respective depths (according to the indications given for localisation by the so-called "knife method," p. 177), nevertheless the exact relationship may be very difficult if not impossible to determine.

We will now consider a double anticathodal tube. It

* R. Ledoux-Lebard and A. Dauvillier, "New Radioscopic Method for accurately determining the Situation of Foreign Bodies during Surgical Procedure" (*C.R., Ac. Sc.*, t. 161, p. 575).

produces on the fluorescent screen two shadows of the same opaque point, symmetrically placed in relation to the normal plane taken in the middle of the straight line which connects the foci (Fig. 180). Assuming $A$ and $A'$ to be the central ray of each focus, $P$ a projectile lying anywhere within the body $S$ of a subject placed on the operating table $T$, we shall perceive on the fluorescent screen $E$ two images, $P'$ and $P''$, of the projectile. If we introduce into the tissues an instrument, $I$, in order to determine its relationship to $P$, then the point of the instrument will give two shadows, $I'$ and $I''$, which will only coincide with $P'$ and $P''$ if $P$ is in the same plane as $I$. On endeavouring to make the shadows coincide, we shall of necessity come across the objects which produced them. On the other hand, it is evident that when the forceps are between the projectile and the screen, that is to say at a lesser depth than the latter, the distance $I' I''$ will be less than $P' P''$, and consequently if the forceps were between the tube and the projectile, that is to say deeper than the latter, then the distance $I' I''$ would be greater than $P' P''$.

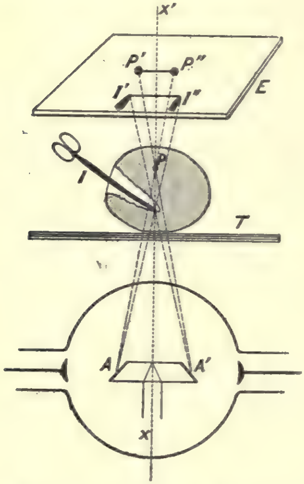



FIG. 180.—Use of the double anticathode tube. Assuming $P$ to represent the projectile included in the part of the body $S$ examined on table $T$ by means of a tube possessing two anticathodes $A$ and $A'$, we shall have on the fluorescent screen $E$ two images, $P'$ and $P''$, of said projectile. If we introduce, to locate it in the tissues, an instrument $I$, we shall have on the screen two images $I'$ and $I''$, of the end of that instrument, and the distance $I' I''$ will be greater than $P' P''$ if the point of the instrument be at a greater distance from the screen—in other words *deeper* in the tissues—than the projectile.

Particularly in the extraction of pulmonary projectiles by the method of M. Petit de la Villeon (see Chapter XIV), it seems that this kind of intermittent control of the screen ought to afford very great facilities for seizing the projectile with the least possible probing and injury to the tissues. We have been able to satisfy ourselves of its value in this and other instances.

However, there are two difficulties in practice which become the more acute the thicker the part which is being dealt with.

The first difficulty is that every projection due to an anticathode is veiled by the other, to such an extent that it is only possible to obtain on the screen two very faint shadows which immediately become invisible when a difficult region is under observation. In order to obtain an adequate image it is necessary to employ a diaphragm which avoids this, and which, at the same time, allows the two shadows to be seen just as dark and sharp as if each of them had been obtained in the ordinary way. This is very easy to arrange.*

The second, but much greater difficulty, is two-fold—firstly that experienced in obtaining double anticathodal tubes which are capable of adequately resisting heavy current, and secondly the difficulty of pairing them. In fact this obstacle, and the impossibility encountered by German constructors in manufacturing symmetrical tubes of this type capable of being kept sufficiently cool, have stopped the development of radiological work in this respect, thus largely preventing the extension of stereoscopic radioscopy.

* For that purpose a diaphragm is mounted above the shield with a rectangular aperture *D*, made of two lead shutters operated by a pinion engaging two racked bars, so that the opening can be changed in a lateral direction. This moves in a vertical direction along a slide-bar, and is so arranged that the centre of its aperture is always on the vertical $XX'$, which is the symmetrical axis of the tube. Having effected this adjustment the method of seeking and finding the foreign body in the radioscopic field is effected as follows:

The screen *E* being fixed above the body of the subject, the diaphragm is opened very wide and fixed on a level so that the two illuminated regions, which appear on the screen, almost coincide. The foreign body is then searched for in the ordinary way and, when located, the tube is so moved that the two shadows are adjusted symmetrically with respect to the black line separating the two illuminated regions. The opening of the diaphragm can then be reduced so as to increase the clearness of the shadows.

In spite of the present difficulties one of us has been fortunate enough to succeed, in conjunction with Mr. A. Dauvillier, in having manufactured by M. Pilon, according to fresh plans, a double anticathodal *water-cooled* tube, *which can be placed equally well under the radiological table* as on a tube stand ; this tube can easily withstand 2 milliampères per anticathode with penetrating rays and is of perfect symmetry. Although the considerable difficulties of manufacture which constitutes a real triumph in producing a tube which German industry has been unable to produce, seem to prevent its being made commercially *at present*, the problem has nevertheless been solved in a practical manner, and we believe that its application will become more general in future (see § 42). The Coolidge double anticathode tube will, doubtless, finally be manufactured in this form, not only for this kind of simplified stereoscopy (or, to be more exact, the transition method between localisation by displacement of the tube and true stereoscopy), but also for *stereoscopic radioscopy*, which is also a very attractive subject.*

* With regard to the whole of this chapter it will be interesting to read the recent work by Sir James Mackenzie-Davidson, *Localisation by X-rays and Stereoscopy* (London, 1916).

## CHAPTER XI

### ANATOMICAL LOCALISATION

§ 45. After having determined the presence of a projectile and its exact depth from a given point on the skin, the work of the radiologist for the surgeon is not by any means completed. It is, in general, much more important for the surgeon (for the sake of safety, promptness, and success in his operation) to know the *anatomical site* of a projectile rather than its exact depth in millimeters.

It is, for instance, of much less importance for the operator to know that a metal fragment is lodged in the thorax at a depth of 32 or 38 millimeters, than to be certain whether it is intra-pulmonary or not. That a shrapnel bullet has its site 61 or 71 millimeters deep at a level with the lumbar spine is of much less interest than the knowledge as to whether it is within the body of the vertebra or in the surrounding tissues.

However, it certainly seems that this point of view is not generally shared by all radiologists, perhaps because certain surgeons do not always sufficiently realise the extent of the information in this respect which they can demand and obtain; and also because some radiologists, being neither medical men nor anatomists, are unable to give them correct particulars. Now it is precisely here that the *absolute necessity* is felt that the radiologist should have a knowledge of anatomy and possess a sound medico-surgical education.

The sad consequences of neglecting to determine the anatomical site of the projectile to be located become manifest by studying works already published concerning the extraction of projectiles. The following observation is frequently met with therein: "The operation commenced was abandoned owing to the injuries it might have caused." It is therefore evident that the surgeon who knows the topographical site of a projectile will be well aware of the anatomical difficulties he will have to overcome, and he will not be ignorant of the injuries his interference may cause. If he undertakes it on these conditions, that is to say with full knowledge, he will have no other valid reasons for interrupting it excepting in the one case the impossibility of finding the projectile, or perhaps the subject is a bad one for anæsthesia, or an anatomic difficulty impossible to foresee and exceedingly rare, such as a vascular anomaly, an arteriovenous aneurism, or, finally, an operative accident, such as opening a large vessel in the course of the search. We are of opinion that the fear of injury is too often claimed in order to conceal a failure.

The utility of anatomical localisation has, besides, been recognised and already noted by many radiologists. MM. Arcelin, Belot, Brocq, Robineau, Viallet, amongst others, have frequently insisted upon its necessity, and have indicated (with regard to various parts of the body) how it was possible in most cases to arrive at precise data of very great importance to the surgeon, by making use of the various resources of radiological science. M. Zimmern endeavoured to find an easy solution to the various problems involved by publishing a series of sections of the body and limbs ; once the depth has been ascertained, it is sufficient to refer to these, in order to determine the exact anatomical seat of the projectile. The anatomical sections, and especially the collection of those by Doyen, may certainly be of some service and it will be useful to consult them occasionally. However, they are possibly only of real assistance in difficult cases. In fact, it is evident that anatomical conditions vary too much between one case and another by reason of the thickness of the soft parts (fat, muscles, etc.), and also on account of the great degrees of difference in the dimensions of the various parts of the skeleton. It will therefore be impossible to adhere exactly to the data supplied, and so they lose all their importance so far as the practical point of view is concerned, and that alone is of interest here.

Whilst making a summary in this chapter, we shall see, that if radioscopy is practised by making use of that elementary knowledge of anatomy and physiology which every medical man ought to possess, the position of the projectile can nearly always be indicated in a topographical manner. This *anatomo-clinical* localisation, to use Viallet's expression, is still possible in those cases in which the object is not found by screening in various positions, or by taking two radiographs at right angles to each other, or by stereoscopic radiographs, or by localising methods such as those of Belot, Hirtz, etc., in relation to the skeleton.

Sometimes it is necessary in order to obtain quickly important information and to avoid gross blunders, to practise active or passive movements of the region to be examined, bearing in mind the classical principles of physiology. The patient can be made to perform certain movements, the operator then can palpate him under the screen and mobilfse him by the aid of some rigid instrument.

Let us bear in mind that it has been possible, by examining both from the back and front, to diagnose quickly to which side the projectile is nearest; that the exact localisation of the depth has been effected; that the position on the skin of the normal ray passing through the projectile has been precisely determined (called by Viallet surface localisation), and that *one* negative and perhaps *two negatives at right angles* or a stereoscopic image in the case of a difficult projectile have been, or will be, taken. Finally, if the situation of a projectile is to be determined in relationship to certain muscles, then the screen examination can be employed with advantage.

We shall now briefly consider the problem for each particular region of the body, describing only some of the chief points in connection with each. Every one will easily be able, with a little practice, to complete for himself those details which must necessarily be omitted by reason of the limited scope of this work.

§ 46. **Head and Neck.**—(1) *The Skull.*—As to the skull, two examinations (by screen or negatives) at right angles to each other, generally furnish sufficiently precise data as to the exact seat of the projectile. With respect to certain regions, such as the temporal fossa in particular, attention will, however, have to be paid to a cause of error (due to the special configuration of the skull) which may cause projectiles, really situated outside the cranial cavity, to be regarded as intra-osseous or intra-cranial.

The following diagram shows that a projectile situated

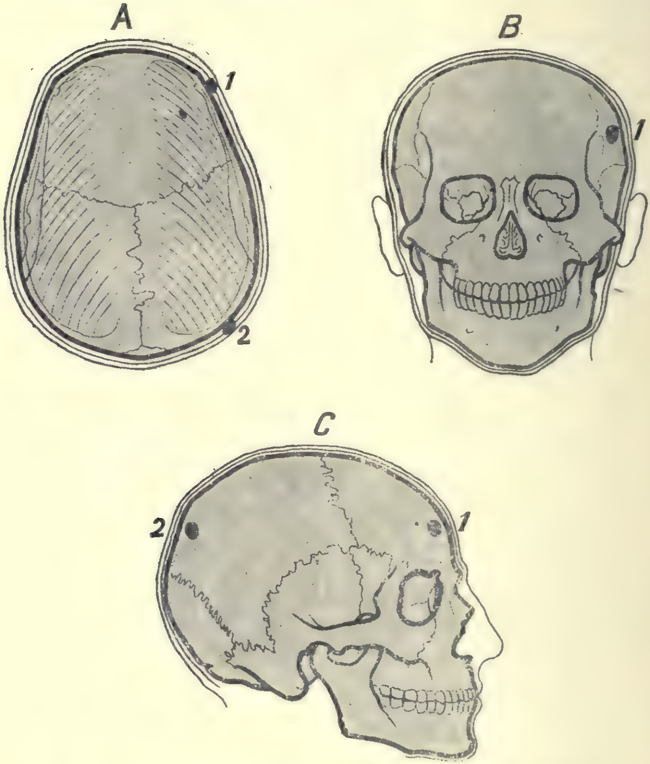



FIG. 181.—The horizontal section *A* of the skull shows how a projectile situated at 1 or 2 outside the skull, but in the soft parts, will nevertheless cause its shadow to appear to be inside the skull as seen at 1, figure *B*, in a postero-anterior or antero-posterior radiograph. In the lateral view (see figure *C*) these projectiles also appear to be situated in the interior of the skull. In these cases therefore the two radiographs taken at right angles to each other lead to an erroneous conclusion as to the seat of the projectile.

at 1 (figure *A*) will appear to be situated within the skull in a radiograph taken in the antero-posterior direction.

A radiograph in a third direction would then be required for purposes of verification, for instance one taken through the *vertex* towards the roof of the mouth or in the opposite direction. Besides, in these cases a radioscopic examination executed with a little care will obviate any mistake, because by turning the head of the patient a position will be obtained at which the projectile will be seen to be extra-cranial. Stereoscopic radiography will also enable one to obtain useful information.

(2) *Face.*—Stereoscopic radiography will frequently have to be made use of for examination of the cavities of the face without which topographical localisation of the projectiles is often difficult as has been proved by us by various examples and researches made in collaboration with Dr. Hautant.

As regards the maxillary bones, negatives should be taken in accordance with the procedure adopted in dental radiography following the Belot method.

(3) *Eye.*—The examination and localisation of projectiles in the orbit constitute absolutely a special chapter of our subject. In the first place the eye is the only organ in which one has to take into account the possibility of removal, and therefore the localisation of metal particles sufficiently small as to be hardly visible is a matter of great importance. The procedure is therefore so delicate a matter that it ought to be reserved for specialists. For this reason we shall not discuss here the question of war ophthalmology, as one of us will shortly devote an extensive volume to this subject in conjunction with A. Terrien.

We shall content ourselves with mentioning that in order to know whether a projectile in the neighbourhood of the orbit is intra-ocular, a question which may occasionally have to be solved by any radiologist, and the solution of which may have very great importance as regards the permanent sight of the wounded, the following procedure should be adopted.

The exposure of the negative is commenced with the patient looking upwards. It is interrupted for a moment and then continued whilst the patient looks downwards.

Except in rare cases in which the projectile occupies the centre of the eyeball itself, a double image of the projectile will be obtained on the negative if the foreign body is situated in the interior of the eye at any other point than at its centre or in the muscles, because in this method if the head is kept absolutely motionless only the eyeball will have moved.

The remarks made by our colleague Terrien on the importance of immediate removal of these projectiles, and on the use of large electro-magnets and of small magnets for this purpose, forms so special a subject in ophthalmology that it cannot be dealt with further here.

(4) *The Neck.*—It is very rare for the radiologist not to succeed in determining the exact situation of a projectile in the neck, if a lateral and an antero-posterior view is obtained and the depth is known; this is a point of great importance in extraction as, owing to the extreme mobility of the head and neck, the least obliquity is important.

In the case of the larynx, as in the œsophagus, a lateral view should be obtained with a soft tube, and the patient should be made to carry out the movements of swallowing; —in this way any projectile in this situation will be observed to move and the position can then be noted either in the semi-oblique or lateral view, as one of us has been able to observe in conjunction with Hautant.

Sometimes it is a good plan to make the patient eat bismuth tablets or bismuth milk, in accordance with the usual methods of radiological examination of the œsophagus.

§ 47. **The Thorax.**—The exact localisation here is of great importance and can be rapidly and accurately carried out in a properly conducted radiological examination, and at the same time other conditions such as pulmonary abscess, pleurisy, etc., may be revealed—a point of great importance to the surgeon in view of what decision is to be made.

As well as conducting an examination in this case, as in other parts of the body, with the patient in the operation position, it is important also to examine him vertically behind the screen, turning him in every direction.

The first question arises as to whether the projectile is nearer the front or the back. The difference in the size of the shadows in the two situations will clearly enlighten us, unless it is situated almost exactly half-way between the two, a fact which can be determined in a lateral view. If situated laterally we can determine whether it is purely parietal and extra-thoracic by turning the patient obliquely so as to cause the shadow to appear outside the costal margin (Fig. 28). But when it is very near the middle line of the body either in front or at the back, examination of the profile may not be absolutely conclusive and may be difficult. Besides, the projectile may be contained in a rib (Fig. 1, Plate V), between two ribs, or immediately underneath a rib and yet extra-pulmonary. Upon placing the subject in the position in which the shadow is clearest, we can cause him to breathe deeply and slowly, and so by careful observation on the screen we can then determine whether or no the shadow moves with breathing.

This will not be *absolutely* impossible unless it is on the middle line or near same and close to the back wall. The measure of the depth and the indispensable profile negative will then enable us to obtain complete certainty (see *Spine*).

If it is only very slightly movable, rising at inspiration and descending at expiration, the projectile is most likely parietal. Let us fix on the skin near it a small piece of lead by means of an adhesive. We shall then see if the shadow of the projectile and that of the mark exhibit the same amount of movement. This rise on inspiration is, besides, a little more marked in front than at the back and attains its maximum at the sides.

At the level of the bases projectiles are sometimes observed lying free in the pleural cavity, being either present in an effusion or having fallen into the pleura in the course of an extraction. These projectiles, which hardly move at all on respiration, nearly always go to the most slanting part with the patient's movements.

It is, moreover, much more frequent to see them fixed in the costo-diaphragmatic groove either in consequence of the resorption of fluid or directly through adhesive pleurisy. They are then almost motionless with respiration, but when examined at a proper angle and with *forced inspiration* if the diaphragm is not completely immobilised by adhesions, it will be found that they stand out quite clearly against the rest of the lung.

Projectiles should not be considered to be actually within the lung unless on radiographical examination very extensive respiratory displacement is noticed. This is correct in all cases of projectiles situated below the hilus, or in the lower lobe, as these exhibit the greater mobility the nearer they are to the diaphragm, so that they follow its movements exactly to its full extent when they are very near to it. It will therefore evidently be necessary to examine these projectiles in the condition of apnœa if useful information is desired.

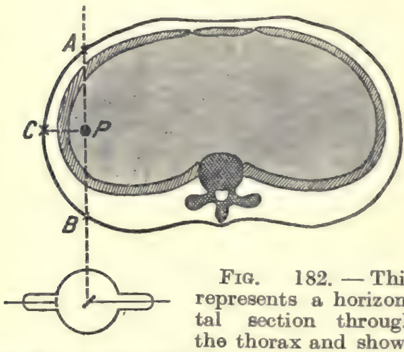



Fig. 182. — This represents a horizontal section through the thorax and shows us that a projectile, *P*, located at 12 centimeters from the posterior wall and 10 centimeters from the anterior wall, for example, may quite likely only be 4 centimeters distant from a point on the lateral wall of the thorax. It will therefore always be necessary, before making the localisation, to ascertain the approximate site of the projectile in relation to the lateral wall and to make sure that it does not afford a better way of access.

On the other hand, projectiles of the upper lobe and of the right middle lobe or of the postero - superior part of the lower left lobe are little or very little affected by respiration. In the middle, the centre of respiratory immobility, they may even be quite immobile. This fact also should not be forgotten, namely that they follow besides in these cases the pulmonary movements of coughing.

Examination in various directions must take into account the necessary orientation for finding the nearest way of access. The diagram (Fig. 182) shows that a projectile, *P*, may have been localised at 10 centimeters, for instance, from the anterior wall, but may be quite near the lateral wall. The radiologist should always draw the attention of the surgeon to this fact for his own guidance, but he will of course choose the most suitable way for himself.

It need not be pointed out that the radiologist must take notice of the condition of the lungs during his examination and take into consideration the presence of any abscesses, patches of opacity, condition of pneumothorax, diseased glands, tuberculous lesions, traces of pleurisy, pulmonary scars, which may indicate the path of the projectile (Belot), and, above all, the presence or absence of pleural adhesions, all this information being important as regards the question of operation.

*Calcifications.**—We have already mentioned in Chapter V the errors of diagnosis so often caused by the presence of glands caused by pulmonary or pleural calcifications which stand out very sharply in the clearness of the pulmonary field and easily lead to confusion with a projectile; and this is especially the case in radioscopy. In all doubtful cases the operator should proceed as we have indicated, placing near the suspected body a metal body and comparing the two shadows radioscopically and radiographically. By following this course he will generally succeed in suspecting the calcareous nature of the shadow seen which is almost always less dense than the shadow of a metal fragment (aluminium alone excepted).

The most frequent of these calcifications are evidently those of glands in the trachea, bronchus, and mediastinum which are very often pulsatory in character, but the anatomical distribution of these should cause him to suspect their nature. But calcareous concretions of various forms—pulmonary stones or thin plates—are often met with all over the lungs. A position near the hilus must not therefore necessarily be supposed to be due to a projectile. We have in this manner removed a calcareous plate from the lower lobe, and one of us has also extracted, with Gosset, a concretion of the size of a large pea which was almost sub-cortical, and, with Dr. Gandar, a large stone together with a shell splinter, the stone having been in close proximity to it.

*Pulsatory Projectiles.*—Even without breathing many

* See also the interesting article by Albert Weil in the *Paris médicale.*

thoracic, pulmonary, or mediastinal projectiles—especially near the middle line—are very difficult to locate on account of the pulsation transmitted to them by the beating of the heart and aorta. Besides, this pulsation may often, no doubt by reason of the elasticity of the pulmonary tissue, be communicated to a great distance and one will find projectiles pulsating very far from the middle line in the right half of the chest or away from the heart in the left half of the chest. We have already mentioned a few pages back (a fact known to all radiologists) that the same kind of pulsation is frequently observed in cases of tracheobronchitic glands and various interpulmonary calcifications. We must also mention in passing the existence of pulsatory pleurisies.

*Foreign Bodies in the Trachea and Bronchi.*—The diagnosis of the intratracheal or intrabronchial site of a projectile cannot be made with certainty unless a special movement on coughing is observed. But as a matter of fact, this is a rare site for projectiles, and personally we have only come across one case of this kind. The subject had a small intrapulmonary splinter and he was operated on by M. Robineau during an intermittent screen examination. In the course of the examination the patient had a fit of coughing, after which the projectile was seen no more on the screen, but a more complete examination showed it to be in the other lung. It was expectorated afterwards.

But if projectiles situated in the trachea and bronchus are rare, the frequency with which foreign bodies, especially nails, are swallowed by accident, in children is well known.

We do not wish to discuss these cases here at length because of the number of considerations which would lead us outside our subject. We shall content ourselves regarding this subject with referring to the recent remarkable work by Chevalier Jackson and with mentioning that extraction of foreign bodies from the bronchi is greatly assisted by a screen examination in two positions.

*The Heart and Pericardium.*—Projectiles are often observed to be lying free in cases of pericardial effusion; they are then movable and fall towards the most dependent point on altering position of the patient. When they are fixed in a localised pericardial effusion the question of possible aneurism must be considered.

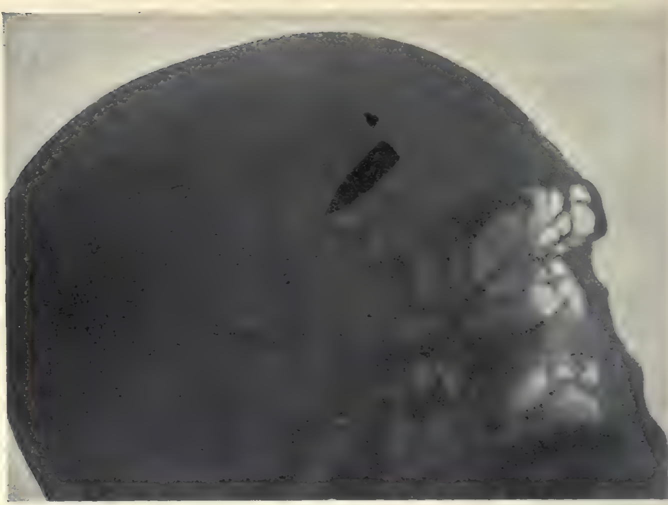


Fig. 1

Fig. 2

## PLATE IV.

FIG. 1.—Side view of a radiograph of the skull as seen from the right side. The shadow of a whole bullet from a German rifle will be noticed the point of which is directed backwards and downwards towards a level which corresponds approximately to that of the body of the corpus callosum. A little above the projectile is a small shadow, less dense, due to a sequestrum.

FIG. 2.—Front view of a radiograph of the skull. The shape of the bullet at this angle should be noticed. The shadow is seen approximately exactly in the middle line. In this negative will be noticed the *frontal sinus*, *the frontal-parietal suture, and occipital suture*, which is especially clear, and the trace of a trephine hole caused by a first attempt at extraction. By making use of this opening the bullet was easily extracted by means of an electromagnet.

Radiographs of the skull, particularly side views, furnish, it should be noted, first-rate data for *the anatomical localisation of cranial lesions*, thus providing the surgeon with topographical information of the greatest importance.

Unfortunately we cannot deal with this very interesting question here, even very briefly, as it would lead us outside our province.

We shall content ourselves with drawing the attention of radiologists to the use of the set of diagrams for the localisation of cranial lesions published by Pierre Marie, Foix and Bertrand (Paris, Masson & Co., publishers). These can be drawn on tracing paper and then placed upon the negatives, in which manner they can be used to great advantage in all laboratories of radiology.

## PLATE V

FIG. 1.—Radiograph of the left half of the thorax seen from the back. The shadow of a bullet from a German rifle is seen at the level of the fourth rib which appears to have been fractured. It is probable from this diagram, that the projectile remained partly embedded in the fractured rib, which may account for the absence of new bone formation. (Verified at operation.)

In this plate will be noticed (in the 6th and 7th intercostal spaces) shadows of calcified glands, which must not be mistaken for fragments of projectiles.

FIG. 2.—Radiograph of the right half of the chest seen from the back. Note the shadow of a bullet from a German rifle situated just above the right dome of the diaphragm. As it moved extremely well with respiration during the radioscopic examination, it was therefore certainly intrapulmonary. (Verified at operation.)

FIG. 3.—Radiograph of the left half of the chest seen from the back. The shadow of the projectile was entirely obscured by the diaphragmatic shadow during expiration, but allowed the point to project into the pulmonary clearness during average inspiration (phase shown here) and disengaged itself almost entirely during forced inspiration. This projectile is therefore intrapulmonary. (Verified at operation.)

FIG. 4.—Radiograph of the right half of chest seen from the front. The shadow of the projectile did not disengage itself from the hepatic shadow even with forced inspiration, but it was observed that the right dome of the diaphragm was *irregularly concave* above. It was motionless during respiration and the right costo-diaphragmatic notch had disappeared. The patient had spat up blood after being wounded. The projectile had therefore traversed the lung and most likely was situated, in view of its situation on the walls and its depth, in the costo-diaphragmatic sinus which had been closed by adhesions. (Verified at operation.)

PLATE V

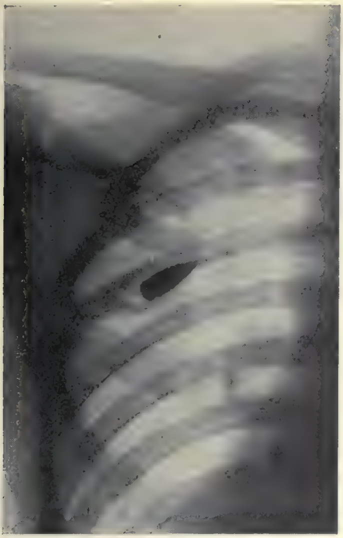


FIG. 1

FIG. 2

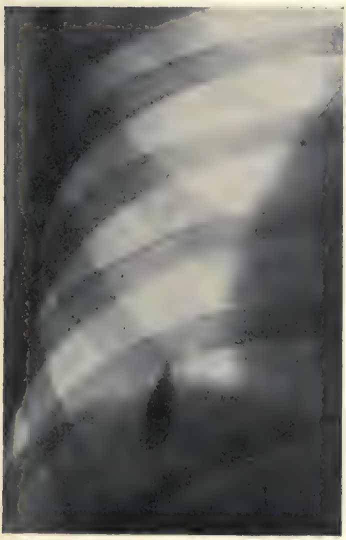


FIG. 3

FIG. 4

As to projectiles actually in the heart, they are not so rare as might be thought, and we have come across about ten of such cases.

Among these cases there must be distinguished in the first place those properly described as intracardiac, *i.e.* those lying free in the cavities, in which they are free to move like a pill in a box (see Plate VII).

As to those embedded in the walls, their diagnosis is often difficult. It must be ascertained by an examination carried out in different positions that in no position is the shadow of the projectile dissociated from that of the heart (see Fig. 2, Plate VII). Thus a positive result can be obtained for the apex and the left half of the heart, but a mistake may be made at the base if the projectile is in one of the cardiac (coronary) grooves or between the large vessels.

From the radiographic point of view it should be noted that good negatives will only be obtained by means of instantaneous exposure (see R. Ledoux-Lebard, *Journal de Radiologie*, 1916).

§ 48. **Diaphragm.**—We shall devote a special paragraph to projectiles in the region of the diaphragm, whether intra-thoracic or intra-abdominal, because to the radiologist of experience and understanding they lend themselves to easy topographical deductions which are of special value to the surgeon, but they very often cause unqualified specialists to make mistakes, which are unfortunately shared by the operator.

A projectile, which in a front view of the patient is seen in the shadow of the diaphragm like the bullet *P* in the diagram (Fig. 183), may really (as is shown in Fig. 184, which shows the side view of same) be either in the space between the lung and diaphragm or within the thickness of the diaphragm itself, that is to say it may be still in the abdomen (and, in that case, either below the diaphragm or intra-hepatic in the example which we have chosen). In all three cases the projectile will present very marked respiratory movements of almost identical amplitude. How shall we make the differential diagnosis of the exact position?

In order to ascertain whether it is within the lung we can make the patient breathe deeply and try in this

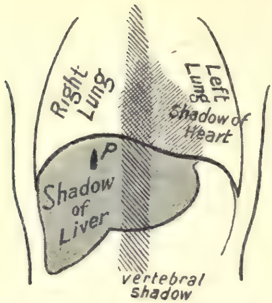



FIG. 183.—Diaphragmatic region seen from the front. The projectile $P$ is shown in the hepatic shadow, under the right dome of the diaphragm.

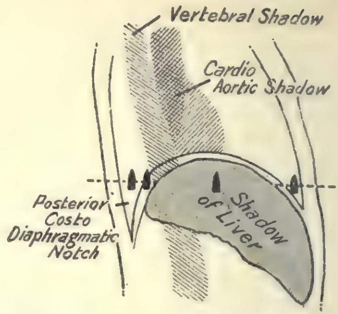



FIG. 184.—Diaphragmatic region seen from the right side. Observe the different situations in which the projectile may be, as shown in $P$ in the preceding figure.

manner to cause the projectile to be seen—wholly or partly—in the pulmonary clearness when the dome of the diaphragm descends. Fig. 185 shows us the appearances seen from the front in the usual examination.


FIG. 185.—The figures 1, 2, 3 respectively indicate the position of the diaphragm at expiration, at average inspiration, and at forced inspiration. It can be seen that the projectile $P$, first hidden in the shadow of the liver, under the dome of the diaphragm, will first show its point and then appear entirely in the pulmonary clearness, thus revealing its seat in the lung.

It is evident that radioscopic or radiographic examination in the lateral position will give us the best information, but it will sometimes happen (owing to weak installations, thick subjects, etc.) that this method of examination is impossible or very difficult. The diaphragm, even in forced inspiration, will not show up the projectile in an examination conducted from the front without any other precaution.* We should then

* It is interesting, in some cases, to cause the diaphragm to contract greatly on one or both sides by the faradisation of one or two phrenic nerves.

remember what we have already said in Chapter III about employing oblique rays. The figure will, in fact, show us for instance that by raising our tube and making use of oblique rays we shall see a bullet, hidden in the costo-diaphragmatic space, quite clearly on the screen.

In cases of sub-diaphragmatic projectiles we must essentially have recourse to the method of lateral and oblique examinations, making use sometimes of various methods (bismuth meals or enemata), and especially insufflation of air in the large intestine or distention of the stomach with gas. In the absence of these methods the knowledge of the point where the shadow of the projectile is projected on the surface of the body, coupled with estimation of depth and the clinical examination, allows a fair notion as to position to be obtained, but is not always exact.

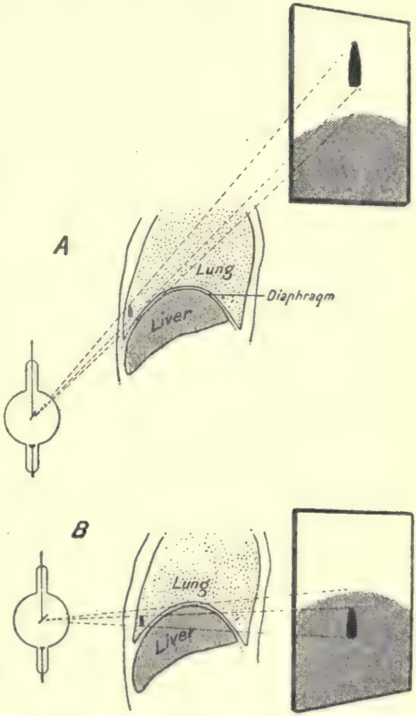



FIG. 186.—The diagram *A* shows us how an examination with oblique rays reveals the presence of a projectile in the lung by causing it to appear in the clearness of the lung shadow, which the ordinary normal position of the tube would not do owing to the shadow thrown by the diaphragm (see Diagram B).

Even with the aid of an oblique examination we shall sometimes be at fault in cases in which pleurisy has ended in a process of adhesions with complete disappearance of the costo-diaphragmatic notch, causing an abnormal aspect of the diaphragm which may present the appearance of a concavity at the upper border, and especially the disappearance or considerable limitation of the movements of the diaphragm. (See Plate V, Fig. 4.)

§ 49. **Abdomen.** — Intra-abdominal sub-diaphragmatic projectiles belong to the class of which it is often most difficult to determine the exact topographical site by X-ray examination; this must be partly ascribed to the uniformity of abdominal shadows which do not easily permit a differentiation between the different organs. It will be advisable in certain cases to facilitate the examination by inflating the large intestine with gas in the manner recommended by one of us long ago, which will often indicate the limits of the various organs in a useful manner. Finally also and especially after this inflation very important information will often be obtained by a lateral view.

In the case of the thorax, but to a much lesser degree, the study of respiratory displacements will be of use. One must not forget the movement of the liver in contact with the diaphragm, nor that of the right kidney moving with the liver. On the other hand, palpation, almost useless for the thorax, will be of great assistance here, and will furnish us with important data. Care should be taken to examine the patient both in an upright position and lying down, making him turn over on his side in the latter position. It will also be very useful to examine him by the Trendelenburg method, but few tables, with the exception of the radio-surgical table, constructed for us by the firm of Gallot (§ 15), lend themselves conveniently to this practice. This method will reveal by the movement of the projectile its site in the omentum, in the lumen of the intestines, the colon, or certain parts of the mesocolon, or, although it rarely occurs, whether it is entirely free in the peritoneal cavity. Palpation will complete these data in a useful manner.

It must not be forgotten as regards intra-abdominal projectiles, that they may penetrate by gradual breaking down of the walls into the cavity of certain hollow organs, and be thus eliminated sometimes through the natural channels.

It will be possible, in certain cases (Viallet), especially with regard to the bladder, to suspect the site of the projectile as being inside a hollow organ when by localising alternately from the back and abdomen, results are obtained which disagree as regards the total thickness of the subject, and are notably less. This is explained by the displacement of the projectile from one position to the other.

It should be noted that in order to obtain good results one must not neglect in these deductions the various causes of error and one will always associate together clinical surgery as much as possible with the X-ray examination.

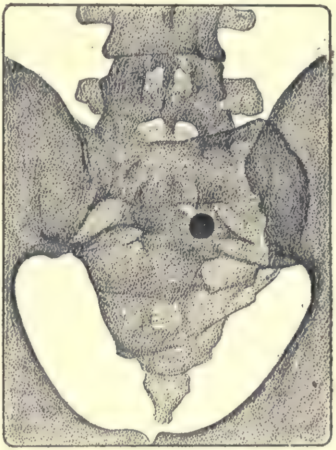


FIG. 187.—Tracing of a radiograph seen from behind. The shrapnel bullet of which the shadow is seen was 9 cm. from the dorsal skin. It was impossible, according to these data, to know with certainty whether it was lying in front of the sacrum, and at what level, or whether, on the contrary, it was included in the bone, a question which presented much interest from the operation point of view. (See Fig. 188.)

§ 50. **Spine and Pelvis.**—*The Vertebral Column.*—It is perhaps with regard to the spine that the necessity arises for two plates at right angles to each other, that is to say one antero-posterior and one lateral negative, and makes itself felt most frequently and urgently, to judge by the number of observations on this region to the effect that operation was abandoned "in order not to cause too great damage." These assertions, which remind us of the now legendary phrase of the communiqués with regard to the voluntary falling-back of troops to a position prepared in advance, are in reality inadmissible in most cases. On going into the matter, it will be found that they refer nearly always to cases in which a lateral negative was not taken. Screen examination is not sufficient here, as it does not provide enough detail. It is however known that lateral radiography of the spine is difficult, although this seems to us absolutely unjustified, and we consider that it is generally avoided without proper reason. Besides, it is not a question of making show negatives, but only negatives which enlighten us about the exact site of the projectile in relation to the spine. This is always possible for the cervical column as well as for the lumbar column, and even for the sacrum, as is shown by the radiographs which we are constantly taking at Tours, where not a single spine is operated upon without this precaution. (See Figs. 187, 188, 189, and 190.)

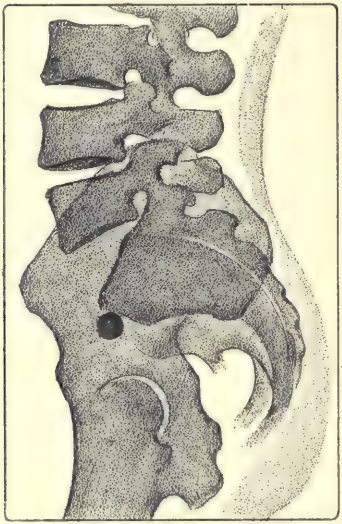


Fig. 188.—The tracing of this radiograph of the same patient as in Fig. 187 shows us the pelvis seen from the left side, and shows the projectile as placed on the promontory. We know now exactly its anatomical position.

From our negatives from the front and side we know exactly where the projectile is situated in relation to the bones, and moreover we know the condition of the bones. Therefore, if we decide to operate, it will be with the full knowledge of the matter, realising the damage we are bound to cause and being quite determined to extract the projectile from the moment in which, having resolved to look for it, we have consequently been able to plan out the exact procedure to adopt in spite of the damage inevitably caused.

It must not be forgotten that projectiles are able to move in the spinal canal, which explains the non-success in the use of the compass in similar cases.

*The Pelvis.*—Projectiles in the pelvis present some special difficulties from the point of view of the determination of their site. One may be dubious in the case of those which are near the iliac bone, even when we have our negatives and have determined the depth, knowing the projectile is for certain in front or behind the bone, or included in its thickness. In such cases stereoscopic radiographs or radiographs taken according to the Belot method will help to solve the difficulty.

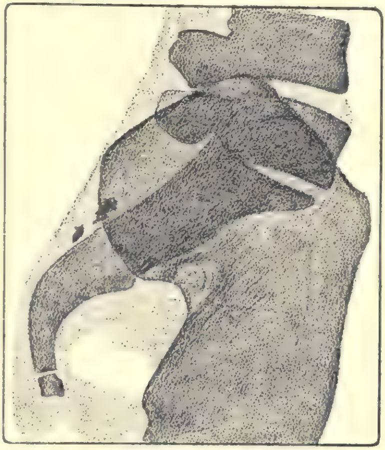


Fig. 189.—The tracing of this radiograph of the pelvis, as seen from the right side, shows us that the splinters which were localised respectively at 44 and at 33 millimeters from the skin of the sacral region are in the soft parts and that their extraction is extremely easy.

When the projectile is supposed to be near the rectum, the practising of "rectal palpation" under the screen will be useful.

§ 51. **Upper Limb.**—*The Shoulder.*—This is one of the regions in which the extraction of projectiles is often difficult on account of the presence of the scapula on the one hand, and of the axilla with its large vessels and nerves on the other. It is therefore one of those parts for which the exact particulars furnished to the surgeon about the exact site will be of greatest help to him, as the judicious choice of the best route of access depends upon this information. The following indications are mainly taken from Viallet.

Let us presume that we have to deal with the examination of a patient who has a shell splinter in the shoulder region. We have placed him on the X-ray table on his face, and we have ascertained that the splinter is neither in the lung nor parietes. It only remains now to consider its relations to the scapula. In order to find out, we ask our patient to keep relaxed, and we take hold of his arm near the elbow in order to raise and lower it successively. The whole scapula will follow, showing a wide range of movement. We may see the shadow of the projectile moving at the same time seven to eight centimeters. In order to confirm this result further we then tell the patient to put his hand on his head and then to place his arm along the body. The scapula describes thereupon a movement like that of a bell, which the projectile follows more or less accurately.

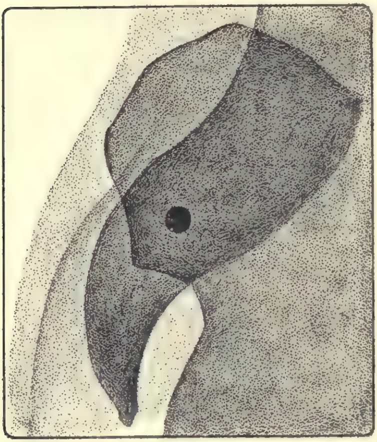


Fig. 190.—This tracing shows a piece of shrapnel embedded in the sacrum.

As the projectile moves with the scapula we know that it can only be in the subspinous fossa, in the thickness of the bone itself, or in the sub-scapular fossa. Palpation and movement of the tissues as well as the knowledge of its depth should furnish us with the desired data for determining its situation, being helped, if necessary, by all the resources of radiography.

Let us now take a projectile which we suppose appears in a position in which it lies over the head of the humerus. The patient will this time be on his back, the arm is in abduction and the fore-arm bent on the arm. In the first place we must make sure, by moving the soft parts in front or at the back, that the projectile is neither in the mass of the pectoral nor latissimus dorsi muscles. It is therefore either in the joint or embedded in the head of the humerus.

In order to be certain, let us make the head of the humerus describe a rotary movement in its glenoid fossa by moving the fore-arm, keeping it bent at 90° on the arm, the latter being in abduction at 90° on the trunk. If the metal fragment is near the capsule, the movements of the latter will cause it to change in position. If it is in the head of the humerus, the movement of the latter will communicate to it more or less important displacements according to its situation as regards the ray passing through the centre of the sphere to its periphery. If it is exactly in the centre of the sphere, it will remain immobile or almost immobile. If it is on the surface, the movements will have their greatest amplitude.

One can, besides, be guided by the fact that one of the tops of the bicipital grooves generally shows on the screen a long clear shadow which is easily recognisable, the relationship of which to the shadow of the projectile on rotation gives us useful information. So when the projectile is clearly on the posterior side, a change of position is produced between the two shadows during the rotation of the head.

Moreover, those observations made in paragraph 13 with respect to intra-osseous projectiles and their little areas of decalcification should not be forgotten.

It is, besides, only on negatives—and good negatives—that these details will be seen.

It has often been claimed that one special difficulty in the good localisation of shoulder projectiles arises from the impossibility of taking satisfactory images at right angles to each other in that region. This, however, is a complete error. It is perhaps somewhat delicate, but not at all impossible to take a lateral view. Moreover, one can still take a negative through the axilla in the case of patients who are not affected by complete ankylosis of the shoulder.

*Arm, Elbow, Fore-arm, and Hand.*—There is very little to add as regards these different segments of the lower limb. What we have already said applies also in these cases as regards localisation. The elbow and carpus will be the only two parts which are somewhat delicate and require good negatives which are indispensable for appreciating the state of the joints, the knowledge of which is generally important for operation.

§ 52. **Lower Limb.**—*The Hip and Thigh.*—One must not forget that the hip is, like the shoulder, an especially difficult region, and for which an exact localisation is of great importance for the surgeon, as this alone gives him the correct information necessary for choosing the proper route of access. He should therefore never undertake an operation for the extraction of a projectile which is somewhat deep in the region of the hip without being absolutely certain about the situation of the metal fragment in relation to the femur, and without knowing whether it is above within or below the neck, for instance. The screen examination may be rather difficult in these cases. One must always try, when executing it, to move the neck of the femur by rotating the foot alternately from side to side.

FIG. 191.—Tracing of a radiograph of the right foot seen from the plantar aspect. A shrapnel bullet is seen at the level of the middle part of the third metatarsal. As it was very movable through palpation of the sole of the foot and was situated 6 cm. from a point on the dorsal surface, it was therefore in the soft parts of the sole at 1·5 cm. away from the latter, the thickness of the foot, measured at this level, being 7·5 cm. Operation by lateral incision is indicated (see Chapter XVI).

The difficulty in taking a lateral negative is greater here than in the region of the shoulder. One may however do this successfully and obtain if not marvellous negatives at least plates which give the required information. Stereoscopic radiography is also of the greatest help.

We may see—and it is as well to recognise the possibility of this—projectiles included in the head of the femur without any lesion or bony change visible in the negatives: these are generally pieces of shrapnel. We must not mistake in radiographic examination the small trochanter for a piece of shrapnel nor the area of osseous condensation of the cotyloid ridge for a piece of shell splinter (see Chapter V).

In the soft parts of the buttock and of the thigh the search for projectiles, especially of small splinters, is also very laborious on account of the considerable changes of situation which the slightest modification in the attitude of the limb may cause between the position during localisation and the position during operation. Pierre Duval stated (see also Chapter XIII) that a rifle bullet situated in the adductors was displaced seven centimeters, and we have noticed similar displacements ourselves on various occasions.

Palpation under the screen with the aid of a rigid rod will be of great importance here for the determination of the exact site.

*Knee, Leg, and Foot.*—As floating projectiles are particularly frequent in the knee joint, account should be taken of this fact. The determination of the exact site is always very easy in the region of the knee and leg. For the foot, stereoscopic negatives will often be of service which will be much appreciated by the surgeon, enabling him to see for himself the exact situation of the foreign body.

The above remarks apply, it should be noted, to cases of embedded pins and needles, of which the knee and the foot represent, together with the hand, the most common situations, the extraction of which will only be executed in future, let us hope, with the aid of the fluoroscope.

§ 53. **The Migration of Projectiles.**—After having examined thousands of persons with projectiles in their bodies, many of them several times, and at very long intervals, we are under the impression that migration of projectiles is infinitely rarer than one would believe when judging from the well-known fact of the migration of needles. It is besides sufficient to have extracted projectiles which date back for some time from cicatrised wounds, and to have seen the trouble one has in liberating them from their fibrous capsule and in extracting them from the tissues in which they are embedded, to be sceptical about the possibility of their changing their situation in the body, excepting certain well-established cases.

*Brain.*—The migration of brain projectiles with the tendency to occupy the most sloping point of the head of the patient when lying down (occipital fossa) is well known. The same tendency to migrate is noticed with respect to the projectiles causing by their presence an abscess of the brain. This explains itself.

*Serous Membranes and Joints.*—In the splanchnic serous glands as well as in the joints one finds very often free projectiles which are consequently very movable, but one can hardly call these cases of genuine migration. The same is the case with regard to free projectiles seen in the spinal canal, of which we have met a few examples, and with respect to projectiles in the omentum (see Chapter XVI).

In the neighbourhood of all the *hollow viscera* one can confirm the passage of a projectile into the organ. We have thus observed the passage of a projectile lodged near it into the œsophagus and its elimination by the natural channels.

Similar occurrences have been noted with regard to all parts of the digestive tract, with or without elimination through the natural channels. One has also observed the passage of one into the bladder, and we had occasion to extract a rifle bullet from the bladder of a man who has never had hæmaturia, and in this case it is probable that its entry into the bladder was a secondary result. (See also the interesting communications by Legueu, *Soc. chir.*, 1916.)

Of less frequency are migrations in the respiratory apparatus. In a case known to us a violent attack of coughing caused a projectile to pass into the other lung in the course of an operation being performed for its extraction. This projectile in the bronchus was, moreover, spontaneously expelled afterwards during coughing.

We also know of the existence of some migrations of projectiles through the course of blood vessels. The best instance is doubtless that of Grandgérand, in which a projectile which was at first lodged in the heart, was extracted from the femoral vein. The relative frequency of intracardiac projectiles will no doubt multiply these kinds of observations. Finally we must mention the possibility of the migrations of projectiles which follow the paths of purulent fistulæ. This is well authenticated and moreover quite logical.

Apart from these various eventualities, even if we strictly admit the possibility of certain migrations of projectiles, we see nevertheless that they must be absolutely exceptional, and we ourselves have never met with a definite example.

# CHAPTER XII

## INDICATIONS AND CONTRA-INDICATIONS FOR THE EXTRACTION OF PROJECTILES

THE close collaboration of radiology and surgery has caused such progress to be made in the methods of the extraction of projectiles that in a certain number of units the percentage of successes varies between 95 and 100%. This great success under favourable conditions has caused some surgeons to make it a general rule that *all* projectiles should be extracted.

We do not share this point of view, although we have so far been successful in extracting all projectiles which we have searched for at our Central Service at Tours.

Two factors must be considered and balanced in our opinion when it is a question of deciding whether or no such a foreign body should be extracted: *the trouble resulting from the presence of the projectile in the body must be weighed against the inconvenience or dangers resulting from its extraction.*

It is evident that this balance can only be established after the patient has been screened and when the situation and the depth of the projectile in relation to certain points marked on the skin have been accurately determined.

§ 54. **Indications for Operation.**—TROUBLE RESULTING FROM THE PRESENCE OF THE PROJECTILE. This trouble varies considerably with the situation of the projectile. Nevertheless it can be classified under two heads: pain and functional trouble.

*Pain.*—This varies from simple inconvenience up to the most severe pain. For instance, shell splinters situated in the sacral-lumbar mass, in the muscles of the vertebral grooves, cause inconvenience. These foreign bodies cause much pain on bending forward and prevent the patient from stooping.

On the other hand metal fragments running through a nerve trunk or situated in the substance of a thick never, like the sciatic, give rise to great pain. We have seen a certain number of these cases.

However, it often happens that a patient who has a projectile in a region generally slightly sensitive, for instance the mass of the gluteus maximus muscle, suffers pain of an intensity which is quite out of proportion to what might be expected. It is said that it is absolutely impossible to walk with a small splinter situated in the soleus or in the gastrocnemius muscles.

Is it necessary to admit that the foreign body is in certain cases in direct contact with nerve endings directly irritating them ? This is possible, and this hypothesis would indicate the necessity of removing it.

Can it be believed that this foreign body plays the part of an irritant provoking a reflex contraction which produces considerable inconvenience in walking ? This explanation is no doubt valid in a certain number of cases, and the experience gained since the war shows us that these contractions resist every treatment, until the irritant which gives rise to the spasm has been removed.

It is however right to consider the part which the psychical condition of the wounded man may play in the production of the pain from which he says he suffers.

It is certain that a fairly large number of patients exaggerate the inconvenience and the pain which a retained projectile causes them, but we are convinced that it is mostly a question of unconscious rather than voluntary or reasoned exaggeration.

This unconscious exaggeration may moreover vary very much in its amount. Sometimes it is a question of a patient who has heard the doctors and nurses around him expressing serious apprehensions or a serious prognosis from the point of view of the recuperation of the injured limb. Upon his organism weakened by his wound, on his nervous system shaken by the battle, the suggestion will have great effect, and the patient, who retains a small fragment of metal in the calf, who has been told not to rise because he could not walk, is really unable to walk when asked to do so.

This exaggeration may make him hysterical. We have heard wounded men complaining of violent pain because they thought they had a projectile in a part of the body which they indicated, but which only existed in their imagination.

Finally, in the case of certain very much depressed patients we have noticed a serious neurasthenic condition accompanying the persistence of a projectile in the tissues. They were troubled about the future, asking themselves what troubles this foreign body may cause, what accidents it may lead to some day, and this fixed idea was continually present in their minds. They only thought of their projectile, continually feeling the region where they thought it was situated, and analysing the pain which they thought it caused them.

In our opinion, account should be taken of this unconscious exaggeration of the pain caused by a projectile in the body. Not only do we not refuse to extract a projectile seated in a muscular mass, for instance, in the case of one of these exaggerators, but we think that this operation, if it is simple and without undue risks, is the most rapid and the best means to dispel all the troubles complained of by the patient as well as all the pain which he says he feels.

We therefore consider it advisable to take account not only of the wishes of the man, but also of the degree of pain which he says he feels, even if we have reason to think that the pain is involuntarily exaggerated by the wounded.

If we think this exaggeration is voluntary, we shall follow the same course and, except in the cases of the contra-indications which we shall mention hereafter, we shall advise the extraction. Moreover, this is one of the best procedures which we have for recognising in this exaggeration the part of a conscious will, as we shall then meet with a refusal to operate. However, we say again that we think these cases are very rare.

*Functional troubles.*—They evidently vary with the regions and the organs in which the projectile is lying. Giddiness, epileptiform crises, hæmoptysis, diminution of air entry to lung, hæmaturia, paraplegia and syndrome of the cauda equina are the most frequently observed. We shall mention these again later, region after region. We must balance the indication for operation against the danger and the damage that may be caused by the operation.

§ 55. **Conditions Favourable for Extraction.**—Amongst the motives to be considered in deciding upon an extraction, certain conditions of the situation and size of the projectile must also be mentioned.

One will hesitate less in deciding on the extraction of a large projectile, situated at a small distance from the skin, sometimes perceptible to careful palpation, situated in a region which is not traversed by important vessels or nerves, than if the contrary were the case.

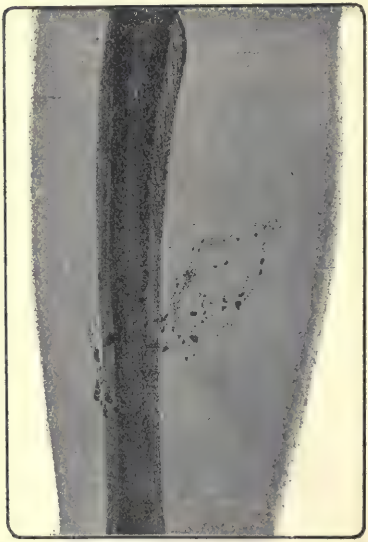


FIG. 192.—Radiograph of the left fore-arm seen from its ulnar side. A trail of metal dust will be noticed in the soft parts (grenade).

§ 56. **Contra - Indications to Extraction: Danger and Operative Damage.** — Every surgical operation, no matter how small, always involves some danger. We shall not deal further here with this point of general surgery.

*Danger.*—The extraction of projectiles involves however special risks according to the region in which they are retained, and we shall consider them with the regions. The consideration of this risk should be weighed when it is a question of deciding for or against operation. These operative risks are limited almost exclusively to hæmorrhage coming from vessels of such importance that it will be very difficult to control it. We shall deal with this presently.

Besides the danger of which every surgeon thinks who knows anatomy, the operative damage to adjacent tissues must be taken into consideration beforehand, and we are under the impression that it is not sufficiently considered in a great number of cases.

*Operative damage.*—A projectile is situated in the pterygo-maxillary fossa, where it causes extreme inconvenience. In order to extract it the zygoma must be cut, the masseter must be detached, the coronal must be cut, and the temporal raised. Will not the functional inconvenience resulting from these various disturbances be more important than that which is involved through the presence of the foreign body?

Fig. 193.—Radiograph of the right hand seen from its palmar side. At the level of the three first inter-osseous spaces especially very numerous metal splinters are seen, the largest of which is hardly bigger than a grain of corn, with innumerable fragments of metal dust, the excision of which is obviously impossible.

The effect of the operative damage, of the incisions in muscles, of the cutaneous scar which will result from the operation, must therefore be carefully estimated before the decision is taken to extract a projectile.

*Unfavourable conditions.*—The smallness of the foreign body is a relative contra-indication. We have been compelled to look for a metal fragment smaller than a grain of corn because it was adjacent to the ulnar nerve in its epitrochlear groove. We should not look for the same fragment in the gluteus maximus, because the operative damage done would be out of proportion with the existing injury.

Its depth also is a relative contra-indication, for the same reason. Finally, the same is the case when a large number of small metallic foreign bodies are present.

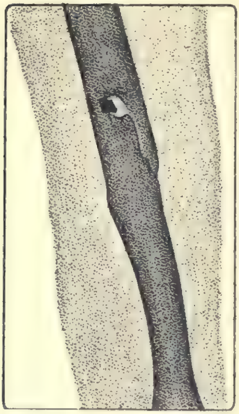


FIG. 194. — Radiograph of the right arm seen from its posterior aspect. A shell splinter is visible and is seen in the shadow of the humerus at the level of a cavity (clear zone), without doubt hollowed by the projectile at the moment of its penetration. The diaphysis of the bone was split from that point, and one can still see the presence of this fissured fracture united with slight deformity. The persistence of suppuration, the X-ray aspect of the osseous cavity, hardly half filled up by calcified tissue one year after the wound, allow the supposition that the process of osteomyelitis, although *clinically* stopped, is yet still latent, and that the extraction will determine its recrudescence, which in fact frequently happens.

Besides, it is often the case when these innumerable small fragments are searched for that no real metallic masses are found, but a kind of incrustation, a tattooing of the tissues by metal dust. These metal splashes occupy especially the cellular tissue and the aponeuroses (Fig. 193), incrusting the tendons. It is impossible to remove them without excising the tissue which contains them. In this case also the damage is out of proportion to the foreign body to be extracted.

We must bear in mind also that certain extractions will almost certainly result in complications. We wish to mention projectiles which remained included in the centre of old foci of osteomyelitis complicating fractures. We have come across this eventuality especially in the case of men wounded in the first months of the war, when only a few rare units possessed X-ray installations. A fracture caused by a bullet united more or less well, but a fistula persisted. This is attributed to the osteomyelitis, all the more since through its orifice splinters were eliminated. The fistula heals up and the patient is considered cured. We have seen such wounded patients coming back to the hospital on account of persistent pains at the site of the old lesion. An X-ray examination revealed the presence of a metal fragment in the osteomyelitic cavity (Fig. 194).

In these cases it is rare that the extraction is not accompanied by a fresh outbreak of osteomyelitis at the level of the central part, and that a fistula does not persist afterwards for a variable time.

These are briefly the elements of indication and contra-indication for the extraction of projectiles.

§ 57. **Anatomical Situation of the Projectiles.**—We have mentioned above the dangers of certain extractions due to the vicinity of important organs. This implies an exact anatomical knowledge of the situation of the projectile. There are cases when this is easy to presume; there are others when it is particularly doubtful, because the figures of depth supplied by radiology are of no absolute value and vary according to the subjects. (See Chapter XI.)

A wounded man has a shrapnel bullet eight or nine centimeters deep from a mark situated in the dorsal region, three centimeters from the median line. He suffers referred pains in one side of the chest.

If it is a man with strong muscles and very tall, the projectile will probably have its seat near the nerve root orifice; it can, by its mere presence, determine the painful phenomena from which the patient suffers. If it is a small and weak person, the projectile may be seated on the side of the vertebral body, at the level of the great vessels. The pains in that case are no more attributable to the projectile, but they are due to the lesions it has left during its passage, and they will probably persist after the extraction. The extraction will, besides, be much more dangerous on account of the presence of the pleura and the great vessels.

In such cases we never hesitate to call for a supplementary investigation, consisting in the taking of a fresh radiogram at another angle, especially the side view, and in a fresh examination under the screen if there is a doubt as to the anatomical localisation of the projectile (we have seen, in § 48 above, what is important with regard to projectiles near the spine from the point of view of their localisation by X-rays). The side view of the dorsal spine allows us to appreciate the relations of the projectile to the vertebral body or the transverse process.

We have also frequently asked for a supplementary profile view at the level of the sacrum which gives us the most useful indications in order to establish the anatomical position of the projectile.

From this information we obtain a most important operative indication, namely, the route of access.

§ 58. **Surgical Route of Access.**—The choice of a good way of access is a problem which has not to be faced in the case of recently injured patients, the wound of which is still widely open. In these cases the projectile will be removed most advantageously through that wound in a very large number of cases.

The case is quite different with wounds of old standing which are entirely healed.

In such cases the surgeon must select a route which is at the same time the shortest available, and which enables him to avoid the important organs which may be encountered. A bullet for instance is intracerebral and exactly in the median line, four centimeters deep. It will be advisable to approach it outside that line in order to avoid the superior longitudinal sinus, and the passage made will have to be somewhat long. A close collaboration between the surgeon and the radiologist in these cases is necessary to ensure consistently successful results. Whenever the X-ray examination could not take place in the presence of the surgeon, the latter should not hesitate to ask for a confirmatory investigation. In the particular case under review, if the localising mark on the patient is nearer the middle line than is desired by the surgeon, the latter should ask for a fresh indication of depth from a favourable point of access exactly indicated by him.

It is only after having reduced to a minimum the factor of danger, by judiciously choosing the way of access, *even modifying it several times*, that the surgeon will be in a position to decide whether the extraction of a projectile should be advised. We are under the impression that at the rear, where the surgeon is never, as at the front, worried and compelled to somewhat hasty decisions, he does not perhaps take all possible precautions before deciding to intervene or not.

The formula which guides us is the following :

*A projectile should be extracted when the dangers and destruction of tissue necessitated in its extraction are less than the pain involved.*

§ 59. **Conditions Bad for Extraction.**—This formula however was made for the Central Services, where we do not consider any chances of failure, as our material installation and the method we employ give us the certainty of carrying through our extraction if our localisations are correct.

All units during this war and all practitioners after the war cannot always reckon with such perfect material conditions.

The X-ray installation may be insufficient to enable us to carry out an extraction with the aid of the intermittent control of the screen, or the available local supply may only lend itself with difficulty to the execution of the work. In such cases as we have already seen the X-ray cars attached to the bases may nearly always be substituted for the local installation. The same will be the case when the outfit required for localisation, which can easily be improvised however at small cost, is not provided.

What will often be wanting more than the outfit, especially during the period of the war, is the competent radiologist who is capable of utilising it (see Introduction), to supply the surgeon with exact data, and to guide him with precision and safety. This is therefore purely a question of personnel.

Although it is indispensable to possess extensive medico-surgical knowledge in order to do one's very best as a radiologist, the title of doctor is not sufficient to make one a specialist.

We have met radiologists, medical men—at least as far as the possession of the diploma goes—who took the end of the coracoid for a shrapnel bullet, organic calcifications for projectiles, directing the surgeon at the beginning of his operation, then changing their minds about the shadow which was at first taken for that of a metallic foreign body and finally giving up the search.

On the other hand we have seen, it is only right to say it, a pupil of the Beaux-Arts School who before the war had no knowledge whatever of radiology, but who possessed sound notions of anatomy, become in a few weeks a collaborator sufficiently competent to enable the surgeon of the place where he was acting as assistant to obtain a series of 100% of successful results.

The operator—just the same as the radiologist—may be incompetent. We have seen one passing under the foreign body, displacing his incision after the localising mark was applied, deviating every minute from the vertical line he should have followed, and which the radiologist had just indicated to him.

Others are constantly searching with the fingers for an illusory tactile sensation ; one does not feel when touching a small foreign body encysted in muscle, or one takes for the foreign body a fibrous cicatrised module left by the passage of the projectile. These are solely and essentially questions of individual technical skill with which we shall not deal any further. It is quite evident that a bad surgeon and a bad radiologist together will never do any good, and if one of the two collaborators is inefficient, the work executed can only be mediocre.

In order to obtain the best results in the extraction of projectiles good surgeons and good radiologists who have good outfits and who are efficient are necessary.

When all these conditions are fulfilled, the experience of this somewhat special surgery affords the operators a much greater rapidity and certainty. We have had personal proof of this.

Moreover, without going as far as to ask for a special service at the base for the extractions of projectiles, we nevertheless think that *one would obtain better results from the point of view of rapidity and efficiency by using for preference real centres for extraction, where there is an equally competent radiologist and surgeon.* This suggestion has besides been made on the rostrum of the Academy of Medicine by Prof. Laurent.

The services of consulting surgeons and those of some local surgeons are all intended to play that part.

If the resources in outfit and staff are insufficient for endowing every one of them with a connected radiological service, the X-ray car of the region can be attached periodically to the surgical service which undertakes the extractions. This organisation is in operation in the ninth region, where we arranged it a long time ago.

However, the above only applies to the base. The conditions are different at the front. While there are at present many special ambulances supplied with excellent X-ray installations, there are also other ambulances to which the wounded can come, in case of emergency, with projectiles at the bottom of open wounds. In these cases extraction is often easy, the projectile felt by means of a probe at the bottom of the gaping wound being easily removed with a curette.

There are more complex cases in which the intervention of radiology plays a part, but where the circumstances, the outfit, and the pressure of time necessitate—or rather have necessitated—methods which are not precise. The enormous progress made in the organisation of the health service since the beginning of the war justifies the hope that such chance procedures will be less and less used.

## CHAPTER XIII

### PROCESSES OF EXTRACTION

THEY can be conveniently grouped, in a general manner, under three headings: The chance processes, the precision processes, and the processes of certainty. We are going to study these three groups in succession, considering only the surgical side of the question, as the radiological aspect has been dealt with in detail in the previous chapters to which we refer the reader.

§ 60. **Chance Processes.**—*Two images in perpendicular planes.*—Two images obtained in two perpendicular planes give, as we have stated above, very useful information from the topographical point of view. A projectile which is from front view on the external edge of the patella, for instance, and from profile appears to be in contact with its posterior surface, is sufficiently well located that one can be almost sure to find it *if it is of sufficient size.* But this process can only be of value in certain regions of the limbs where it is easy to make a localisation from bony points. Generally it is absolutely insufficient. Exactly the same will apply in the processes based on radioscopic examinations in two directions by marking the points of emergence of the rays on the skin and materialising them in any way whatever in order to obtain the situation of the projectile which is at their point of intersection. We refer to what we said in Chapter VIII about these various processes, remarking once more that they are only applicable to the limbs. We shall only mention here specially the ingenious variation called the lead bracelet, which one of us has employed with Haret at the beginning of the war, when the first X-ray car came to the military hospital at Verdun where no permanent installation existed at that time.

On that day a large number of projectiles were thus removed by the use of this method alone. But the operator retains the mortifying recollection that he was not able to find a whole rifle bullet placed vertically and parallel to the humerus. This process may therefore be of great service, but no precision can be claimed for it.

*Anatomical localisation.*—Further we still classify amongst the chance processes the extraction practised after an anatomical localisation.

The latter when it is well carried out and accompanied by an accurate knowledge of the depth of the projectile is certainly one of the most satisfactory and least fallacious processes, especially in the case of projectiles of a size sufficiently great that they can be felt, and M. Robineau has been able, on the anatomical localisations with depth gauge made by Viallet, to extract 52 projectiles out of a series of 54, viz. about 96% of successful results.

Nevertheless, the fact that one has not at one's disposal any means of assistance when the projectile is not found at its supposed site, and the facility with which even fairly large metal splinters may escape our touch, especially in muscular masses, indicates, we think, quite well that we have here only a part of the information needed for successful extraction and that it requires to be completed by a method of guidance and control in order to become a process of precision.

*Needle process.*—We also count amongst the chance processes, in spite of its appearance of certainty, the process which consists in sinking a needle through the soft parts during the screen examination until its point comes into contact with the projectile. The patient is then taken to the operating theatre. The operator follows the needle and comes down on the foreign body.

This method has been recommended by a large number of German and Austrian authors, and it is difficult to say who was the real originator of it. In France, it has often been used with success by Charlier, Vergley, etc., whilst some people have adapted to it the method of a needle bent at right angles suggested by Wullyamoz (see later).

Although it may be thought that these needle pricks are harmless, we are, however, of the opinion that puncturing at random is not without danger because the needle may meet a nerve or a large vessel. Then, in the darkness of the X-ray room, the deeper the foreign body is, the more chance there may be of such an accident occurring.

However, this is not the principal objection we have to this process. It is not very difficult to insert a needle by following the normal ray, but it is then not easy to see on the screen, since it only shows as a point. On the other hand, if the needle is inserted obliquely in relation to the normal ray the method is far too laborious. We may put it in above or below, and it may be necessary to puncture several times before coming down on the projectile. In fact, there is no guide whatever for knowing the level at which to aim unless we are dealing with a limb which can conveniently be examined in two different planes during this small operation. These repeated punctures are not without inconvenience. The method which consists in inserting several needles multiplies these inconveniences, and the more or less ingenious devices proposed for facilitating and rendering the correct aim more certain demonstrate that the problem is only simple for superficial bodies which can easily be removed in any way.

*Moreover, the needle must be sterile. It can therefore not be handled by a hand in a protective glove such as that of the radiologist. The surgeon who locates it by searching with an unprotected hand is exposed to the rays to a very considerable degree, which we consider is sufficient to condemn this procedure.* Finally, is there a surgeon who would willingly use it, in certain dangerous regions, without any exact data as to depth ?

There is, besides, the possibility of the needle moving during the inevitable movements between the X-ray examination and the extraction. This is a fatal drawback, as there are no further means for re-establishing the lost route.

We are therefore right in classifying this method under the head of chance processes. It may often be useful, but it cannot be raised to the position of a general method and used systematically. We think it can only be recommended for certain units at the front, where one must try to work quickly and well—that is to say, remove the largest possible number of projectiles with the minimum of damage, and where one will thus save much time for intramuscular splinters in particular. (See the article by MM. Averous and Gouin in the *Journal de Radiologie*, T. II, No. 4).

§ 61. **Precision Processes.***—We describe as precision processes those which are based on the use of *mechanical guiding apparatuses*, commonly described by the generic term of *compass*.

These instruments, the compasses by Contremoulins, Hirtz, Saissi, Marion-Danion, have already been studied (Chapters VIII and IX) from the point of view of the theories of their working, their details of construction, and their regulation. We shall therefore only speak here of the *surgical* occasions for their use.

*Theoretically*, the preceding calculations being supposed as correct, and the regulation exact, if the projectile were immobile and the compass applied on an unalterable solid part, the information furnished by the indicating needle would involve a mathematical certainty.

*In practice*, errors of calculation and of regulation are *almost impossible*, unless the radiologist is unskilful, because certain signs, such as the absence of horizontality of the three fixed arms of the Hirtz compass, for instance, would notify the error.

Movement of the projectile inside the tissues of the body is very rare, still it sometimes happens. In that case the compasses would lead to a fatal error. However, the fact that the human body is susceptible to change of shape is the great cause of error in the use of this apparatus. The various manifestations of this susceptibility to change of shape should be studied in detail.

We shall deal successively with the extraction of projectiles with the aid of the compass, then with the inconveniences, the causes of failure, and finally with the total results derived from this apparatus.

*The extraction of a projectile with the aid of a compass.*—We shall describe here the extraction with the aid of the Hirtz compass, perhaps the most valuable and the most

* One should not fail to refer to the excellent article by Pierre Duval: "The method of extracting projectiles under the guidance of the Hirtz compass," conference held at the Ocean ambulance, at La Panne (Belgium), published in the *Revue de Chirurgie*, January 1st, 1916.

frequently employed at present, without doubt, of all similar apparatuses.

The compass has been regulated as stated above. As every surgical unit can probably only possess one compass, this apparatus should be sterilised very often by boiling. The Poupinel sterilisation can only be effected for the first projectile of the series to be extracted. It would take too long to repeat a hot-air bath sterilisation between each operation, or even between the extraction of the two projectiles in the same patient.

The radiologist who will make the "trials" washes his hands and puts on gloves, if necessary, as the surgeon's assistant.

Pierre Duval * describes the operation as follows :

"When the patient has been anæsthetised and the compass has been put in place and the penetration needle brought in contact with the skin, it gives the point of incision, the depth of the projectile, and the direction. The compass is removed. A free incision at the point marked is made, and then without forceps on the skin, without retractors, without any disturbance of the anatomical structures, incision of the aponeurosis, division or separation of the muscular fibres in the direction indicated to a depth about equal to but never greater than that of the projectile.

"At this moment, still without retractors or forceps which pull the planes apart, because, if a vessel had to be clipped, it was immediately tied and the forceps removed, the left index finger is put into the wound. Above the left hand the compass is put in place and firmly held by the radiologist. With the right hand the operator himself takes the indicating needle and presses it down in the route prepared by the left index. If the prepared route is not deep enough or is not in the right direction, the compass is removed, the route put right again or deepened by the grooved probe, then the compass is put back in its place.

"When the needle is at the end of its prescribed distance, the left index, which has not left the wound, feels the projectile at its point.

"If the extraction cannot be done without seeing it, but only in this case, retractors are inserted, the finger always keeping contact with the projectile.

* Pierre Duval, *loc. cit.*

"The principal factor is not to derange any anatomical plane, not to displace any organ when one has reached the soft tissues."

This is the ideal operation. It is, in short, a research *with the aid of the intermittent control of the compass.*

But the use of this instrument is attended with some difficulties and there are causes of failure.

Difficulties and Causes of Failure of the Compasses.—The three points marked on the skin for the legs of the compass should constitute a triangle which should be as large as possible. As they must not be covered in the field of operation, it makes it necessary to leave uncovered a large area of skin during the operation, which is sometimes an inconvenience. But most of the trouble and lack of success result from the fact that the soft parts of the patient are liable to change of shape.

*Attitude.*—The patient should lie either on his back or on his belly. It is practically almost impossible to perform an operation with the compasses on a patient lying on his side, as we often have to do in our method, for thoracic projectiles.

In fact, the attitude at the moment of operation with the aid of a compass should *strictly* be the one assumed by the patient during the preceding X-ray examination. The lateral decubitus is essentially unstable and cannot be reproduced with mathematical accuracy.

Even in the dorsal or ventral decubitus it is not always easy to re-establish the identical attitude, which is, nevertheless, indispensable to obtain success. "We have sometimes fixed this position by photography," says Pierre Duval. "A simpler means is to take a simple but strictly exact sketch of the position of the arms, the legs, the head." This "strictly exact" sketch is not always so simple to take.

*Muscular relaxation.*—"It is indispensable," proceeds Pierre Duval, "to take the radiograph with the greatest possible muscular relaxation, not to put the limbs in a position which necessitates the contraction of a muscular group, because if this contraction were to disappear during the anæsthesia, the situation of the projectile would be considerably altered."

Duval quotes the example of a bullet seated in the adductors of the thigh which changed its position as much as eight centimeters according as the muscles were contracted or relaxed, and which was missed twice.

"This necessity," he says, "to operate only in complete muscular relaxation makes the extraction of intramuscular projectiles under *Hirtz's local anæsthesia impossible*. The inevitable muscular contractions displace the foreign body and cause it to escape under the finger."

*Instruction not to separate the lips of the wound.*—It is understood that in order to carry out the Hirtz method in the course of an extraction the lips of the wound must not be separated at the moment of the passage of the indicating needle. However, as soon as the depth attains six to seven centimeters, it is impossible to introduce the needle further without making a place for it at least by one retractor. Moreover, if the needle is not pointed accurately into the line of incision, it acts itself as a retractor on one of the lips of the wound.

The compass now only rests on two localising marks, the two marks situated on the side of the incision which is supposed immobile; the third mark, being displaced, no longer corresponds to the third leg of the apparatus. It is necessary therefore, for the third ordinate, to be satisfied with the horizontality of the three fixed arms of the compass. However, the instrument, being in equilibrium on two legs, has completely lost its precision, since that horizontality is guessed at,* and the two localising points utilised may have been displaced by the forced separation of one of the lips of the incision.

*Elasticity of the tissues, muscular tonicity.*—There are tissues which when incised are spontaneously displaced. We mention certain aponeuroses, particularly that of the sheath of the lumbo-sacral mass.

In the muscular tissues it is not always possible to separate the fibres parallel to their direction without rupturing any of them. These fibres immediately resume their position on account of their tonicity, and they can, in moving, displace the projectile which is being looked for.

* For further details see the paragraph devoted to the extraction of skull projectiles in particular. It may be useful to add to the compass two small circular spirit levels.

It would therefore seem that the susceptibility to change of shape of the soft parts is the important cause of the failures of the compasses, which possess very great advantages and give the maximum of guarantee of reliability when they are applied to a part of the body which is not liable to change of shape, such as the skull, in which region the localising marks cannot be displaced. Nevertheless—this fact should be well noted—it is for these cranial projectiles that M. Hirtz * himself no longer relies entirely on the compass, but uses an "auxiliary" apparatus for extraction under the screen. We think it would have been preferable to use the intermittent control of the screen pure and simple. But in this respect we are of his opinion. One of us has once missed with the compass an intracerebral bullet with M. Contremoulins, and never since the war have we had a failure with the aid of the intermittent control of the screen.

*Failures are irremediable.*—When the needle of the compass arrives at the end of its set distance, if the projectile is not in contact with its extremity, the surgeon has no other resource than to suspend his operation and to postpone it to a future date. Whatever may be the cause of failure to find the projectile, whether this was due to a mistake in the calculation, in the regulation, in the horizontality, the elasticity of the skin, the tissues, tonicity, voluntary or reflex muscular contraction under the local anæsthesia or under a bad anæsthesia in general, it matters very little. *If the projectile is not found at the end of the needle, the operation has not succeeded.*

A skilful surgeon still might sometimes be able to find the projectile when it is in a region of little importance from the point of view of the neighbouring organs, and if the projectile is sufficiently large. However, the search is blindfold, without knowing in which direction to feel. The guiding line has been lost and very often reason counsels us not to continue under such conditions.

This is the enormous disadvantage of the compass that one is not able to reset it. On the other hand, the intermittent control enables one to find the direction of the needle again, whenever it is lost.

*Mobile projectiles.*—It is evident that when a projectile

* Hirtz, *Presse médicale*, 1916.

is mobile in the tissues, it is useless to attempt to search for it with the aid of the compass.

Much more often than one would admit it is very probable that this so-called mobility is frequently only the excuse given for the non-success of an attempted extraction.

That mobility can only be relative. If the projectile is fixed in a mobile organ such as the diaphragm, the displacement is generally not so great that the compass should prove a failure, because the operator is conscious of this physiological mobility if a preceding X-ray examination has taken place (which, as we have seen, should always be the case).

Intrapulmonary projectiles also move with respiration. If the lung is adherent the compass needle still leads to the projectile with fair precision sufficient for practical purposes. However, if the projectile is free in the lung the aid of the compass can no longer be relied upon unless the pleura is open and the pneumothorax produced has allowed the lung to retract.

In order to avoid this difficulty Pierre Duval advises a little artifice which is utilised on arriving at the parietal pleura before opening the pleural cavity.

At the point of the compass needle a curved needle is inserted through the parietal pleura into the lung tissue with a strong suspension thread, then, the lung being thus fastened to the exact point marked by the compass needle the pleura is widely opened, and the total pneumothorax produced slowly, progressively, and without danger. By traction on the suspensory thread a cone of lung tissue is made, the height of which is slightly more than the intrapulmonary depth of the projectile given by the compass. The projectile can then be felt with great ease.

However, if the thread tears the friable pulmonary tissue, the surgeon finds himself absolutely deprived of the aid of the compass and has no other guide than palpation. From the moment when the lung comes into contact with the external air through the gap in the chest wall the compasses become useless. If, in an effort of reflex coughing, the lung escapes the fingers which are holding it and falls back into the pleural cavity there will be no indication as to which part of the lung should be caught and brought out of the wound. We have often seen these cases in which the intermittent control method would soon show us the position of the projectile.

Finally, we have observed a curious case of great mobility of a bullet in the abdominal cavity. It was encysted the extremity of one of the appendices (fimbria epiploicæ) of ten to twelve centimeters long and moved with it, from time to time, from the left to the right iliac fossa. It is evident that a compass would not have assisted in finding it.

The use of compasses therefore involves a certain number of causes of failure. It is quite certain that these failures will become rarer, the better the surgeon and the radiologist know their work.

The statistics of the compass by Hirtz published by M. H. Barnsby and by MM. Desplas and Chevallier show that they have been able in 138 and 110 cases respectively to extract the localised projectiles without a single failure. In the first and the most important of these series MM. Barnsby and Hirtz were in collaboration, and in both series visceral projectiles were rare. M. Barnsby says, however, in spite of his excellent series of cases, " that he remains a warm partisan of the ingenious and valuable method of extraction by means of the intermittent control of the screen " ; later he says that he considers it as " indispensable for the intracerebral projectiles," and that M. Hirtz himself has adopted it for such cases himself, as is shown by his recent article in the *Presse médicale*.

However, the impression obtained is somewhat different when one listens to those who have used the compasses during the war without any previous special experience of its use, and who have only short unpublished statistics on which to form their opinion.

The average results of the Hirtz compass in the hand of the local surgeons will not according to our information exceed 90% of successful extractions, which is in itself satisfactory.

Abandonment of an attempted extraction on anatomical grounds undoubtedly occurs, but it is the result of a badly made localisation. It is common to all methods of extraction. The reason is that the situation of the projectile has not been sufficiently well ascertained, most often because the preceding X-ray localisation, on which the surgeon must plan out his operation and choose the way of access, was insufficiently accurately made.

PARTICULARITIES CONNECTED WITH THE USE OF CERTAIN COMPASSES.—*Hirtz Compass.*—This is the one we have taken as a type in the preceding explanation. We need therefore not say anything further about it.

*Contremoulins Compass.*—Although it was perhaps the first amongst the instruments of precision, this apparatus has never been employed except by the inventor himself. Its complexity, its cumbrousness and its price have excluded it from ordinary practice.

*Saissi Compass.*—What has been said about the Hirtz compass applies to this one at least as regards precision and especially as regards rapidity. This is a very practical instrument and can be recommended for the limbs and the lung. It should be sterilised by boiling, as there is a risk in flaming that the solder will melt.

*Marion-Danion Compass.*—It has only two localising points on the skin. It should be placed as far as possible in a horizontal position, but this is not so important as in the case of the Hirtz compass. As to the results, M. Marion had 16 failures in 362 projectiles, that is more than 4% of failure. M. Marion says: "I failed in sixteen cases, mostly referring to small shell splinters situated in the muscular masses, or projectiles located in regions anatomically inaccessible." As to the "anatomically inaccessible" projectiles, a preceding screen examination by demonstrating their relative positions would have saved him from having to give up his search for them.

The compasses by Aubourg, Debierne, Grandgérard, Jallot, Morin, etc., do not require any special remarks, and it may be taken that there is very little difference in the surgical use of these various instruments.

All these apparatuses, whilst giving a mathematical precision when correctly applied to solid parts not susceptible to change of shape, lose however greater or less part of that precision on account of the variations of attitude which exist between the patient who is conscious during the X-ray examination and unconscious during the operation, and especially on account of the changes of position of the soft parts which take place in the course of the operation. A skilful surgeon can reduce these displacements, but he cannot entirely prevent them. Applied to the patient the compasses lose the character of absolute precision which they have in the laboratory. Nevertheless they are very ingenious instruments of admirable ingenuity which have rendered and will still render priceless services especially the Hirtz compass when aided by the screen.

§ 62. **Processes of Certainty.**—All these processes are based on the same principle, viz. : the patient lies on the X-ray couch, the tube under the couch, this enabling the operator to *see* what he is doing or what he should do.

The application of these processes presumes the use of an apparatus producing high-tension current to energise the tube, an X-ray couch under which the tube provided with its diaphragm moves, and a fluorescent screen on which one can follow the position of the foreign body in the course of the operation. But there are two quite different methods for utilising the screen for the extraction of projectiles.

In the first method the operator himself is the observer and picks up the projectile when he sees its shadow and in doing so is exposed to a certain quantity of harmful rays, besides being obliged to work in special lighting conditions which are generally defective. This is *the extraction under the screen.*

In the second method, as the operation proceeds the radiologist demonstrates when necessary the point vertically below which the surgeon will find the projectile. In this case however the surgeon stands back whilst the rays are passing and only returns afterwards. This is *the extraction with the aid of the intermittent control.*

*Historical Review.*—The idea of utilising the direct control of the screen for the extraction of foreign bodies, opaque X-rays, is certainly as old as the discovery of the rays themselves. It must have occurred simultaneously to many observers and it is difficult especially at present when there is no facility for bibliographical research, to say who was really originator of this method. The following observations have therefore no claim to completeness, but only review the principal stages in this evolution of this radio-surgical technique.

Grashey was one of the first to think of a device enabling one to operate by following the operation with one eye whilst the other one could examine the fluorescent screen and verify on it the respective position of the foreign body and of the instruments. Fig. 195 gives the outline of the equipment employed and which has been several times taken up again and perfected by the originator and by several other people.

It is however quite evident that the process was only exceptionally applicable in that form. We have said (§ 5) and we have repeated it several times that in order to see well on the fluorescent screen a good receptivity is absolutely indispensable, but this is impossible to realise if one of the two eyes is exposed to the light. Besides the sensation of very great fatigue which results for the observer from the unequal work imposed upon the two eyes, he is restricted in the use of this process to the extraction of foreign bodies situated in very thin and very transparent parts, such as the hand and the foot.

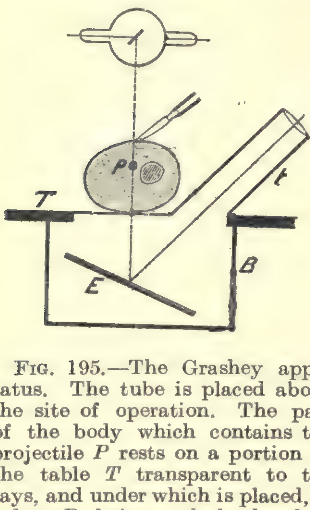



FIG. 195.—The Grashey apparatus. The tube is placed above the site of operation. The part of the body which contains the projectile $P$ rests on a portion of the table $T$ transparent to the rays, and under which is placed, in a box $B$, being a dark chamber, a fluorescent screen $E$. The surgeon can follow with one eye through the tube $t$ the projection on the screen $E$ of the shadows of the extremity of the bistoury and of the projectile.

It was this frequent and well-known difficulty in the search for needles in the limbs, especially in the hand, in spite of numerous and excellent radiographs, which caused the method to be evolved, and it was to their extraction that those who practised this combination of radiologist and surgeon had to limit themselves almost exclusively. The evident advantages which ability to see the foreign body in the course of the operation presented to thinking people caused them to look for a method making it available for opaque foreign bodies of the thick regions, that is to say, in conditions which demanded good radioscopical receptivity. Operations were then undertaken in the darkness of the X-ray room, the tube being placed under the table. The operation took place in feeble light with a coloured or obscured source of illumination. Thus the receptivity was perfect and permitted a sufficiently satisfactory view on the screen, which was placed above the site of operation when its assistance was required. It must be pointed out that in this darkness the possibility of asepsis was often doubtful and that difficult operations in deep or dangerous regions were contraindicated. We need only mention the difficulties and dangers of the anæsthesia. Under these conditions the radio-surgical combination was perhaps still less satisfactory than in the preceding case. Its application is almost exclusively limited to a few cases, surgically simple, most often operated upon the radiologist. Besides, the insufficiency of material at the present moment will not allow the regular use of this method. With the progress of this technique a series of French, American, and German publications have appeared on this subject between 1904 and 1910.

The projectiles searched for with the screen were most often not accurately localised beforehand. At most the two radiographs at right angles or one localising screen examination gave an approximate idea of its supposed site. Under such conditions the search, even under the screen, was sometimes singularly difficult and long, and often unsuccessful. Wullyamoz originated a process which theoretically at least gave certain and rapid access to the projectile.

He uses * to effect the extractions (in any kind of operating room and in daylight, of course employing an X-ray couch and a fluoroscope) instruments, especially his forceps bent at a right angle. The forceps are shown in Fig. 196. The width of the point is only two millimeters, so that it can penetrate easily into the tissues like a needle. The two blades can be slightly separated from the point upwards, so that their image appears on the screen of the fluoroscope and enable the operator to know where the

* Wullyamoz (of Lausanne), *Extraction of Foreign Bodies by means of Right Angular Forceps*, Paris, Maloine, 1911, 8° pamphlet, 54 pp., 34 illustrations.

forceps are and in what direction. There are several types in which the length of the bent part is more or less long, according to the depth at which one has to operate. The five illustrations on p. 299 show clearly how the operator who is about to search for a foreign body in the tissues should place the extremity of the forceps in order to reach it. Briefly he guides the bent part of the forceps in the axis of the normal ray which passes through the projectile and causes it to follow exactly that ray until contact is established with the projectile.

FIG. 196.—The right-angled forceps of Wullyamoz.

A series of instruments based on the same principle: rectangular separators, hollow needles for local anæsthesia, rectangular bistouries, complete the surgical outfit. All these instruments are difficult to use, and only the bent forceps with short arms should be retained which may be of service for superficial projectiles or the forceps with long arms for soft organs, such as the lung and the brains. Its relative advantages do not outweigh the inconveniences of such an extraction which is not a good surgical procedure and where the interference of the radiologist however little it may be is always undesirable.

Finally, an argument which dominates all the others is the danger of radiodermatitis inherent to the method and we ask ourselves how Wullyamoz could have written in his pamphlet (p. 24) the following sentence:—"We prefer especially (as a couch for extraction) the type in which the patient is lying on a board and not on webbing. *In this manner the soft rays are stopped by the wood which acts as a filter and protects the patient and the surgeon against all dangers of radiodermatitis.*" We cannot sufficiently protest against that assertion and warn surgeons against it.

Moreover, the bent instruments are very inconvenient in practice. The rectangular forceps grip very badly and can have very little force applied. Finally, what kind of an operation is it in which instruments are blindly sunk into the tissues without one's being able to control the damage caused ? It may be tolerable in the thenar and hypothenar eminences, but accidents have already been reported in the palm of the hand (injury to the palmar arch).

Nevertheless, especially for the extractions of needles the facilities offered by the various modalities of the new science were such that most of those who have used it have returned to it willingly, and nearly all devised in turn radio-surgical operating tables, the most perfect type of which was suggested by Haret and described by him at the Milan Congress in September 1906 as follows : "The table measures 1 meter long by 60 centimeters wide ; another

197 198 199 200 201

FIG. 197.—The bent forceps are used for searching for the foreign body and are here directed exactly on the foreign body.

FIG. 198.—The extremity of the forceps deviates to the right.

FIG. 199.—The extremity of the forceps deviates to the left.

FIG. 200.—The extremity of the forceps deviates above.

FIG. 201.—The extremity of the forceps deviates below (according to Wullyamoz).

ordinary table can be applied to either end in order to form an operating table of the required length.

"The X-ray apparatus is fixed under the first table on a carriage movable in all directions. The diaphragm is formed by two sheets opaque to X-rays and pierced by two notches, which can be brought near or moved farther. The screen is carried by a vertical support and can, by means of a simple mechanism, be placed above the patient at the will of the surgeon. The aseptic technique is not in any way interfered with by the X-ray examination, as the site of operation can be easily covered with sterilised towels which are transparent to the rays. This device is destined to render great services in the search for foreign bodies."

However, the relative infrequency of the extractions of foreign bodies compared to other operations caused only a few surgeons to adopt the fresh procedure the technical complication of which appeared to them much out of proportion to the results obtainable. Besides the aid of the screen which was used by all the observers presented a number of inconveniences. Those who operated in daylight obtained a very imperfect vision, only enabling them to extract very large bodies, or those situated in the regions of small thickness. Those who operated in a dark chamber were exposed to a series of operative accidents, considerably limiting the usefulness of the method. Those who made the radiologist perform the extraction limited also by this very fact the applications of a process which became not strictly surgical. Finally, all took absolutely insufficient account of the considerable risk of radiodermatitis to which the hands of the surgeons were exposed, which hopelessly condemned the process. It did not therefore come into general use in spite of the fresh efforts made from time to time in France as well as abroad. But none succeeded in removing the defects pointed out, although the fluoroscope with its human eye-glass, an indispensable element for success, had been invented a long time before by Seguy, and reproduced in a diminutive form in the manudiascope of Bouchacourt.

The present war, whilst giving to the surgery of projectiles an importance never thought of previously, should soon restore to honour all the different methods which have been modified and more or less perfected of searching for and extracting them.

M. Mauclaire, for instance, has worked at the solution which consists in operating in the dark.* Although he may have been able to extract projectiles satisfactorily in this manner, he has nevertheless not found any imitators, which can only be too easily understood. †

M. Rechou has happily modified the Wullyamoz process and has justly insisted upon the absolute necessity of a

* See also the excellent series by M. Brindeau, *Bull. soc. chir.* 1915.

† He has, moreover, recently brought his process nearer to ours and adopted the "intermittent" control. See *Soc. chir.*, October 31st, 1916, p. 2425.

preceding localisation, but the interference of the radiologist in the surgical act does not seem to us to be justifiable.

The problem has been studied in several regions at the base, and M. Lobligeois has made use of the assistance which the radiological motor van services could give, which can be perfectly well used for operations under control.

We ourselves, since the creation of special centres, have recognised the incomparable advantages which the control of the screen presented if it were possible to utilise it with simple technique, really surgical and free from inconveniences mentioned. After numerous trials we think we have succeeded in this and we shall describe later in full the manner of procedure which we have adopted.

Our publications and those of the surgeons of the ninth region, who all adopted our process definitely after having tried it, contributed to propagate the method which is to-day in use at most of the bases as well as in the army zone.

Our method of procedure is based upon the collaboration of the surgeon and the radiologist and aims at leaving to each his part, ensuring a genuine surgical operation and saving the surgeon from many errors which are inevitable without adequate radiological evidence.

However, the number of professional radiologists is very small in proportion to the number of radiological installations at work. Certain authors have therefore tried to find a solution in enabling the surgeon to become his own radiologist. They were met by the insurmountable difficulty of providing for one and the same operator a lighting of the field of operation, which is never too perfect, whilst allowing a visual accommodation which darkness alone gives.

We may mention that M. Bergonié has recommended operating in red light, his idea being that since red is the complementary colour of green, the surgeon's eye will accommodate to greater advantage to the green colour of the fluorescent screen.

There is no need to point out the various inconveniences of operation in semi-darkness. This method has an added disadvantage in the difficulty of arresting hæmorrhage from a bleeding surface which can be seen with difficulty. Moreover, the argument in its favour is theoretically inaccurate. The careful research work of Parinaud has shown long ago that the retinal sensibility increases most rapidly in violet light whilst it increases much more slowly in red. If one really wishes to utilise this idea of operating in monochromatic light of little intensity it will be necessary to use violet light as the monochromatic light without being prejudiced by the fact that violet is not the complement of green, the light of greenish fluorescence of the screen being far from being a single colour, representing on the contrary a composite mixture.

M. Petit (of Château-Thierry) has also used the screen with red light. What is evident from his publications is that one can extract projectiles by this process, with the valuable aid of the screen in spite of the considerable inconvenience experienced during the operation by the red light, extremely tiring in itself, as can be easily proved by a somewhat prolonged stay in a photographic dark room, and which very often causes extreme fatigue and even sickness in the case of certain surgeons.

As to M. Mouchet, he has modified the extraction in red light by wearing a frontal mirror by Clar, because he could not see sufficiently well without it to operate satisfactorily as he himself has admitted. Operating in an artificially lighted room would give him the same advantages without the inconveniences. M. François operates in the same manner, but with a black background, but we think this means complicating matters too far.

We are now going to describe our method in full after having given some general indications with regard to the X-ray outfit (refer also to Chapter IV).

§ 63. **Extraction with the Aid of Intermittent Control.**— The principle of the method which we recommend is the following: At the moment when the surgical operation is to begin the radiologist indicates by means of a point the exact spot corresponding on the skin to the normal ray passing through the projectile.

The operator need therefore only cut down vertically to find the foreign body. If he does not find it at the supposed depth in the gaping and widely separated wound, the surgeon asks again to be given the point where the normal ray corresponding to the projectile ends at the bottom of the wound. Then he resumes his search. The vertical line of the foreign body is thus supplied by the radiologist as often as required, but while he does so the surgeon stands back and does not expose himself to receive any harmful rays.

Were we the first to employ this method? This is hardly probable. In view of the danger of the injurious rays the idea naturally occurred to cut off their emission at intervals.

However we have improved the details of our method and made them more precise. We have shown that the operation should not proceed, except during the period when the emission of the rays is suspended. We have succeeded in arranging that the surgeon should at no time be reached by the rays. The radiologist, on the other hand, has only to do work to which he is accustomed and in the course of which he can effectively protect himself if he has learned how to do it.

In fact, we consider it a duty on the part of the surgeon not to expose his hands to the harmful action of the rays.

This precaution is legitimate. The hands of a surgeon who has taken many years to become perfect in his profession belong not only to him and those he calls his own, but also to his hospital service and to his country. The surgeon's hands are his fighting weapons which he has no right to injure uselessly, his duty being to safeguard them as far as possible. It is possible to do so, as we are going to prove hereafter.

THE NECESSARY RADIOLOGICAL INSTRUMENTS.—What is required in order to carry out extractions with the aid of the intermittent control of the screen?

From the X-ray point of view any outfit which should include a couch with a tube carrier with diaphragm beneath it, movable in all directions, will be suitable if it is capable of producing from 1 to 2 millis in a fairly hard tube (10 to 12 centimeter spark at least). This is a condition which is at present fulfilled by even the most modest installations, and as regards this we simply refer to the conditions given in Chapter IV.

The couch constitutes the most important part of the installation. The ideal one is represented by the metal table so arranged that one end can be quickly tilted up for abdominal operations—such as we have had constructed by the firm of Gallot-Gaiffe and which we have reproduced in Figs. 68, 69, but the couches by Drault of the Béclère type, by Gallot-Gaiffe of the Belot type, the Rechou type, the tables of the X-ray cars by Gallot-Gaiffe, etc., will also be found to be extremely satisfactory for the work required. Finally, one can—we are not afraid to emphasise it—even do the work perfectly well with a much more rudimentary material, and can improvise almost everywhere much less expensive yet adequate "radiological couches."

A "bonnet" (or a band fluoroscope) will complete the X-ray outfit. It may be an ordinary fluoroscope, and one will do well to provide oneself in that case with a pair of spectacles, the lenses of which are of very dark smoked glass

A B C D E

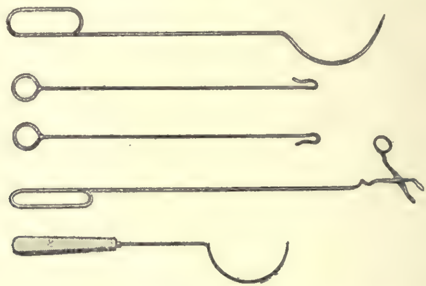


FIG. 202.—The sighting needle (*E*) which we use for the first control. It should be at least 50 centimeters long, so that the hand holding it remains safely outside the cone of rays during the aiming. The large control needle (*A*) *should not be less than forty centimeters* long. The same applies to the two separating hooks (*BC*). A pair of forceps (*D*), mounted on a stem of the same length, will sometimes be useful for sponging the blood in the wound during the control (*Gallot & Co.*).

(see Chapter IV), or, what is simpler and more convenient, with a Dessane eclipse-fluoroscope.

We wish to draw attention to an indispensable precaution which consists in never undertaking an operation with the aid of the intermittent control if one does not have at disposal a *well-trained* spare tube which can replace at once the one which is under the table in case the latter should become useless.

From the surgical point of view, a sighting needle of the kind which is represented by *E* in the figure 202 (Gallot-

Gaiffe), which can easily be replaced by any other suitable instruments, even by a rod of thick iron wire, or still better of brass wire, another one, longer (shown by *A*), easily replaceable by two retracting hooks *BC*, quite simple to improvise and which can, besides, be substituted by several pairs of forceps hooked together, two Ombrédanne separating forceps (Fig. 203), constitute all the special material required. It is advisable to add a hysterometer, suitable for measuring the depth.

It will be seen that there is nothing complicated in this outfit, nor anything which cannot be ordinarily procured in all the more important centres at the base as well as in the army zone. Moreover, all the X-ray cars lately mobilised are provided with the Dessane Bonnet and needles of our pattern.

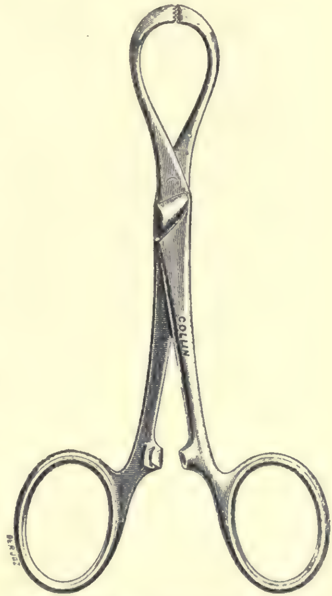



FIG. 203.—Ombrédanne retracting forceps (Collin type). These forceps, which were used long before the war, do not cause the skin to necrose at the points of contact. The Ministry of War supplies them at present to the surgical units.

LOCALITY.—In any place where there is no X-ray installation a room in which the operation can be performed is all that is necessary, so that by ordering up the X-ray car with which each army as well as each base is provided (there are generally several cars for each army and two for each base), it should be possible to start to operate with the aid of the intermittent control within an hour.

The problem seems less capable of being solved in a satisfactory manner in the civil establishments, such as especially the Paris hospitals, or in private hospitals and clinics—at present so frequently converted into auxiliary hospitals. The latter hospitals, although they have in principle no right to any free X-ray supply by the Health Service, have been authorised by a ministerial circular to avail themselves of the X-ray cars free of charge.

As regards the hospitals in which there are often radiological laboratories a long way from the surgical department and where it would be very inconvenient to go in order to operate, it seems that transportable X-ray outfits of the type which one of us had constructed by the firm of Gallot-Gaiffe as described above (§ 14) represent an ideal arrangement *which can be immediately installed in any operating theatre which is provided with electricity.* It seems that this will also be the most perfect arrangement for the hospitals and clinics which are still without X-ray installations and which will ultimately not be able to do without them, since it lends itself admirably to all the screen and X-ray examinations of ordinary practice, whilst it has the advantage of costing relatively little.

One of us was able, without any previous trial, to go to the Salpêtrière and install this outfit in any room, examining the patients and localising their projectiles, then transferring the whole outfit to the operation room of Dr. Gosset, who effected with the greatest facility, with the aid of the intermittent control, the extraction of difficult projectiles which had already been looked for in vain several times.

Therefore, no matter what the conditions may be, it will be easy to adapt them to the very small requirements of our method for effecting extractions with the aid of the intermittent control.

Lighting.—In the case of difficult and deep extractions as well as in the case of any delicate operation the lighting at disposal is never too perfect. The fact that one of the dominant considerations in the choice and establishment of operating theatres is a good lighting supply is enough to show how illogical and contrary to common sense are the methods which place the same surgeon in darkness or semi-darkness when there is really nothing to make this necessary.

The ideal for every surgeon obviously is to operate in *his* operating theatre and *in full daylight.* This ideal can be realised either with a transportable outfit of the kind which we have described above, which can at will be immediately installed in the theatre if the latter is provided with the electric main supply, or with the necessary X-ray outfit.

In certain cases, however, it will be convenient to operate in the X-ray room specially arranged for that purpose. This is the solution we have adopted at Tours on account of the local arrangements. In similar cases the natural light of the room is generally insufficient for looking for a projectile in a deep wound. We have, moreover, seen Pierre Duval installed in a luxurious hotel and operating in full daylight with a compass, availing himself also of an electric lamp which was directed on to his field of operation. At Tours we do not possess a theatre with top lighting as we are working in a school, and we have therefore thought it most advantageous and simple to look for our projectiles by artificial light. Need we say that it should be as abundant and convenient as possible ? This lighting can be altered at will. Lamp holders with powerful reflectors can be placed in every direction and light at will the field of operation (this being a resource which may frequently be useful for operations carried out in full daylight). Finally, all precautions should be taken to have spare fuses ready so that there may be no lack of illumination for more than a moment in case of their burning out.

In these conditions the artificial light gives the surgeon when he is accustomed to it the same facilities as natural daylight, and allows the radiologist the great advantage of an almost instantaneous receptivity if he takes care not to place himself where the light is strongest.

However, whether one operates in daylight or artificial light, in an operation room with special movable apparatus or with the outfit of a X-ray car in an improvised operation room, or finally in the usual X-ray room, *the procedure will be exactly the same*, the radiologist being receptive and capable of remaining so as we have pointed out.

We will now describe in full our technique at the operation itself.

§ 64. **The Operation with the Aid of the Intermittent Control of the Screen.**—*Preparation of the patient.*—The existence of the projectile having been ascertained, its depth determined from a favourable point of access, its topographical situation fixed, and the operation decided upon, all the information required is complete, as we have pointed out. The patient has been prepared, as for all surgical operations, under general anæsthesia (ether : Ombrédanne apparatus).

*Preparation of the room.*—Two tables are prepared : in the centre is the X-ray couch of thin wood covered with aluminium under which is the tube which can be moved in every direction. This is the operation table.

At the side a strong table or a trolley can be used for the early stage of anæsthesia, so that if he makes violent defensive movements at the beginning of the anæsthesia there is no risk of his breaking the thin board of the X-ray couch (Fig. 204).

If cushions are required, these, of course, should consist of bags filled with oats transparent to the rays, not opaque sand-bags.

The anæsthetised patient is placed on the X-ray table in the position indicated by the operator. The latter takes his place at one side opposite the radiologist, who should have in his hands the handles which actuate the movements of the tube shield and the diaphragm. (It is nearly always easy to place the patient in such a position that the respective positions of the surgeon and of the radiologist can be taken up without any hindrance to the course of the operation.)

During this time the radiologist has put on his fluoroscope and allowed his eyes thereby to become accommodated.

*Preparation of the region.*—The operation zone is disinfected and protected as usual. The four towels being fixed, *a fifth is thrown over the whole.*

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Explanation of Fig. 204 (p. 309).—The operating theatre—whether an ordinary theatre or an X-ray room specially arranged for that purpose—has been prepared as usual and according to the surgical requirements of the proposed operation. To the left is *the X-ray couch which will serve as the operating table*, covered with a sterile cloth. To the right the patient is anæsthetised on a solid table in order to protect the X-ray couch from the violent defensive movements which are so frequent at the beginning of the anæsthesia, as the table may be damaged. A trolley on wheels can be used to advantage for the beginning of the anæsthesia. Once properly unconscious the patient is carried to the X-ray couch and placed in position for the operation (from a drawing by J. G. Goulinat).

Fig. 204.

"The Point" (Figs. 13, 14, 15).—Whilst the operator and his assistant prepare their instruments the radiologist steps forward. He looks for the projectile, centres it, *then closes his diaphragm to such an extent that he only leaves on his screen an area about the size of a 5-franc piece illuminated with the shadow of the projectile in its centre.*

He is then handed a sterilised pointed rod. We have for some time used a Doyen needle or one similar to it. However, it is as well to use a thicker instrument which would be seen more quickly. Further, after having tried a rod bent at a right angle, according to the Wullyamoz principle, and having ascertained its uselessness, we have adopted, because it catches less in the towels, the thick bent rod pointed at its extremity and mounted on a metal handle, represented by E in the illustration. Its convenience recommends its use, but in its absence any kind of metal instrument may be used instead. No matter which is adopted, the radiologist places its point on the skin (Figs. 205 and 206) in the centre of the image of the projectile (or at any other part of the image, point or base, for instance in the case of a bullet, etc.). Fig. 207 gives an idea of the image which the screen in his fluoroscope will supply if he has just "given the point" to the surgeon over a bullet. He gives the order "Stop." The current is cut off.

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Explanation of Fig. 205.—The anæsthetised patient is placed on the X-ray couch in the position for operation, and care has been taken that this is done in such a manner that the side of the couch where the controls are is opposite to the side occupied by the surgeon. The operation region is prepared, asepticised, the towels are placed as usual. *Then a large supplementary towel covers the whole region.* At that moment, *and at that moment only*, the surgeon and his assistants stand aside, the tube is set going, and the radiologist, with his fluoroscope in position, approaches and looks for the foreign body. When he has found and centred it in the middle of his diaphragm reduced as much as possible, the needle previously sterilised shown on Fig. 202 is handed to him, or any other instrument which can serve the same purpose. He places the point of this needle at the level of the point of exit of the normal ray and pricks the skin at that spot (see Fig. *K*). The tube is stopped, the surgeon approaches, raises the fifth towel and makes sure of the situation of the point thus marked. He knows *that a perpendicular dropped from that point to the plane of the table passes through the projectile.* The radiologist retires and the surgeon commences his operation as usual (from a drawing by J. G. Goulinat).

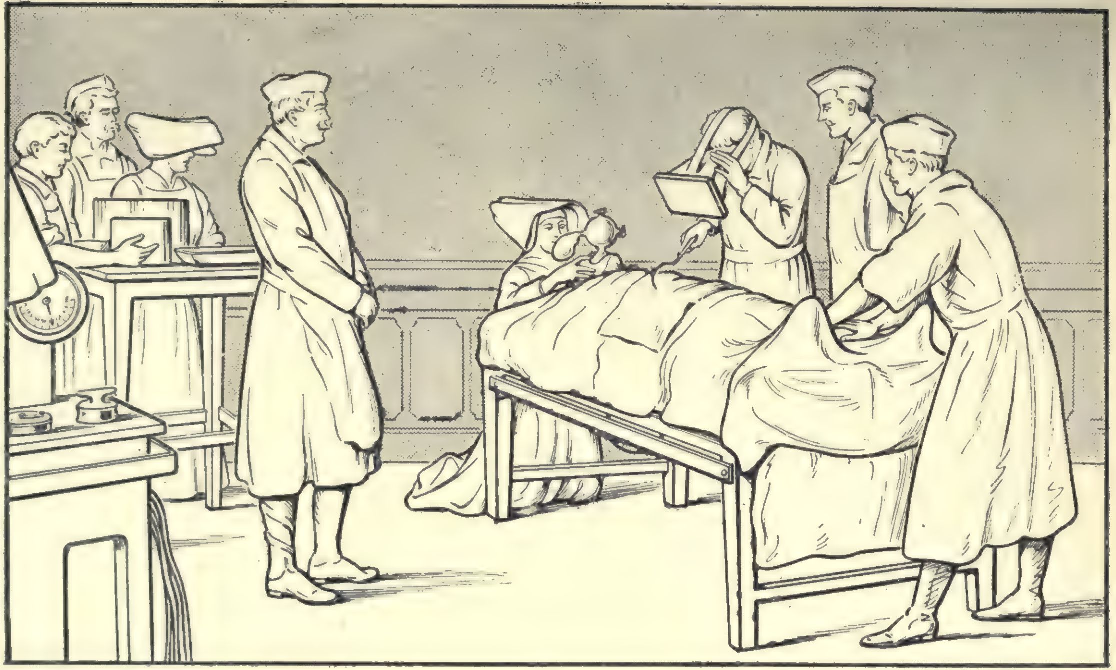
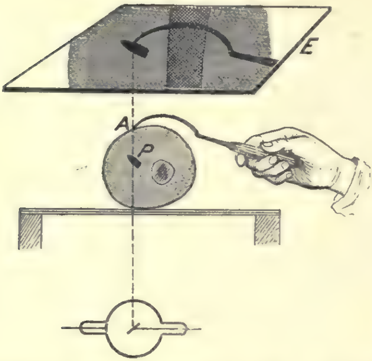


FIG. 205.

The surgeon steps forward, raises the fifth towel, and




FIGS. 206 and 207.—These figures show what occurs when the radiologist "gives the point" to the surgeon at the beginning of the operation, that is to say when he makes the shadow of the projectile (or of a particular point of this projectile, here the middle part) and the shadow of the point of his needle coincide on the screen. In order to do this he keeps the curve of his needle in an almost horizontal plane. He raises it afterwards, making it describe a quarter turn and presses its point slightly into the skin through the sterile towel which covers the operation area. He thus marks, at the last moment, the point of emergence on the skin, at the level of the incision line chosen, of the normal ray passing through the projectile. It is this normal ray, *this imaginary plumb-bob*, by means of which the radiologist will enable the surgeon to find the direction again in subsequent examinations. In this diagram one has assumed that this manœuvre was carried out on a simple screen and without using a diaphragm. In practice this is not so, of course. As soon as the projectile and the needle are seen, the radiologist cuts down his diaphragm as much as possible, and the drawing 207 shows us the image which he obtains on the screen of his fluoroscope.

sees through it the point of the needle pressing down the skin.

Frequently this puncture is at one or two millimeters from the marked localising point. Again, the distance is often two

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EXPLANATION OF FIG. 208.—When coming to the level of a bone and wishing to be sure of passing it at the most suitable point, or when having reached the indicated depth and wishing to know the exact direction in which the projectile is, the surgeon requests the radiologist to give him a control, that is to say, to give him exactly the direction of the normal ray passing through the projectile (from a design by J. G. Goulinat).

FIG. 208.

and even three centimeters out when the position of the patient is not a normal one, or when the lower limb is concerned,

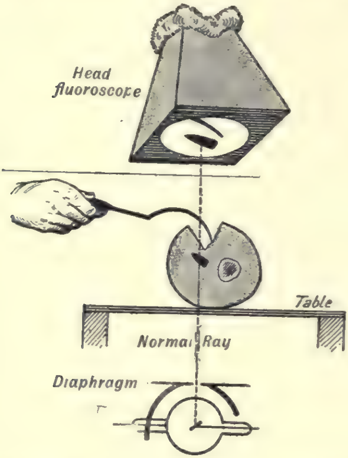



FIG. 209.—This diagram shows what occurs when the radiologist makes a control examination. The surgeon has placed the point of his large needle on the point of the wound which he thinks corresponds to the normal ray passing through the projectile. The radiologist looks and ascertains, seeing on his screen the image of the figure 210 *A*, that the point of the needle is badly placed. By his first instruction ("move back two centimeters"), he makes the surgeon bring his point back to the level of the projectile (Fig. 210 *B*). By his second instruction ("one centimeter to the right"), he effects the coincidence of the shadows (Fig. 210 *C*). The point of the needle is on the course of the normal ray passing through the projectile. The surgeon has only to go deeper, following this direction vertically. The instructions given should always be extremely precise and clear and should preferably be given in relation to the position of the surgeon.

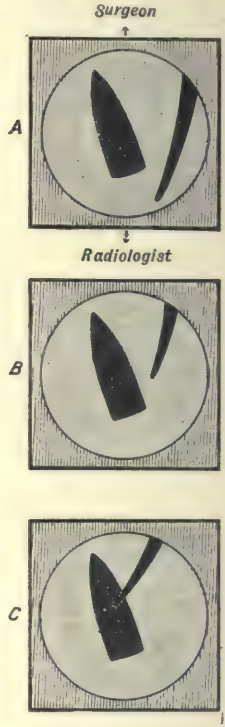



FIG. 210.

which it is very difficult to replace in a position identical to that in which the localising mark was made. These are the cases which most frequently cause the projectile to be missed with ordinary radiographical methods, although this difference does not hinder our extraction in any way. The surgeon asks for the figure of the depth to be repeated, and makes his incision through the puncture in the skin.

He then proceeds vertically downwards towards the projectile until the required depth is reached or until he reaches the level of the bone. Sometimes the projectile is found at once. This is a rare occurrence in the cases with which we have been concerned.

FIRST CONTROL.—In the ordinary case nothing is seen at the depth stated, and the period of groping for the projectile would commence, or one may be on the level of the bone, when one must proceed carefully. The operator stops, ties any vessels to free the field of operation from the forceps which would interfere with the view of the foreign body, and says to the radiologist: "*A look.*" The surgeon and his assistant move away. A towel is thrown over the patient. This towel is raised by the two corners at the side of the surgeon who can look underneath, whilst the radiologist with his fluoroscope is on the other side above it (Fig. 208). During this manœuvre the wound is kept open by the following means. In the rings of each of the Ombrédanne retracting forceps (Fig. 203) is placed a steel wire 40 centimeters long (Fig. 202, *BC*). By means of that hook the surgeon and his assistant keep the sides of the wound open. The radiologist now makes his second observation. Instantaneously he finds his projectile again in the centre of the luminous spot, and says, "*I see it.*" The operator then comes forward, holding in his right hand a large needle of the same type as the one which was used for the sighting, but 40 centimeters long (Fig. 202, *A*). If necessary, he stops the oozing of the blood by means of forceps carrying a compress, also 40 centimeters long (Fig. 202, *D*).

Then, placing the point of his needle at the bottom of the wound (Fig. 208), he asks: "Is it there?" and displaces it until its shadow coincides on the screen of the radiologist's fluoroscope with that of the projectile (Figs. 209 and 210). The radiologist indicates to him: "Front, back, left, or right," then "You are there," and "Stop." The tube is cut off. The assistant removes the fifth towel, and the surgeon, having at the end of his instrument the exact point of the bottom of the wound corresponding to the projectile, proceeds to go deeper.

SECOND CONTROL.—Very often the projectile is reached at this control. If in proceeding we come upon a viscus, a second even a third control examination may be necessary, which is done in exactly the same manner. Sometimes the surgeon has to ask as many as five or six times, even more, for the "look" of the radiologist in very difficult cases. It matters little, it is only a question of a minute. Frequently also, when a retained bullet has been extracted, for instance, the surgeon will have to ask the radiologist to verify whether the whole of the apparent shadow has disappeared.

This is our procedure. By this method, except in the case of a badly planned operation which necessitates the abandonment of the search on account of a physiologically insurmountable obstacle, an anatomical anomaly, or an accident impossible to foresee, such as a serious collapse from the anæsthetic, the possibility of failure cannot be conceived, seeing that the operator can ask again for the right direction whenever he loses it. Guided step by step, no matter what the position is, the nature, and the size of the projectile he has decided to recover may be, he is sure of extracting it. The moral confidence which this certainty gives should certainly not be neglected.

His only care should therefore be to follow the ray perpendicular to the plane of the table, the ray on the axis of which the foreign body is, and of which the radiologist has marked at the beginning of the operation the imaginary point of issue on the skin in the position chosen. He knows that by following that ray, the direction of which is easy to follow, and which will be demonstrated to him again as often as he likes, he cannot but find the foreign body. Certain interosseous projectiles furnish one of the most simple applications of the method. When placing the shadow of the foreign body in the centre of the ring of a trepan, all that need be done is to bore vertically into the bone in order to find the projectile without any groping for it. We are surprised that this method, especially in the case of the skull—the method having been very well explained before the Surgical Society by Lefort and

Desplats—has not yet been adopted unanimously by surgeons.

*Inherent dangers as regards the absorption of the rays.*— The intermittent control, carried out according to the technique which we have just explained, does not appreciably lengthen the duration of the operation. A control examination by the radiologist with his fluoroscope does not take longer than putting a compass in place in the course of an operation. Every Monday morning from 9.30 to midday we undertake five difficult extractions. For those who know the time taken up by the dressing of the patient operated upon previously, the quick cleaning, the arrival of the next patient, the time required for the anæsthesia, the average duration of half an hour constitutes what may be called a rapid operation, where the actual operation itself only takes a few minutes.

As to the complications which may follow, they are much more apparent than real, since we have seen that at any radio-surgical centre or at any place possessing a special outfit any kind of operating theatre is immediately available without any other preparation than setting up the X-ray table and operating on it. This means that this method can be applied anywhere where an X-ray equipment is installed, particularly at the front as well as at the base. In civil life, apparatus like that which one of us had made by the firm of Gaiffe and which we have described and shown above (§ 15) will fulfil the same purpose in any kind of hospital service and in any kind of clinic.

Besides, the communications made to the Surgical Society since the beginning of the war by MM. Pierre Delbet, J. L. Faure, Goset, Imbert, R. Lefort, Mauclaire, Potherat, Routier, Schwartz, Soulignoux, Temoin, Toussaint, etc., have shown what interest is shown everywhere in the extraction of projectiles under the control of the screen by reason of the incomparable facilities which it offers. It seemed useful only to determine by experience the exact method to be employed for combined X-ray and surgical manipulation. We think we have succeeded in doing this, and a communication by M. Brin to the Surgical Society shows well the facilities which our procedure has afforded him.

We are now going to show that with the precautions taken by us, *our method has*, in the case of ordinary extraction of projectiles under the screen, *the advantage of suppressing absolutely all the risks of radiodermatitis.*

*In order to avoid this calamity there are two conditions to be observed by the radiologist if he strictly observes the precautions indicated by us; namely, the various means of material protection, on the one hand, and the short times of exposure on the other.*

*Finally, protection is assured absolutely for the surgeon* from the fact that, never being himself exposed to the rays thanks to the very simple arrangements which we have described, or some other similar arrangement, consequently he will never feel any harmful effects.

The radiologist finds himself under the ordinary conditions of a screen examination. The table has an aluminium top. The cryptoscope is provided with a fluorescent screen already rendered very opaque in itself by being covered with lead glass. The radiologist puts on his protecting gloves and must not take them off. He can besides wear if he likes an apron of opaque rubber and also spectacles of lead-glass, but we think these are superfluous.

The tube is protected in such a manner as not to emit lateral rays.

In the first place, the protective shield of lead glass or ebonite mixed with opaque salts only allows the emission of rays in the form of a cone. The adjustable diaphragm attached to it continually restricts that cone during movements of the tube in such a manner that the rays *never spread beyond the fluorescent screen* which is fixed to the bottom of the cryptoscope. Moreover, in our model of X-ray table, lead screens are adapted to all sides so as to protect laterally the legs and feet of the surgeon, radiologist, and even of the anæsthetist. In the case of other types of X-ray tables it is easy to achieve the same results by means or ray proof cloth.

It is of importance to examine carefully all the shields and all the protective glasses and never to forget to put on gloves in order to be protected against dermatitis. This is shown during the war by the example of radiologists, who in their X-ray vans often make an *average* of more than ten screen examinations per day (our colleague Viallet has made 1,097 in four months in our district, and one of us has sometimes made more than 50 in one day) without any harm to their hands owing to their taking the necessary precautions.

Besides, it must be considered that those radiologists whose names are well known everywhere, and who have suffered extensive damage from the rays, obtained their painful and sometimes terrible lesions in years gone by by using a technique now recognised as essentially dangerous and in which their hands were constantly directly exposed to the rays without the interposition of any protective substance. Moreover, there is in these cases a particular kind of sensitiveness ; the smallest quantities of radiation falling on the skin already attacked are sufficient to cause a chronic dermatitis (see Chapter IV).

Take, on the contrary, the case of radiologists, who have come in prolonged proximity with rays since the danger was well known and have taken precautions to interpose opaque substances, and one will find that their hands are free from injury. If any of them shows marked lesions, he has either momentarily neglected the necessary precautions or, being too confident, has used gloves and lead glass insufficiently opaque without first examining their opacity, or has noticed their defects too late. The others are free from injury, although most of them practise radioscopy as we do day after day and are facing a tube working almost every day for several hours. They know now how to take the necessary precautions.

The surgeon benefits in the first place by all these material protections against lateral radiations from the tube.

During the first entry of the radiologist for the " POINT " he stands two meters away from the table, where he cannot be reached in any way by the rays.

During the first control and the following controls he comes somewhat nearer.

Ordinary gloves do not protect the hands. The Mauclaire gloves are no better. Let us presume his hands are bare.

At that moment the sheaf of rays is reduced to the diameter of a 5-franc piece. His hand need not penetrate that cone, since the instrument he handles offers, in the case of the types adopted by us, a minimum length of forty centimeters, and penetration takes place only in the cone of rays.

The hand of the surgeon never receives any rays, since it need not ever be placed in the only path illuminated by the rays. He is therefore essentially safeguarded against any accident. M. de la Palice's axiom which should be emphasised is that the risk run of acquiring dermatitis is absolutely nil. Extraction with the aid of intermittent control presents therefore infinitely greater guarantees than direct extraction by the surgeon, who in the latter method receives on his hands the cone of X-rays, and *we can affirm to all operators that if they will follow our method strictly they will not run any risk whatsoever*.

All those who practised direct extraction under the screen according to the old method are so aware of the extent of the objection that they have tried to find means of protection. For instance Mauclaire has recommended an opaque paste * with which the operator should cover his hands before putting on his rubber gloves. Apart from its great inconvenience, this paste, which it is impossible to apply in an uniform layer and sufficiently thick, does not ensure anything but an illusory protection as the experiences of Lance have shown and as can be easily imagined. Therefore this method in our opinion adds to the danger. Whilst working the operator believes that he is protected and consequently is less afraid of contact with the rays and is therefore more exposed to danger. If one uses gloves which are *really* a protection, their thickness and want of pliability would make it impossible for the wearer to do his work properly.

This exposure of the surgeon's hands to the action of the rays is considered by us to be a fundamental vice of this method, a vice which nothing can at present alter. No matter how much it is persisted in, we, together with Pierre Dellot and other operators, give our warning against it, and we condemn the method most strongly, since we have another method which enables us to escape entirely any risk of dermatitis, whilst giving at least equal, if not better, results.

* We may mention his formula : Thick rubber solution, called by motorists *dis-solution*, 90 grammes; mineral essence, 50 grammes; carbonate of lead, 100 grammes, ground up in a mortar, passed through a silk strainer, and spread out in a layer. Four layers to be applied. Let it dry half an hour between each layer.

There is every advantage in making the professional radiologist look at the screen and avoiding the necessity for the surgeon to make his eyes receptive.

DIFFICULT CASES.—Is it then always easy to extract any kind of foreign body by the method which we recommend ?

The answer is positive when the incision follows a vertical line, in the same direction as the ray going from the projectile to the screen—and negative when the incision has to follow an oblique course in relation to the normal path of rays.

The latter case is illustrated by projectiles situated between the scapula and the costal margin, or by those of the internal iliac fossa arrested near the iliac bone or the sacro-iliac synchondrosis or by those which irritate the roots of the sciatic nerve, etc. These we shall mention further in the following article.

The indicating needle which the surgeon employs may have its extremity apparently situated on the projectile, and may nevertheless be in front or behind it. When we operate, as is generally the case following the vertical line, we are "in the open sky" and the projectile can only be behind the needle, when there is therefore no difficulty. It is not the same if we operate obliquely in the tissues when we are no longer "in the open sky."

In such cases clinical evidence, the careful examination of the X-ray negative and the preceding radioscopic study, together with localising, should furnish enough important information to avoid much groping about.

Manipulations of the instrument very often allow the direction in which the foreign body is situated to be ascertained quite easily.

However, it is sometimes advisable in such cases to possess a method of radioscopic determination of the relative situation in space of the projectile and of the instrument. This can be achieved either by moving the tube and ascertaining thereby whether the projectile or the end of the forceps undergoes the greater displacement, or by employing a double anticathode tube according to a process published by one of us in conjunction with Dauvillier which is fully described at another place in this book (Chapter X).

With this data the radiologist can not only tell the surgeon that he is on the vertical line with the foreign body, but he can also direct him to go higher or lower on this vertical line until contact with the foreign body is established.

Difficulties relating to the small size of foreign bodies have never stopped us. It has once happened to us that we removed one with the compress when sponging at the junction of an irritated nerve trunk. It was only the X-rays which showed that the body in question had disappeared, and enabled us to find it in the dressings by looking at the compresses used after the operation with the cryptoscope.

THE ADVANTAGES OF OUR METHOD.—To resume, if we compare our method with those different methods of precision which consist in the use of the *compass*, there is no comparison between the two.

The compass leads direct to the foreign body to be extracted, provided that the foreign body has not been displaced since the localisation, and that the indicating marks are strictly unaltered. We have already mentioned a certain number of cases in which we have extracted projectiles which would certainly have been missed with the compass. We have explained the reason for this (§ 61).

The method which regulates the compasses, no matter of what kind, is a particular example of the *general method of intermittent control*. The operation takes place, in full daylight, without the operator ever receiving on his hands any X-rays. Then, from time to time, once at the beginning of the exploration and as many times as necessary during its progress, the surgeon asks again for confirmation as to his position. This information is given *immediately* with our method, the radiologist telling the operator where the projectile *is at any particular moment*. In extraction with the compass this same information is given indirectly in the form of a *record* made by a measuring apparatus, the record in itself being exact, if the conditions of relationship of the apparatus to the body of the patient (which are easily altered) have not changed. This establishes the essential inferiority of *intermittent control by a recording apparatus* to *direct intermittent control of the screen*.

If we now compare our method of direct extraction under the screen we find that it has a certain number of advantages of capital importance.

(1) *For the surgeon.*—Extraction under the screen exposes the hands of the surgeon to the harmful action of the rays more or less, and in practice rather more than less. In our process his hands never come nearer than forty centimeters to the path of the rays. This means that he is ENTIRELY protected against the accident of dermatitis.

(2) *For the radiologist.*—In the course of his investigations his eyes are protected by a cryptoscope provided with lead glass, his hand is protected by heavy lead gloves, which are practically impermeable to the rays. Consequently no greater field for harm from the rays is offered than occurs in the course of any radioscopic examination whatever, during which he knows how to protect himself effectively if he has taken the necessary precautions mentioned above.

(3) *For the patient.*—Intermittent control of the screen definitely exposes the patient for less time to the action of the rays than processes of direct extraction under the screen. The matter would be of small importance if he were submitted once only to the action of the rays, but it is not rare to find men who have already been radiographed about ten times. Consequently, the time of exposure is not a matter of indifference. Let us point out also the following material errors: Substitution of plates, of records or multiple wounds, mistakes of side, etc., are always possible in clinics however well organised, but are always very regrettable, and are only avoided by collaboration with the screen.

On the other hand, of greater importance is the *absolute certainty* of carrying out the extraction of the projectile successfully—and this is not a negligible factor for the patient. On our arrival in the ninth district there were many men who refused to submit to the extraction of projectiles which had previously been *missed* in the course of previous attempts. Since our results have become known, our difficulty is rather not to accede to the wishes of wounded men who want to get rid of their projectiles, as they are certain that an extraction undertaken by us will be successfully carried out.

Even for the surgeon that certainty, as we have said before, constitutes a moral factor of considerable importance.

Criticisms.—If we consider now the criticisms levelled against our method by certain operators, none of whom have taken the trouble to come and see us operate, what do we find ? Is it that the apparatus is complicated ?

We have already replied to this previously in advance, having shown, on the contrary, that *everywhere*, both at the front as well as at the base, it is easy to operate with the aid of intermittent control and in the absence of any fixed installation, by using the travelling X-ray cars.

M. Pochas has told us that we cannot remain aseptic. If he had come to see us he would have changed his mind and our results are there to reply to him.

What we have described in full may seem a complex method. In practice it is simplicity itself.

It has been said several times that our method requires the collaboration of a medical man who is a professional radiologist. This is true if one wants to obtain the maximum benefit, but is not a good surgeon required in order to carry through successfully any delicate operation ? Only the united efforts of two real specialists will give the most perfect result, and every diminution in value of one of these two factors will diminish the total value. The real outstanding reproach which can be in our opinion put forward, is the temptation to extract too many projectiles in the absence of definite indications for doing so, as one might easily be inclined to do on account of the certainty of success with the aid of intermittent control.

Numerous surgeons, however, have come to see us operate and others have tried our method themselves, and we think all of them have taken away with them the conviction that it really is a method of *certainty*, not involving, for the operator, *any risk whatever* of contact with the harmful rays, which is the object we have aimed at. The fact that all have recognised the value of it, and that such operators as H. Barnsby, Brin, Dujarrier, Duroux, Pierre Duval, A. Gosset, Labey, Lapeyre, Ch. Martin, Mornard, Robineau, Vouzelle, etc., have accepted the principle, affords the best reply to all criticisms. Finally, there are figures to support our assertions.

Statistics.—We have already reported to the Surgical

Society at the meeting on November 3rd, 1915, a complete and consecutive series of 110 attempted extractions of projectiles with 110 successes, these projectiles representing 100 patients. On February 16th, 1916, we presented to the same society a fresh series of 100 wounded (109 projectiles) with 109 successes. That is 100% on 200 wounded and 219 projectiles. In this series we count as one projectile groups of projectiles situated in the same region which can be reached by a single incision (by counting them separately the total would have been 319 projectiles extracted). We arrive to-day at a total of 310 patients with 330 projectiles and 330 successes, viz. 100% of successes in 330 consecutive extractions. We interrupted one operation on account of formidable hæmorrhage of the main iliac vein —probably. The arrest of hæmorrhage was difficult, and we preferred to take out the bullet a little while after at a second operation. We do not think that a similar result has ever been obtained before our time, and we doubt very much that it could be obtained otherwise than with the aid of the intermittent control of the screen for a similar series of projectiles of like difficulty.

If we consider the results obtained by those who have adopted our method we find that they fully confirm its value.

Dr. H. Barnsby has reported to the Surgical Society that after a series of extractions in which the proportion of non-success was 20% he has been able to remove *without any failure* 63 consecutive projectiles according to our method.

He has since come back, having been with the armies, and after having made a series of extractions, and being exceptionally fortunate with the Hirtz compass aided by our screen control, he has been good enough to communicate to us the list of extractions made by him with the collaboration of Dr. A. Barnsby in a surgical ambulance at the front, *without one failure*, from June 22nd to August 14th, 1916. It includes 100 extractions of projectiles (several interosseous, intercranial, pulmonary, etc.).

Dr. H. Brin forwarded to the Surgical Society in March 1914 the list of 117 extractions executed by him in collaboration with one of us and which included a number of projectiles of an exceptional difficulty. There was only *one failure*, due to the stoppage of the operation *on account of a chloroform accident* at the moment when he felt the projectile, which was moreover easily extracted a little later under local anæsthesia.

MM. Beaudouin, Boureau, Belgrand, Cheve, Duroux, Lapeyre, Ch. Martin, Morel, Mornand, Perrin, have, with the collaboration of M. Dauneau, Dr. Fleig, Dr. Menuet, Dr. Homme, M. Taveneau, or one of us, removed altogether 975 projectiles without a single failure.

Dr. Labey, together with Dr. Fleig, M. Malaquin, or one of us, has extracted a series of 120 projectiles ; M. Robineau a series of 160 with M. Fleig and one of us. Two failures in that number : One was a piece of shrapnel, situated behind the bifurcation of the iliac vessels with a widely spread arterio-venous aneurism, which produced such difficulties in arresting hæmorrhage that the projectile, though felt with the finger, was abandoned. The other case was that of an intrapulmonary projectile, the record of which is given in the next chapter.

*There is thus a series of more than* 1,300 *extractions of projectiles for which we have to record only* 3 *failures, viz.* 0·3 %. *No comment is needed on such a total.*

# CHAPTER XIV

## SPECIAL PECULIARITIES OF CERTAIN REGIONS

*Indications for operation* and the *route of access* vary essentially according to the region of the body in which the surgeon intends to perform the extraction of a projectile.

We have already pointed out the advisability of considering this extraction to be definitely shown when the dangers and operative destruction of tissue necessary are less than the pain suffered by the patient. We are going to point out the dangers and injuries to tissue for every region in particular.

On the other hand, the route of access is based on the topographical anatomy of the region where the projectile has its seat. In a general manner the problem to be solved before undertaking an extraction consists *in so arranging matters that the surgical route of access coincides with the normal ray passing vertically through the projectile.*

We have already explained (see Chapter III) what should be understood by the normal ray. It is practically the pencil of X-rays given off from the anticathode and passing through the centre of the diaphragm attached to the tube, perpendicularly to the plane of that diaphragm. Apart from a few exceptional cases which we shall mention, the tube, when performing extractions with the aid of intermittent control, is arranged under the operating table. The diaphragm is placed directly above the tube, the normal ray is, and therefore remains, vertical and perpendicular to the plane of the table, no matter what displacements are carried out with the tube in the horizontal plane subjacent and parallel to the plane of the table and in which the stage bearing the tube moves (see Chapter III). These displacements have the purpose of causing this vertical normal ray to pass through the projectile, that being so it is sufficient to cause the way of surgical access to coincide with this vertical normal ray in order to solve the problem.* As regards the radiological details we refer the reader to Chapter XI, which is devoted to the anatomical localisation of projectiles in various regions.

We cannot think here of giving a complete study of the extraction of projectiles belonging to each region, as we should thereby entirely exceed the object of this work. We shall give essentially *practical* indications resulting from *our own personal experience.*

## I—Head and Neck

§ 65. **Intracranial Projectiles.**—Extraction is necessary whenever there are signs of abscess of the brain or convulsions, but if the trouble is reduced to chronic headache with tendency to vertigo, the problem is more difficult to solve, and the indications for extraction are still under discussion.

As far as we are concerned, following the advice of our colleague Clovis Vincent, we attach great importance to the result of lumbar puncture, and if the case presents moderate operative difficulty we intervene if a definite lymphocytosis is ascertained in the liquid. We think it is too late to wait for operation until signs of meningitis appear, and that hyperleucocytosis of the cerebro-spinal fluid is a sufficiently alarming symptom for justifying operation.

The route of access will be chosen according to the situation of the projectile. Nevertheless, we shall remember the comparative lack of risk with which we can explore through the frontal lobes.

The regions to be avoided are:

(1) The large sinuses—*i.e.* the superior longitudinal, lateral

* In those exceptional cases when it is very difficult, almost impossible, to follow the direction of the normal ray, operation with the aid of the control of the rays is rendered somewhat less easy and rapid. Still it is possible however to obtain its full value. It will then suffice to examine the region of the body in the course of the operation in two different directions in order to guide the surgeon exactly. Finally, if that manœuvre cannot be realised, it will still be possible, by moving the tube and making controls in two different positions of the tube, to obtain data sufficient to guide the surgeon's instrument, although this may cause some probing.

and the torcular Herophyli. It is advisable not to allow the trephine opening to approach nearer than two centimeters to the middle line;

(2) The cerebral ventricles. The fact of having to open a ventricular cavity singularly increases the seriousness of

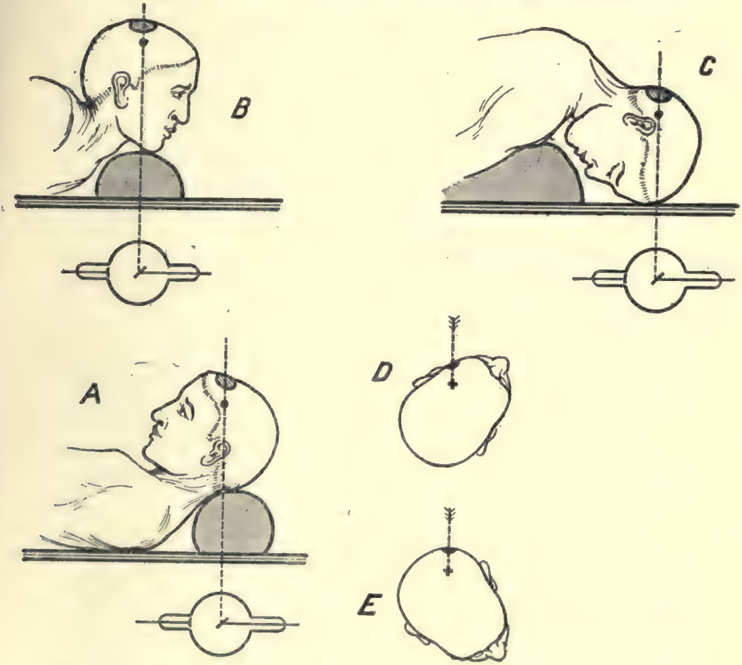



FIG. 211.—The drawings *A*, *B*, *C* indicate the movement of flexion or extension of the head which will allow the normal ray, which passes through the projectile, to emerge exactly at that point on the cranial surface selected as the centre for the trephine opening. The drawings *D* and *E* show the movements of *rotation* of the head necessary for placing it in the required position.

the operation, and we try carefully to avoid it, if possible.

The method followed by us is perfectly definite. We operate once only, as we consider the operation in two stages to be a useless complication.

The projectile to be extracted having been roughly localised by an examination in two directions (or better still by two radiographs at right angles), we demonstrate to the radiologist the exact point on the head where we are going to operate. He assures himself that it is possible to cause the normal ray traversing the projectile to pass through that point. Then he determines exactly its depth on the vertical line in question from the selected point by the localisation process to which he is accustomed (we use the radiobathymeter).

As this determination requires the passage of a normal ray, both through the projectile and through the point required by the surgeon, it follows from this inevitably that this position can be obtained. It is quite easy to find it again, since the whole of the factors are known. At the moment of operation, the patient being anæsthetised and placed approximately in position, an assistant holds the head, which can be steadied by wadding or ball cushions filled with oats.

The radiologist instructs this assistant as to any further displacements of the head, movements of rotation on the one part, or of deflection on the other part, or, if necessary, he himself does this to save time (of course, with all necessary aseptic precautions), thus arranging the head in good position, until the image of the projectile is projected on the required point of attack.*

He then indicates that spot once more to the surgeon with the point of a special needle. The operator then makes at that point (after incising a portion of the scalp) a trephine ring of twenty millimeters, and one only. In the event of hesitation or of slipping of the head, etc., it is easy to put the trephine ring in position and to make the radiologist verify that the shadow of the projectile is projected exactly on the centre of that ring before making the hole. After the trephining has been completed, the surgeon asks the radiologist to look. He finds the projectile again, and, if necessary, *causes the position of the head to change until the image of the projectile is projected exactly in the centre of the* trephine hole. The tube is stopped. Then the dura mater is cut. The blade of the bistoury is sunk

* We refer to that which we said in Chapter XI. The use of a metal ring, especially the ring forceps, is often to be recommended in order to facilitate this arrangement.

*vertically* to the depth required, which has been previously measured off on the blade of the instrument. Sometimes its point brushes the projectile, but this matters little.

If the foreign body is magnetic, the pole of a continuous electro-magnet is sunk vertically in the place of the blade. When the desired depth has been reached, a shock indicates that contact has just been established. It is sufficient then to withdraw the pole of the magnet slowly to take out the projectile. Sometimes the foreign body sticks half way. The pole is plunged in again exactly as in its first passage, finds the projectile again nearer than before, and takes it out again, completely or incompletely.

Two or three of these in-and-out movements will always extract a magnetic foreign body. The contact is announced each time by a click which is heard even by the assistants. We have in this manner removed in the presence of Inspector-General Février a bullet which was seated almost in the centre of the brain (96 millimeters from the base, 132 from the vertex).

If the foreign body is not magnetic, a pair of bullet-extracting forceps are sunk vertically to the indicated depth, previously recorded on its arms and marked by a scratch. When this mark is at the level of the scalp, we open the forceps a known distance, just sufficient according to the size of the projectile; we then thrust down one centimeter further and close the forceps again, the ends of which grip the foreign body.

It would seem that by proceeding in this manner there could not be any cause for a mistake if the head had not moved. In fact we have always effected our extractions of intracerebral projectiles without any difficulty. It has happened to us only once, in the case of a very small splinter, which measured less than five millimeters in its largest diameter, that we did not immediately find the projectile shown by the screen however to be always at the same point in the centre of the trephine hole. On inclining the head and placing it sideways, this unforeseen difficulty was explained. The projectile had emerged with a drop of blood behind the blade of the bistoury, and had fallen down outside, but the operator had not noticed this. By a singular accident it had stuck on the skin of the occipital region, exactly at the point where the normal ray emerged from the centre of the hole. As the figure shows, it appeared on the screen as if it had not changed its place and had not been extracted. Any other method would have led to a multiplication of useless attempts in the neighbourhood, and only increased the traumatism, the matter finally being abandoned in desperation, the operator being certain that the projectile had not been extracted. As it turned out, it was sufficient to incline the head in profile in order to see that the splinter was no more in its place. By opening the diaphragm more it was soon ascertained, that far from having perhaps sunk in deeper after the introduction of the bistoury or the magnet, as we imagined for a moment, it had really been already extracted.

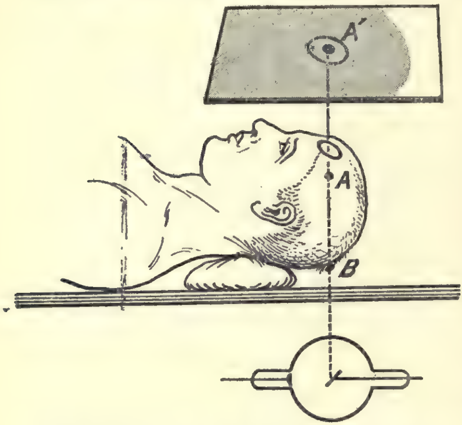


FIG. 212.—The shell splinter *A*, the shadow of which was projected at *A* on the screen, in the centre of the trephining orifice, was extracted without being noticed, and, falling out of the wound, slipped along the shaven skull, being carried along by the blood, finally stopping at *B* in a tuft of hair which had been left by the razor. However, at that point, the shadow was thrown through the same point as *A* on the screen and was therefore, apparently, in the centre of the trephine orifice.

In all difficult cases this procedure of inclining the head shows the situation of the projectile and the end of the instrument in two directions at right angles, and enables therefore any mistake in the position of the forceps or magnet to be corrected immediately. The rapidity, simplicity, and security of the method which we have just described, and which Desplats and Le Fort have already rightly recommended to the Surgical Society, appear to us to render other methods superfluous. It seems also that all who have tried it have found it suitable, seeing that M. Rouvillois, who recommended at first the use of a telephonic probe, has become converted to operation under screen control, and M. Hirtz himself, after having operated with M. Barnsby, has recently published an article in which he describes an adaptation of his compass to this extraction under screen control. We are however of opinion that his device presents a complication which does not seem indispensable. If one wants to operate with any compass whatever, and with that of M. Hirtz in particular, nothing prevents it being done on the X-ray table and in that case, if the foreign body is not reached at once, the simple method explained by us can be employed.* The same applies, of course, to cases of projectiles in fresh wounds of the skull, when one will naturally utilise the opening made by the woun l unless there are exceptional indications against doing so.

Projectiles of the Orbit and Eyeball.—Great care and moderation are needed as regards the extraction of projectiles in the orbit. Pain, diminution of vision by compression of the optic nerve, and appearances indicating the possibility of sympathetic ophthalmia are evidently very important reasons for extraction. However, no matter what operative method is followed, whether above or below the eyeball, it must be considered, if the eyeball is sound and sight has been preserved, that the extraction of a projectile from the orbit seriously exposes to injury the nerves supplying the muscles of the globe, thus leading to paralysis of some of these muscles, strabismus, and diplopia. These difficulties should be carefully weighed in dealing with projectiles embedded in the orbit.

Our method of extraction will however be of the greatest help in that difficult region, enabling the operator to find projectiles searched in vain by other methods, which fact one of us in conjunction with F. Terrien † has been able to ascertain by operating successfully on patients who had already been subjected to as many as four operations

* Le Fort, *Soc. chir.*, July 27th, 1915; *Rouvillois*, August 17th, 1915, and February 1st, 1916. Abadie, January 11th, 1916. Hirtz, *Presse médicale*, 1916. The ingenious apparatus by MM. Tanton and Viallet is also very complex (*Soc. chir.*, October 1916).

† F. Terrien and R. Ledoux-Lebard, *Ann. opht.*, 1916.

## PLATE VI

Fig. 1.—Antero-posterior radiograph of the lumbar spine. A shrapnel bullet is seen throwing its shadow between the third and fourth lumbar vertebræ, the bodies of which appear to be broken. A shadow of new bone formation is seen surrounding the projectile between the vertebræ. The bullet is probably included in the newly formed osseous shell and is lodged between the two vertebræ (see fig. 3).

Fig. 2.—Radiograph of the right half of the thorax as seen from the front. The shadow of a shrapnel bullet is present at the level of the eighth rib. At the periphery of the lung can be distinguished two encysted areas of localised pyo-pneumothorax. A probe has been introduced in the lower area. Notice the diminished transparency of the lung in the area surrounding the projectile.

Fig. 3.—This lateral radiograph of the lumbar column as seen from the right side confirms the conclusions established in fig. 1, which have, besides, been verified on operation. The projectile was removed by Dr. H. Brin with the aid of intermittent control, the patient having been placed at the time in the lateral position lying down.

Fig. 4.—Radiograph of the right ilium as seen from behind. A shell splinter has perforated the bone (the perforation can be clearly seen). It was probably partly embedded in the bone, as can be presumed on account of the area of decalcification which is visible round its lower half. One should be careful not to mistake for bony perforations those transparent areas due to bubbles of gas in the intestines, which are frequently so apparent in the pelvic region.

PLATE VI

FIG. 1

FIG. 2

FIG. 3

FIG. 4

without result. Let us repeat here that all projectiles of the orbit, which can be removed by surgery, will be rendered visible, especially with the use of the Dessane fluoroscope. In difficult cases advantage will be taken, as for the skull, of examination in two positions, face and profile, during the operation, in order to guide the operator.

As to projectiles in the eyeball itself, we have remarked that they are almost the only projectiles which may not be amenable to localisation nor to radioscopical examination. Indications for their extraction may then exist for such small splinters that they almost escape the eye and can only be removed by the giant electro-magnet. Their extraction requires a method and knowledge of so special a character that we can only mention it here in passing, and we refer in this connection to the special works on the subject.

Projectiles in the Maxillary Sinus.—The only interesting detail which we have noticed in this respect is that we have often found pieces of metal embedded in bony shell, when we were very much inclined to think that they were near the roof of the maxillary sinus surrounded by soft tissues.

Projectiles in the Pterygoid and Maxillary-pharyngeal Regions.—In these cases one must absolutely avoid any external scar, and try to operate through the mouth, availing oneself of screen control and of examination in two different planes during the operation, the position of the projectile having been previously studied and measured. One of us has thus extracted, with Ch. Martin (of Agners), several difficult projectiles from the pterygoid fossa.

However, we do not recommend this method for the maxillary-pharyngeal region, especially when there is the slightest doubt as regards the relations of the projectile to the bone. In conjunction with Dr. Labey, one of us once observed during an exploration for a difficult projectile of the pharyngeal region, the disappearance of the projectile, the shadow of which, quite clear at first, was no longer seen on the screen. Before examining the whole region with an open diaphragm, the splinter of metal was noticed in the œsophagus ; it had been liberated and swallowed.

Projectiles of the Carotid Region.—We have removed metal fragments in contact with the blood vessels and pneumogastric nerve. This is a region where the surgeon should be able to see especially clearly in the course of operation. It is also a region in which compasses must be applied very carefully, any displacement of the head having a considerable influence on the situation of the projectile in relation to the fixed measuring points, which can only be taken at a sufficiently great distance and on parts of the body subject to movements. The necessity of dissecting out the blood vessels exposes also the position of the required metal fragment. That is to say, that there is almost a necessity for control of the screen in order to carry out an extraction in that region with certainty and safety.

The same remarks apply to the projectiles situated near, or in contact with, the œsophagus.

## II—Thorax

We shall not say anything further about projectiles in the walls of the thorax, as these do not require any special remarks.

§ 66. **Intrapulmonary Projectiles.**—The extraction of intrapulmonary projectiles is important on account of a statement, the credit for which goes to Marion, who has thrown much light on the subject since the beginning of the war. That is—the little importance to be attached to the presence of a pneumothorax and the uselessness, already pointed out by Bazy, of the apparatus for introducing excessive or diminished pressure of air into the lungs during operation.

All intrapulmonary projectiles should not be removed. Here also it is necessary that the trouble resulting from their presence should at least be equivalent to the operative danger and inevitable damage caused through operation.

Amongst the complications we have met with, and which we considered were indications for extraction, we must mention hæmoptysis, abscess formation, with fever and purulent expectoration and painful dyspnœa. Our colleague Denéchau, Médecin de Secteur, has observed four cases of pulmonary tuberculosis at the place where pieces of metal were imbedded. The danger of witnessing an outbreak of future bronchopneumonia on the occasion of a slight attack of bronchitis, or influenza for instance, seems to us an argument not without value, but has not yet been supported by a sufficient number of exact facts. This consideration would lead to the extraction of all pulmonary projectiles without exception—a procedure which we do not advise. The principal contra-indications to extraction are in our opinion: the smallness of the projectile (corn grains) and its situation at the hilus or its immediate neighbourhood. This region is particularly dangerous—more on account of the numerous *ramifications*

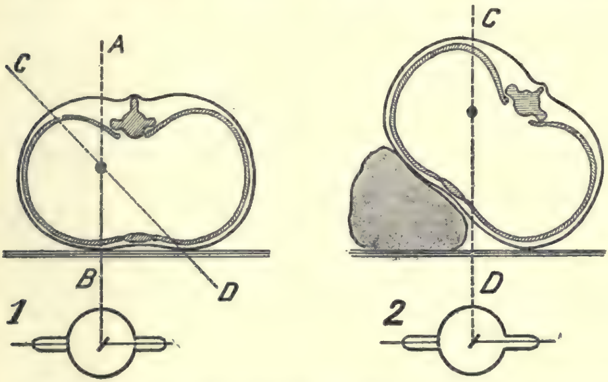



Fig. 213.—By varying the angle of the patient's body the normal ray can be made to emerge at will through any point chosen on the thoracic wall as the route of access.

*of the vagus nerve* (Leriche), than by reason of the grouping together of big vessels.

The route of access is indicated by the depth of the projectile in relation to various points of the thorax.

When operating from the back as well as from the front one should keep away as far as possible from the middle line. Thus will be avoided any difficulties caused by the transverse processes and in front by the internal mammary artery. In such cases a cushion filled with oats (not with sand, which would be opaque to the rays) can be placed under the lateral wall of the thorax on the injured side so that the normal ray emerges a little more to the outside.

Several times we have effected our extractions through an intercostal space without interfering with the ribs at all, but even if the depth of the projectile was considerable we have nearly always been able to avoid costal resection. We cut the rib near the chondro-costal junction. The rib, widely freed at its internal part, is seized, fractured by the hand as far out as possible, and kept raised by a retractor. The space thus obtained is very large especially if a narrow ball cushion causes the thorax to protrude forward. When the extraction is over the rib is turned down like a hinge and fixed at the near end by a catgut stitch passed through it with a perforator. This method gives us the best results.

The approach to the pleura is quite different according to whether it is free or adherent.

When the pleura is free the extraction is mere child's play. Thus, after the serous layer is opened, the examining finger feels whether there are adhesions. If they are soft and give way easily without bleeding it is best to free them first.

In this first case the lung can be easily brought outside through the thoracic gap. Then look for the projectile which can be very well felt by palpation, ask the radiologist to verify, if necessary, whether what is pointed out to him is really the metallic foreign body looked for. All this is easy. We cut the parenchyma at the spot at which we can most easily come down on the projectile, which is generally removed with a certain amount of effort, as the shell splinters often adhere to the pulmonary tissues. In some cases they are included in a small cavity full of thick fluid from which they are easily extracted. When the projectile has been removed, the wound in the lung bleeds only a little or not at all when the lung is free from adhesions. We therefore consider it is generally unnecessary to insert a suture. We have only done it once, and we have never had any trouble with our other extractions in the case of a free pleura. In fact, when the lung is free from adhesions, the retraction of the parenchyma is sufficient to stop any bleeding. Pneumothorax is evidently a very favourable condition for preventing hæmorrhage.

Matters are quite different when the pleura presents extensive adhesions which resist and bleed when one tries to liberate them. This, unfortunately, happens very often according to our records with projectiles retained for a long time. It is then necessary to create gradually a way by means of blunt instruments following the vertical ray, asking if necessary the radiologist to give the exact point when the depth indicated by localisation has been reached.

But the opening made bleeds frequently, because the lung cannot retract. We leave there for forty-eight hours a tent to arrest the bleeding if the oozing is abundant.

The prognosis is very different according to the condition of the pleura. The extraction in the free pleura has never given us the slightest trouble.

In cases of adherent pleura we have recorded two deaths. One occurred slowly in the case of a patient who had a large hæmothorax. The pleura was very adherent, but only at a few points. It was not possible to free it. The free points allowed the formation of a large effusion which became infected and which we had to open at its most dependent part, like an empyæma. The patient succumbed a few days afterwards from embolus.

It was in consequence of this large hæmothorax that we decided to leave in position a hæmostatic tent and we have never seen this accident happen again. In the case of an officer we removed a rifle bullet very near the hilus, because in the four months during which the projectile was embedded he had frequent hæmoptysis. The pleura was entirely adherent. After extraction the hæmorrhage was abundant and we inserted a tent. When it was taken out at the end of forty-eight hours there was again an abundant flow of blood, appearing to come from the site where the bullet had been. We replaced the tent, leaving it twelve days, soaking it every day with a styptic. The tent then came out very easily without a drop of blood and the patient was cured.

The second patient whom we lost after an extraction with an adherent lung succumbed to a pneumonia which started in the affected lung and spread to the opposite side.

This proportion of the number of those operated upon by us is not very great, since we have made forty-seven extractions of pulmonary projectiles. However, we wish to point out that these two accidents and all the lesser adverse symptoms, slight hæmothorax, temperature persisting about eight days, slight pulmonary congestion, etc., have *all* occurred in cases where the lung was adherent, but never when the lung was free or liberated.

The prognosis is therefore very different in the two cases.

It need hardly be pointed out that on account of its mobility, of the total or partial retraction to which it is subject at the moment of opening the pleura, the lung is one of the organs in which the compasses may lead to grave miscalculations in the search of foreign bodies, the extraction of which is only really certain and easy when the control of the screen is made use of.

An intrapulmonary projectile which was rather large, measuring 6·5 cm. by 3·5 cm., was searched for unsuccessfully three times, at least once by a surgeon of the Paris hospitals, before it was extracted by us. In spite of its size it could not be felt with the finger in a lung with a lardaceous area and bands of sclerosis. Besides, have we not ourselves seen *Marion* himself give up the extraction of a bullet in a free lung which had retracted? (Marion, in *Thèse Weber*, p. 87).

However, the relative safety of the pulmonary operations and certainty of operative success afforded by the radioscopic control do not seem to us to justify the adoption as a general method of extractions by forceps under the control of the screen, after simple cutaneo-muscular deep incision, such as practised by M. Petit de la Villéon.

They can certainly be carried out most frequently without difficulty and even very easily and with the certainty of not missing the projectile when a double anticathode tube is employed, according to the method described by one of us with A. Dauvillier (see above Chapter X). They provide for the person operated upon, in favourable cases, a minimum of shock and a rapid cure, but they seem to leave room for too many and too serious possibilities of error for them not to be taken into serious consideration, as M. Silhol has rightly pointed out before the Surgical Society.

In the first place, in such a narrow cavity without the use of a double anticathode tube, the grasping of the projectile may sometimes prove extremely difficult and necessitate serious laceration of the lung. Then if we exclude this procedure in the hilus region rightly contraindicated by the author, can one ever be sure of withdrawing without leaving a bleeding point ? One of us, operating with Labey in the recognised method for a projectile at a small depth (four centimeters) in an absolutely free lung experienced a troublesome hæmorrhage which was only arrested by ligature.*

Moreover what becomes of the small septic foci the contents of which are set free in the lung ?

We think therefore that one should not avail oneself of this method unless the cause is perfectly well known, and we must ascertain by a frequent and particularly exact clinical and radioscopical examination the condition of the lung and of the pleura.

Projectiles in the Posterior Mediastinum.—As a general rule, we think that this is a region where one should not extract projectiles.

We have only once done so with success. The case was one of a bullet in the dorsal region to which the descending aorta communicated its pulsation. We cut two ribs at the level of the extremity of the transverse processes and displaced them outwards. The hand inserted into the pleural cavity felt the pulsating projectile at the angle of the vertebral column, separated from the aorta only by a small amount of soft parts. We were able to disengage the bullet and to extract it, but the venous plexus gave rise to a rather copious hæmorrhage. We had to leave a tent in position for forty-eight hours.

Projectiles in the Anterior Mediastinum.—We have observed a certain number of shell fragments pulsating freely which we have localised under the arch of the aorta, against or in the walls of the heart (see Chapter XI). As

* We have tried to follow step by step the method of M. Petit de la Villéon. It seemed to us that in practice the surgeon put his hands if not in contact yet at a disquieting proximity to the sheaf of harmful rays. Moreover, in the course of one of these efforts we attempted to extract a shell splinter of medium size : we saw it, we established contact with it with our forceps, but it was quite impossible for us to grasp it, although each of us tried to do it in turn.

We had to finish this extraction by our ordinary method, making a temporary resection of one rib. The patient made a good recovery.

Nevertheless it follows that not only may it be difficult to obtain contact with the projectile, but also the grasping of it may be impossible even to operators who have had some experience.

the trouble was insignificant, we did not think it advisable to operate except in three cases.

In one case the projectile was a large shell splinter two centimeters long lying in front of the pericardium. It was easy to extract it directly.

In the two other cases rifle bullets were present to which the impulse of the aorta or of the heart was strongly communicated, very near the anterior middle line, at a depth of about seven and five centimeters, one at the level of the second rib, and the other at the level of the fifth.

In both these cases we made a pleurotomy displacing one rib outwards. The hand inserted into the pleural cavity felt the projectile in the mediastinum separated from the finger by a small thickness of soft parts. By separating well we were able, by means of a grooved probe, to disengage one of the ends of the bullet, which the electromagnet brought outside, without a drop of blood. The first must have been near the aorta, the second near the pericardium. Cure without incidents in the three cases.

PROJECTILES IN THE HEART.—We have not removed since the war any projectile included in the walls of the heart itself, although we have seen several of them. There are, in fact, two regions where the extraction would almost certainly mean death. These are the auricles on the one part, and the groove of the coronary arteries on the other part. One of us published some years ago before the Surgical Society details of a death at the end of eight days of a female patient from whom a sharp needle in the anterior coronary was extracted. Only in the ventricular wall in this region can operation be risked with a chance of success. It is thus only when the projectile is in this situation or when the projectile is free in the ventricle that we should commence to discuss the advisability of an extraction which might sometimes be successful.*

PROJECTILES IN THE DIAPHRAGM.—Probably in consequence of the law of averages we have seen a fairly large number of projectiles included in the diaphragm, and pointing sometimes upwards, sometimes downwards.

They seemed to us to present a regular clinical characteristic, viz. : *the very great pain they cause during inspiration.* They even prevent respiration on that account. One of

* As is shown by some rare published observations.

those operated upon by us, a sapper and miner, did not breathe at all with his left side. He showed a strong right scoliosis, and a marked lowering of the left shoulder. Very thin, he was always in pain, and tried to immobilise the left side of his chest. The projectile had been present for a year when we saw him, and he was deeply cachectic. He appeared to be very much better after the operation.

The only route of access is the transpleural way which is very convenient and very easy. By raising one side temporarily as we have shown, one can see very well what one is doing. We have generally put a suture into the diaphragm, although the wound in it has never seemed to us to bleed.

## III—Abdomen

§ 67. **Projectiles in the Liver.**—The only indication for the extraction of intrahepatic projectiles which we have noticed is the severe pain referred to the right shoulder when this pain dates back a long time, is permanent, and does not yield to medical treatment.

The projectiles which we have extracted from the liver were not very deeply situated in the gland, with exception of one rifle bullet which we had to look for through about six centimeters of hepatic tissue. In that case we bored our opening slowly with a blunt instrument and we effected the extraction without any considerable hæmorrhage. We were able to discover that the point of the projectile projected from the liver and had penetrated the diaphragm, to which the extreme pain suffered was probably due. We left a hæmostatic tent in the wound for forty-eight hours. The patient recovered without any signs of jaundice or discharge of bile. Nevertheless, if our anatomical diagnosis had been better, we should have operated by the transpleural route, which would have been infinitely simpler.

In connection with this we may refer to our remarks in Chapter XI on the difficulties of the localisation of projectiles of the sub-diaphragmatic region, and especially of those which are located under the right cupola, where the large mass of the liver being of uniform opacity, sometimes places serious obstacles in the way of accurate anatomical localisation.

## PLATE VII

Fig. 1.—Radiograph of the thorax seen from the front. One notices, standing out clearly in the shadow of the heart on account of its opacity, the shadow of a round projectile (most probably shrapnel from its shape as well as from the history of the injury) which lies at the level of the right auricle.

Fig. 2.—Radiograph of the thorax of the same patient in the oblique examination. The shadow of the shrapnel is still seen in the cardiac shadow at a level which seems to correspond to that of the right auricle. The projectile is therefore intracardiac and, as the radioscopic examination showed, free in the cavity of the auricle. (This observation was published by one of us with two illustrations in the *Journal de Radiologie* for January 1916.)

FIG. 1

FIG. 2

One should therefore in all these cases, and especially as soon as the operation appears to be likely to present the slightest difficulties, have recourse to all the proper measures for ascertaining the exact site of the foreign body. The radioscopical examination will be undertaken not only from the front, but also from the side, and it will be completed as may be necessary by one or several negatives. Here also it may be advisable to use stereoscopic radiography, although one generally only obtains a not very satisfactory impression of relief of the hepatic image owing to the uniformity of shadow which we have mentioned before and the absence of contrasts. However, it will be rare that one will not succeed, after a complete examination, in knowing whether the projectile is or is not seated in the liver, or at least *under* the diaphragm. It is only when there are pleural adhesions and the costo-diaphragmatic sinus has disappeared that one is sometimes really embarrassed or led into error, as in our previous case. This anatomical localisation is therefore of great importance in order to settle the route of access upon which frequently depends the facility of the operation, the transpleural way being by far the easier.

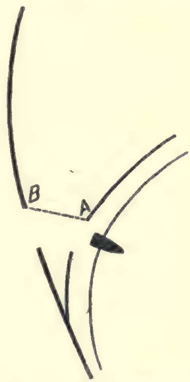



FIG. 214.—The internal lip *A* of the diaphragmatic wound is united to the upper lip *B* of the pleural incision.

In another case we extracted by the transpleural and transdiaphragmatic way a projectile embedded in the posterior border of the liver and round which was an abscess as large as a small nut. After packing the wound to protect the pleura, we united the internal lip of the diaphragmatic wound to the upper lip of the pleural incision, thus placing the track outside and isolating it from the reconstituted pleural cavity (Fig. 214). The pleura did not become infected and the cure was rapid.

In the case of another patient, we removed an aseptic projectile seated between the liver and the diaphragm very easily by that route.

Another projectile at a depth of forty-two millimeters, was very easily extracted from the anterior border of the liver after a laparotomy parallel to the costal margin.

§ 68. **Projectiles in the Abdominal Cavity.**—We have seen relatively few of these. We extracted one, a bullet, between the bladder and the upper edge of the pubis. From the cavity in which it was encysted there was a fistula opening in the middle of the fold of the groin. Its extraction was very easy.

Another, a rifle bullet, was embedded in the mesentery, very near its base. It had been searched for unsuccessfully by an excellent surgeon.

We have removed by laparotomy a bullet localised thirty-four millimeters below the seventh rib. It was seated above the stomach, and had perforated the diaphragm. While the projectile was being removed, air entered the pleural cavity. If our anatomical localisation had been more precise, we should have certainly preferred the transpleural route, because it was not very easy to unite the diaphragmatic orifice on account of its concavity ; the result, however, was excellent.

We have extracted an intrasplenic shell splinter. We had to incise about one centimeter from the cortex. There was no hæmorrhage and we did not suture the spleen.

Finally, we have removed a bullet from a Senegalese sharp-shooter which, clinically, seemed entirely free in the abdominal cavity. It was enveloped and encysted in the extremity of one of the appendices epiploicæ, as large as the little finger, about twelve centimeters long, and it could be displaced from one iliac fossa to the other. The operation was very easy. This extraction would probably have been impossible by the use of the compass (see Chapter XII).

§ 69. **Projectiles in the Internal Iliac Fossa.**—This is a common situation for projectiles, and they are difficult to extract. The frequency is no doubt due to the fact that the iliac bone stops a projectile which has exhausted the greater part of its live force.

They are difficult to extract, because the route of access which we may consider surgically to be the best may be not easily placed in the path of the normal ray.

These projectiles sometimes enter through the buttock, perforate the iliac bone, and stop in the centre of the fracture in the middle of the splinters. These cases are the most frequent. Sometimes they cross the abdominal wall and stop against the bone intact, in the thickness of the psoas or of the iliacus muscle.

In order to reach them we have always followed the extra-peritoneal way. We have prolonged outside, towards the antero-superior iliac spine and even higher, the recognised incision for ligature of the iliac artery. Raising the peritoneum gradually and holding it up with a wide retractor, we have always been able to reach the projectile. In order to be able to use the normal ray one of the buttocks of the wounded should be raised by a ball cushion filled with oats. The wide retractor should be strongly drawn inwards by an assistant. By this means we can obtain sufficient space and a sufficiently wide route of access.

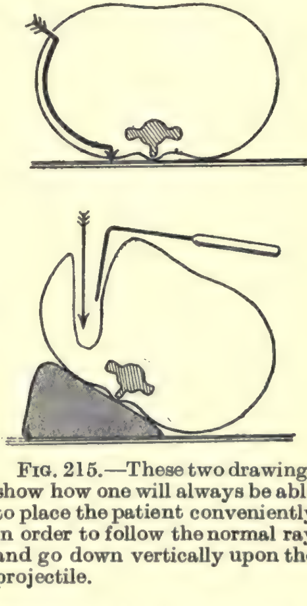


FIG. 215.—These two drawings show how one will always be able to place the patient conveniently in order to follow the normal ray and go down vertically upon the projectile.

The real danger consists in the proximity of the bifurcation of the inferior vena cava. We have had a bitter experience of this.

One of our patients had in the region of the bifurcation a bullet giving rise to great pain. At the moment of extracting it we had a very bad hæmorrhage, which was overcome by packing. On the fifth day when this packing was removed the hæmorrhage recommenced. The wound was again packed. The patient died suddenly on the seventh day from embolism.

In another case a shell splinter was located in the same region. We established contact with it, but it resisted our efforts to extract it. With a curette we levered it up by its rough surface to free it. We managed to displace it, but a hæmorrhage occurred. We arrested this with a finger, and were able to place two forceps above and below the bleeding point, which partially stopped the bleeding. Our forceps however had not grasped the artery, which continued to beat. A moderate packing however completely arrested the hæmorrhage.

After our experience in the previous case we did not remove the tents and forceps until the twelfth day, and recovery took place.

Finally, one of us collaborated with Labey in a difficult extraction of a splinter situated in the main iliac vein which was removed by laparotomy.

The back and lower part of the internal iliac fossa, corresponding to the anterior surface of the sacro-iliac symphysis, and the posterior part of the upper inlet are therefore very dangerous regions.

As one approaches the antero-superior iliac spine the extractions become on the other hand more and more easy and less dangerous.

## IV—Spine. Pelvis

§ 70. **Projectiles in the Spine.**—These are very frequent. Those which are arrested by the spinous processes are superficial and easy to extract. We have not seen any of them ourselves. Those sent to us were principally cases in which the projectiles were arrested by the transverse or articular processes or the heads of the ribs. These projectiles often give rise to great pain owing to pressure on nerve roots.

We have nearly always found round these projectiles bony capsules of recent formation, and they had to be removed with the gouge.

We leave alone projectiles included in the bodies of the vertebræ, which appeared to us to give rise to no special trouble, and we thought that the damage done in extracting them would be more harmful than the existing inconvenience.

We might mention that one of us on two occasions was able to extract with Brin a shrapnel bullet embedded in the thickness of the body of the third lumbar. The operation was performed in the nephrectomy position, but it was possible to follow the projectile with the fluoroscope and to supply the necessary control information.*

When reading the published observations it seems (see Sauve, Surgical Society, July 1916) that the surgeon too often stops in the course of an operation for extracting a projectile in the pelvic region on account of the extent of the damage which must be inflicted, even when the projectile has been localised very accurately as to depth. We have already stated (Chapter XI) that a lateral radiograph which can always be made, gives the necessary topographical information in order to avoid in that region unsuccessful operations which are always so regrettable, and which should not be undertaken except with the most complete information available.

Dorsal and Lumbar Intraspinal Projectiles.—We have removed two of these, both shrapnel bullets.

The first one was lower dorsal (incomplete paraplegia, loss of control of sphincters). We removed one lamina only, and then opened the dural sheath which seemed unharmed. Through the medullary tissue we noticed the shrapnel bullet which appeared to us *intramedullary*. We separated carefully the lips of this medullary wound at each side and with catch-forceps we extracted the projectile. At the moment when it emerged from the lips of the wound the anæsthetised patient made a violent movement with both legs.

At present he walks with the aid of sticks, but the incontinence of urine persists.

The second case was a shrapnel bullet situated in the second lumbar. The wounded patient showed the symptoms of injury to the cauda equina. Laminectomy was performed and incision of the dural sheath made. The projectile was in the middle of the fibres of the cauda equina and was carefully extracted without injuring any of the fibres. The patient has been discharged, and we have lost sight of him.

Projectiles in the Sacrum.—We have removed eight of these, embedded in the bony tissue at various depths. One was entirely in the lateral mass. Most of them were retained in bony capsules formed partly by the sacrum and partly by new formation of bone. We have always

* See Brin, *Bull. soc. chirurgie*, February 1st, 1916.

approached them from the back with the gouge and mallet. In one case, the projectile, situated in the first sacral, was in the middle of the cauda equina, inside the dural sheath. This patient is now an aviator and has already undergone several tests as a pilot. Another of these patients stayed several months in a Paris hospital and was considered after a negative radiological examination as a malingerer. His projectile was however easily to be seen even on the screen.

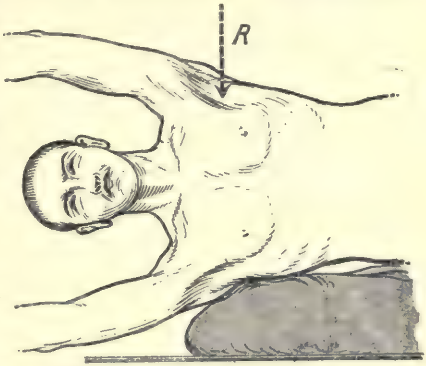
Deep Projectiles in the Perinæum; Ischio-rectal Fossæ.—It is extremely difficult to obtain a normal ray with the patient in the position most convenient for the surgeon for operation.

The patient should be placed in the lithotomy position for extractions of projectiles in this region, and this position in its extreme form is generally satisfactory. Quite recently we met with this difficulty for the first time, which can be avoided by moving the tube or by using a double anticathode tube. We do not think that compasses can be used any more conveniently in this situation.

## V—Limbs

§ 71. **Projectiles in the Axilla and Sub-scapular Region.**—These projectiles are frequent and rather difficult to extract. They are frequent because the scapula acts as an obstacle to the passage of projectiles.

They are rather difficult because an attitude which is not generally used must be chosen to cause the normal ray to follow the surgical route of access, which can only be via the axilla. The difficulty consists solely in keeping the anæsthetised patient in the position required by the radiologist. This consists in maintaining the arms raised vertically (in the anatomical sense), so as to leave the axilla clear, the patient lying on one side which rests on an oat ball cushion. Moreover, the shoulder of the side of the operation should be a little behind the sound shoulder, in order to avoid superposing the images of the scapulæ (Fig. 216). Even then it is not rare that the surgical route of access is somewhat oblique in relation to the normal ray, which necessitates, in the course of the operation, a few displacements of the body of the patient, to re-establish the coincidence of the route followed by the surgeon and of the normal ray or a movement of the tube to ascertain the relative positions of the projectile and of the surgical instrument during the operation.




PROJECTILES IN THE ARM, THE ELBOW, THE FOREARM, THE WRIST, AND THE HAND. — One knows how easily these projectiles are extracted after a preceding radiological examination with the aid of the control of the screen. Nothing special need be said of them.

PROJECTILES IN THE HIP, BUTTOCK, THIGH, KNEE, AND LEG.—Like the projectiles of the shoulder projectiles of the hip are sometimes very difficult to extract, the cause being too often an incomplete radiological localisation, giving simply a depth, but without fixing whether the projectile is above or below the neck of the femur or in the bone. The result is that the choice of the way of access is somewhat haphazard.

FIG. 216.—Position chosen to approach a projectile in the axilla most easily.

This difficulty disappears when we have accurate information.

Small projectiles hidden in the buttocks and projectiles in the muscular masses of the thigh can only be successfully extracted with the aid of the intermittent control of the screen.

PROJECTILES OF THE FOOT.—No matter what the situation may be of these projectiles which so often give rise to pain on walking, the route of access should never be through the sole, in order to avoid the presence of a painful scar.

The projectile will therefore be approached either through the dorsum of the foot or through the lateral side, according to the situation, but never through the sole. In difficult cases an examination in two different directions will always bring the instrument in contact wth the fragment to be extracted (Figs. 217 and 218).

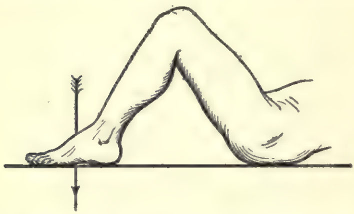


Fig. 217.—Position chosen for projectiles of the foot. Dorsal view.

Projectiles in the Nerves.—We have often removed projectiles, even of very small size, adjacent to the nerves in limbs causing great pain from their proximity to them. Only twice, however, have we found metal bodies included in the nerves.

In one case a thin sharp-pointed metal fragment ran through the radial nerve. In another case a fragment was included in the interior of a fusiform neuroma of the sciatic nerve.

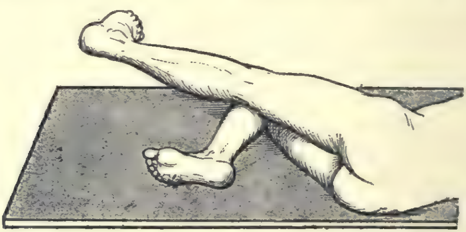


Fig. 218.—Position chosen for projectiles of the foot. Lateral view.

Projectiles of the Vessels.—We have removed metal fragments which appeared retained in the walls of the brachial and of the popliteal vessels.

Can a projectile penetrate into the lumen of a vessel, especially of a vein, and block the orifice? This seems possible to us. The two cases of hæmorrhage of the iliac vessels reported above may be explained thus. We remember an observation by *Robineau* in which the traction on a shell splinter opened the popliteal vein. However, it is possible that in the actual extraction the rough shell splinter may tear the thinned vascular wall to which it adheres. We do not know of any real fact to indicate that a projectile has spontaneously and secondarily eroded and perforated a thick vessel. This is however a possibility which the well-known accidents of arterial wear in contact with drainage tubes for instance permit us to consider probable. It might lead us to undertake certain extractions systematically and in regions particularly difficult. It seems that a more extensive experience should be awaited before committing oneself definitely on this point.

To sum up, the simple problem to be solved for each region is always the same. It comes to choosing a route of access which can be rendered rectilinear, and to place this rectilinear route of access in a manner to cause it to coincide with the normal ray.

We have just shown that, with exception perhaps as regards the perinæum and the ischio-rectal fossæ, this is always possible. Even where it is not possible the examination in two different positions and the observation obtained by mobilising the tube will always give the radiologist sufficient information to enable him to guide the surgeon's instrument until contact with the projectile is established.

§ 72. VI. **Complications associated with Projectiles.**—Abscesses.—The projectiles very often form abscesses round themselves, even after apparent healing. Owing to the special conditions under which our services under Descartes at Tours have worked, we have never observed these to occur. It is probable that all the late abscesses which occurred in the limbs were opened at the front without being referred to the consulting surgeon, and that the doctors attending have then simply extracted the projectile bathed in the pus. We have noticed instances of this. We, who have had to deal with the deep projectiles which appeared difficult to extract, have only noticed once an abscess of the size of a nut round a projectile near the

## PLATE VIII

Fig. 1.—Radiograph of the thorax right oblique front view. One will see, in the middle clear space, the shadow of a projectile absolutely distinct from the shadow of the heart. This projectile is therefore certainly not intracardiac, as had been affirmed, although it projects inside the shadow of the heart in all the other positions, which explains the error of diagnosis made by inexperienced radiologists.

Fig. 2.—Radiograph of the left shoulder seen from the back. The shadow of a deformed shrapnel is projected over the free extremity of the coracoid. Another small fragment of projectile has been detached and its shadow is seen in the soft parts internal to the coracoid (compare Fig. 97).

Fig. 3.—Radiograph of the right hand seen from its palmar aspect. Innumerable metal particles and fragments of very small size (grenade injury).

Fig. 4.—Radiograph of the right hand seen from the palmar aspect. Trail of metal particles, fragments of very small volume. Notice the intense decalcification, particularly marked at the level of the epiphyses, of all the bones of the hand.

PLATE VIII

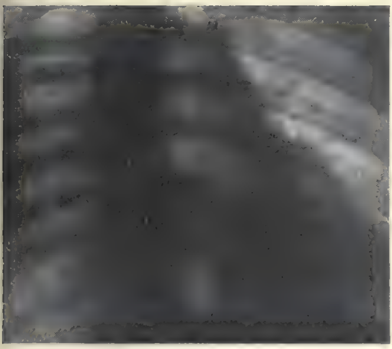


FIG. 1

FIG. 2

FIG. 3

FIG. 4

diaphragm penetrating the convexity of the liver (see above).

What we have seen frequently, in the viscera as well as in the muscular masses, is a small encysted cavity containing some granulations with some thick liquid, yellowish, or more often coloured by the metal oxides of a black or mahogany-red colour. These cystic sacs contain a projectile almost floating in their centre, which can be removed with extreme ease, but when this sac does not exist the shell fragments on the contrary frequently adhere very firmly to the tissues in which they have been retained a long time.

The contents of the sacs never seemed to us to be very virulent. In these cases also the result of various researches made must be awaited, some of which are already published, and especially the reports on the septic troubles which may result from the prolonged retention of projectiles.

Splinters.—In the course of the extraction of a projectile it has happened to us several times that we have removed bony splinters which we found on the course of the route of access. During the extraction of a projectile in the lung of an officer whose operation had been postponed several times we removed first a bony fragment probably of a rib, and found the metal body two centimeters deeper.

The intermittent control of the screen enabled us to be certain that the projectile was still there after the splinter had been extracted and that the operation was not finished. Probably we should have hesitated with any other method and we should have asked ourselves anxiously whether the bony fragment which we had just removed was or was not the foreign body the presence of which was revealed by the radiograph.

We have never found any fragments of clothing or other foreign bodies in contact with any projectile which had been retained and remained aseptic.

*Operative Results of Aseptic Extractions.*—Our organisation at the Descartes school is surgically as perfect as that of the surgical service of one of us in Paris. Our assistants are the students studying surgery. Under these circumstances therefore, considering the results which we always obtain in aseptic surgery, we have a right to say that if certain septic incidents happen to complicate with a certain frequency some special operations they are due to something else than contamination due to the operative technique.

Although when projectiles are extracted from the soft parts healing takes place as a general rule and, in the very great majority of cases, by first intention, we have noticed that oozing of thick serum for eight days or so generally occurs when these cystic sacs have been present, although we generally curetted the cavity.

On the other hand we have nearly always observed some osteomyelitis and suppuration lasting from fifteen days to six weeks whenever the projectile was extracted from the site of a compound fracture with splinters. In these cases there are nearly always granulations round the projectile. It has also seemed to us that the centres containing shell splinters showed themselves more virulent than those in which smooth projectiles, bullets or shrapnel bullets, were included. In any case we have never seen these discharges or these osteomyelitic foci give any cause for anxiety.

*Anæsthesia.*—It is hardly necessary to point out that in the extractions of projectiles with the aid of the intermittent control of the screen the anæsthesia must frequently be administered with the patient lying on his face. The fears of some surgeons who have had no experience of this procedure are absolutely without foundation. The only possible trouble concerns the anæsthetist only and consists in the difficulty which he may encounter in following the patient well and freeing his head sufficiently to apply the Ombrédanne apparatus which we use exclusively. By placing a cushion under the thorax or the shoulders and inclining the head this little difficulty will be very easily overcome. An ingenious inventor of the 9th region, whose improvised radiological table we have mentioned (Chapter IV, Fig. 72), has added to it a device which permits us to raise the plane of the table higher and to keep a free space for the head to render the anæsthesia more convenient.

The same manœuvre can be carried out with our radiological table, but it is not indispensable.

§ 73. **Search for Foreign Bodies other than Projectiles.**—As this work is essentially devoted to the search for *pro-*

*jectiles* we have so far hardly mentioned other foreign bodies.

It is hardly necessary to point out that all that we have explained applies without any modification to *the other metallic foreign bodies* which the surgeon may have to deal with in the course of his practice and especially to the metal foreign bodies so frequently swallowed or inspired by children. We trust that recourse will henceforth be more frequently made to their radioscopical localisation and extraction with the aid of the intermittent control. One may refer with much advantage as regards this point to the important works by Henrard who has recommended and successfully practised for a long time the search for œsophageal foreign bodies with the screen.* It is a valuable adjuvant to bronchoscopy for those who know the use of it in exploration and extraction.

But apart from the metal foreign bodies there are numerous foreign bodies introduced in the organism or formed in the thickness of the tissues for which the principles laid down in this work can be utilised with advantage.

For all those which their relatively small opacity (renal calculus, gall stones, enteroliths, and small splinters, etc.) renders radioscopy less useful, radiographic localisation will give greater and more accurate help. We may employ with advantage compasses, especially the Hirtz compass, for this purpose. In civil practice when time is less precious and expense is less important, the multiple uses to which this admirable instrument lends itself admirably will be found of great value.

We shall not deal further with this subject which is capable of interesting developments, as this would carry us outside the scope of this work. We shall content ourselves with having pointed it out to the attention of the reader.

* One will also consult with advantage the recent work by Chevalier Jackson, *Peroral Bronchoscopy* (Saint-Louis, 1916).

# CHAPTER XV

## THE SEARCH FOR PROJECTILES BY NON-RADIOLOGICAL METHODS

§ 74. THE great facilities, the perfect security which the radiological methods afford us *in all cases* can induce us to think that it is absolutely useless to consider any other method. However even now one may desire to use either for the detection or especially for the extraction of the projectiles *after the radiological localisation* the aid of accessory apparatus in the cases—which, we hope, become more and more rare—in which the operator cannot avail himself of the intermittent control of the screen.

We are going to describe briefly the principal methods which one will do well to retain and which have already stood a test. We shall not deal, of course, with the exploration with the speculum, the only serious process of examination at the disposal of the doctors in former times, nor with chemical reagents. We shall neither try to trace the history—which is very interesting—of this matter, and we refer the reader to the articles in the medical dictionaries. We shall limit ourselves to the study of the modern methods which are all based, like the X-rays, on the direct or indirect use of electricity.*

Projectiles are essentially metal fragments consisting in most cases of steel, iron, or cast-iron. They are therefore always *conducting* bodies and most often *magnetic* substances. These are the two chief characteristics which are going to serve as a basis for all methods of search which we shall describe in this chapter.

* One may consult with advantage in this connection the excellent *Manual of Electro-therapeutics* by Albert-Weil (new edition, Paris, Alcan, 1916), an article by the same author in the *Paris Médical* and a very instructive article by Lebon in the *Science et la Vie.* We have borrowed largely from these authors.

## I—Search for Magnetic Projectiles

Efforts have been made for a long time to make use of the fact that large numbers of projectiles are magnetic in order to find them more easily. Advantage has been taken for some extractions of the properties of *natural magnets*, but their weak force limits their application to a great extent.

With the discovery of *electro-magnets* the power has grown to such proportions that one has been able, as is well known, to apply in a continuous manner (and especially in the domain of ophthalmology) the magnetic attraction for the search and extraction of metal fragments.

Finally, since the war, at the same time as this application of the magnets developed, M. Bergonié has given a fresh impulse to the employment of alternating electro-magnets which excite the vibration of the magnetical bodies and consequently facilitate their detection in the tissues.

We shall distinguish: (1) magnets destined for the attraction, the mobilisation, and the extraction itself of the projectiles—these are the electro-magnets fed by continuous current; and (2) magnets destined exclusively for revealing the presence of the projectile by causing it to vibrate—these are the electro-magnets fed by alternate current or electro-vibrators.

(1) *Continuous Electro-Magnets*.*—Theoretically one could, by supposing an electro-magnet sufficiently powerful, effect directly, through attraction through the tissues of the body, the extraction of the magnetic projectiles, as is practised for the globe of the eye. M. Bergonié and M. Rollet have published papers on these lines and related cases in which the magnet had "mobilised" and brought to the surface projectiles which were deeply retained, or revealed by the raising of the skin the presence of the foreign body and its approximate site. Without speaking of the practical difficulties of the application originating in the necessary power for the electro-magnet, one will easily understand, without it being necessary to emphasise the point, all the dangers which may result from such a

* See Thompson, *The Electro-Magnet*, 1 vol. 18mo (Paris; Des forges).

blind manner of proceeding. It is therefore not surprising that one has not adopted this method more extensively which seems mainly applicable to ophthalmological applications.

The utilisation of the continuous electro-magnets is interesting in *the extraction of projectiles by direct contact in the wounds.* Especially at the front in the case of recent wounds which are still open and into which can be sunk the metal sterile point of an electro-magnet this practice will render according to our belief frequent services, although the necessary provision of a *powerful electric circuit* restricts its application.

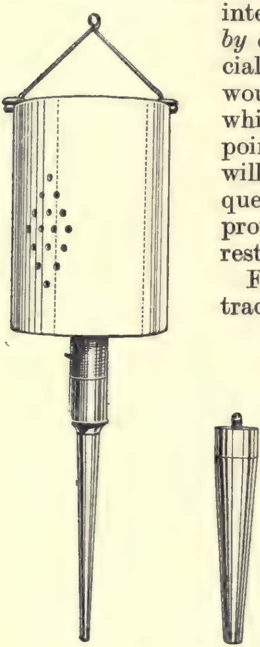


Fig. 219.—Dr. Lyonnais' electro-magnet, with one of its spare points.

Finally, in the course of surgical extractions of long-retained projectiles we think it will always be useful to have at one's disposal a continuous electro-magnet. We often employ advantageously the type shown herewith (Fig. 219), constructed for us by Dr. Lyonnais (of Doué-la-Fontaine) not for taking out a projectile which is still included in the tissues, but simply for "collecting" with a minimum of damage the German bullet or the shell splinter deeply situated, as the removal with the forceps would cause greater injuries or involve difficult manœuvres in the mediastinum, the lung, the deep parts of the buttock, etc. . . . and, *especially, in the brain.** This is a *very valuable adjuvant* of our outfit (but not indispensable). Its utility is obvious in all important and well-organised services. But let us not forget that unless *a really exceptional power* is provided one cannot expect to take out the projectiles through *the slightest layer of interposed tissue.* If it is only as thick as a sheet of cigarette paper it will suffice

* See the preceding chapter.

to prevent the attraction. *The projectile must be able to enter into direct contact with the magnet.* Even if it is easy to obtain a *carrying force* sufficiently high per *square centimeter*, the contact between the point of the magnet and the shell splinter or even the ball is practically limited to one point. Moreover, when an electro-magnet can present a considerable carrying force it only attracts to a relatively small degree a metal fragment which is not immediately in contact with its pole, this being due to the fact that the interference of the interposed substance is considerable and also that the flow diminishes very quickly if one moves away from the poles. The attraction is, approximately, inversely proportional to the *cube* of the distance.

(2) *Alternating or Vibrating Electro-Magnets.**—Taking up on the recommendation of M. Anderson the conclusions of the fine research work by Elihu Thompson on the electro-magnets traversed by alternate currents and the vibrations which they determine in magnetic bodies (and even in certain metals slightly or non-magnetic), M. Bergonié has devised an alternating electro-magnet which is constructed by the firm of Gallot. This is, in short, an inductor of an induction-coil, the apparatus being known under the name of *electro-vibrator*. The magnetic projectiles placed in its field present, in fact, an intense vibration which can be felt and which thus make their presence known.

In order to use it alternating current is of course necessary. If there is only continuous current a rotary converter or, if necessary, turbine interrupter should be employed. The vibrator being essentially very heavy it should as far as possible be suspended from a bracket and it will then be worked easily by means of a counter-weight. The above drawing (Fig. 220) shows the Bergonié apparatus.

The apparatus is applied perpendicularly to the surface to be explored, the fingers being applied to same flatly until the vibration is felt. Then one localises exactly by means of one finger only the point of maximum vibration (Fig. 221). This search is renewed before commencing the operation, then, during its progress, with the finger inserted in the wound. Care must be taken beforehand to protect the

* See the *Archives d'Electricité Médicale* by Bergonié since April 1915. Most of the numbers contain articles devoted to the electro-vibrator.

wound against any possible infection through contact by enveloping the electro-vibrator in a sterile towel.

Moreover the apparatus after a few seconds becomes very hot on account of the intensity of the current which runs through it and sterilises it, but which will not fail to put it out of action if the current is not interrupted every thirty seconds. When the incision is made at the localised point the surgeon is guided by the electro-vibrator into the depth of the wound towards the projectile, by finding with the finger, without pressure, the direction in which the vibration is at its maximum. The operation is then directed towards that point.

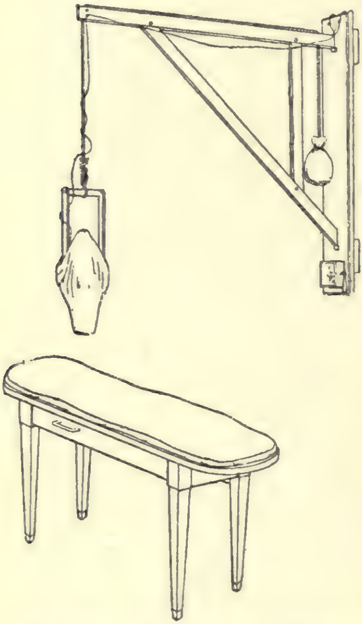


Fig. 220.—The electro-vibrator of Bergonié with counter-weight mounting (bracket) permitting its convenient use above the examination or operation table.

However, all the ordinary instruments used in the operation vibrate, this being singularly troublesome. M. Bergonié has therefore had constructed by M. Collin instruments of a non-vibrating alloy. This however necessitates a rather inconvenient complication of surgical instruments.

The vibrator is a remarkable and excellent instrument which will often enable one to reveal the presence of magnetic projectiles and will render their extraction easy in many cases. However, at least one-quarter of the projectiles searched for are not magnetic and do not vibrate, or at least do not vibrate with certainty. A negative exploration with the electro-vibrator *will therefore by no means prove* that there is no projectile present and that *a radiological examination can be dispensed with.* Moreover, it very often happens that magnetic projectiles are either too deeply situated (more than 10 centimeters) or are too firmly included in the bone to vibrate. Besides, a great difficulty lies frequently in the determination of the *maximum point of vibration.* Finally, even when the projectile vibrates and there is a point of vibration, the surgeon is still without any information as regards the real depth and the anatomical site of the projectile, and if he operates without further examination only under the conduct of the vibrator, he will always find himself in the situation of the operator who would rely on the control of the screen in order to conduct him to a projectile not localised, this without as much as a preceding examination at two different angles, and who would be certain to make mistakes. We have more than once extracted magnetic projectiles relatively rather easily which excellent surgeons could not find by means of the electro-vibrator.

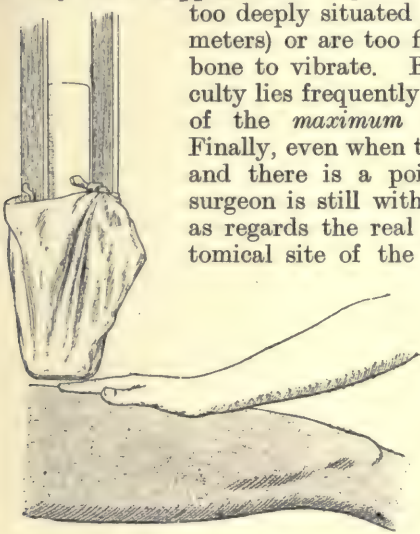


FIG. 221.—Searching for a projectile by means of the electro-vibrator.

Therefore *a complete radiological examination should be undertaken in all the cases with localisation* of the projectiles which one intends to extract with the vibrator. This involves consequently a complication of the outfit, without being of universal application. As M. Réchou very rightly observes, if one possesses a general means one must neglect the particular means.

One must not forget moreover that the vibrator, to be of real assistance, should work under well-determined conditions by using a *considerable energy* which must not be less, according to M. Bergonié himself, than 60 ampères at 110 volts, which nearly always requires the provision of special wiring which is very expensive.

An effort has since been made to produce an instrument rendering the same service with a smaller consumption of energy and of less weight.

Thus MM. Picquet and Egal have constructed a vibrator which presents a much more satisfactory yield although its size and weight are very much reduced. Their apparatus only weighs 4 kilos. The core of the coil, consisting of tempered mild-iron plate blades, insulated by paper, only measures 10 centimeters long by 5 round. It is surrounded by 200 turns of copper wire of 18/10. The coil is mounted in the manner of an axe, to one of the ends of a wooden handle of 70 centimeters. At the other end is a switch. An assistant holds this handle with both hands and holds the vibrator enveloped in a cover of sterilised cloth above the patient in all the positions required by the surgeon. A strap placed round the neck of the assistant facilitates his task in supporting the handle of the apparatus, the most remarkable quality of which is to work efficiently with 15 ampères at 110 volts.*

§ 75. **The Electrical Detection of Projectiles.**—A. *The Induction Balance and its Derivatives.* The Bergonié vibrator is not the only apparatus which is capable of demonstrating the presence of metal projectiles situated in the tissues before incision or the exploration of the wound. A series of very ingenious instruments based on the fact that most metals are infinitely better conductors for the magnetic lines of force than the greater number of other bodies, derived more or less directly from the Hughes balance, can supply us with the same information.†

Hughes has termed *induction balance* an apparatus in which four solenoids (or windings of conducting wire) *A*, *B*, *C*, *D*, are connected two to two (Fig. 222). In the group *A*, *B*, called *inductor* a current circulates which is

* For all details concerning this apparatus refer to the article in *The Radiological Journal* of October 1916.

† We only mention in passing the deviation of the magnetised needle of the compass near the projectiles mentioned by M. Baudouin, but which is only very rarely of practical importance.

supplied by a pile and broken at rapid intervals by an interrupter. The second group, called *induced*, is closed by a telephone. However, one has wound on a similar cylinder or on a similar coil an inductor solenoid and an induced solenoid, $A$ is thus connected with $C$, $B$ connected with $D$, and the groups $AC$, $BD$ constitute each *one of the supports of the balance*.

Now, the inductor and induced windings are in opposite directions. Therefore if the two couples of solenoids are identical (same number of turns and same wire) the two currents which are created in the induced coils are necessarily equal, but opposite, and in consequence they completely neutralise one another. The telephone is then not sensitive and gives no sound. But if on the contrary one makes arrangements that one of the induced currents should exceed the other in intensity, even to a very small degree, then the telephone is audible. What must one do in order to obtain this result? Simply break down the condition of magnetic equilibrium of the area surrounding the two induced coils, by bringing any metal body near to the turns of one of them so that it may be traversed by the lines of force of its magnetic field. Thus it develops in the metal body induction currents which create a magnetic field, which, by reacting on that of the coil, modifies the value of the current which is induced in the latter. The two induced currents being no longer equal do not destroy themselves completely, and the difference passes through the telephone causing a sound to be heard. Pro-

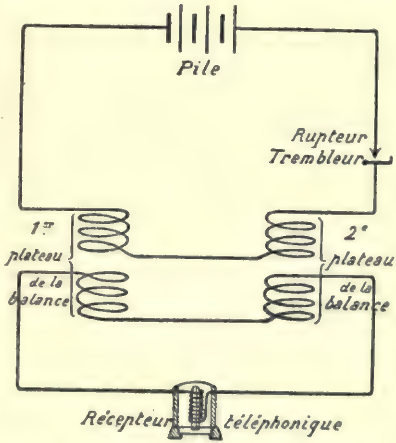



FIG. 222.—Drawing of the Hughes induction balance.

fessor Lippmann reported in November 1914 that the electro-magnetic balance could be advantageously used for discovering projectiles in the tissues.

Kaufmann, who seems to have been the first to think of this use, has simply replaced the clockwork mechanism, which interrupts the current in the circuit of the inductor group of the Hughes apparatus, by a microphone which is connected with a watch. The ticking of the latter produces the alternate make and break of the primary circuit (inductor group) necessary for inducing the currents in the secondary circuit (induced group). The coils being made very small one can easily pass one of the cylinders over the body of the patient. The vibrations of the telephone increase as one approaches the region where the metal body is situated, attaining the highest intensity when one is immediately above, then diminishing until it ceases entirely, when one moves away from it.

M. Chilowsky has had constructed by the firm of Gallot an induction apparatus which only has two coils placed symmetrically in planes perpendicular one to the other (Fig. 223). It follows that the induced coil is not traversed by the lines of magnetic force of the inducing coil. No current can therefore normally make the telephone which is inserted in its circuit sensitive. But if a metal body is placed in the field of the inducing coil and outside the plane of the second soil, induction currents will be developed in that body the magnetic field of which will influence the induced coil and creating a current which will cause the telephone to sound. Hence we conclude that the plane of the induced coil constitutes a plane of extinction of the sound and that of the inducing coil a plane of maximum audibility permitting us to determine the position of the metal, if, as in the case under review, we move the apparatus above a region which a metal fragment may be retained. In practice, as it is difficult to construct the apparatus in such a manner that the planes of the two coils are strictly perpendicular, we introduce in the interior of the induced coil, in series with same and in the same plane, a third coil, capable of turning round a horizontal axis which permits us to regulate the apparatus to zero, that is to say to obtain complete and perfect neutralisation of the inducing and induced coils.

Chilowsky later modified his apparatus by forming it of three coils disposed in three planes perpendicular one to the other (Fig. 223); in order to make it more compact, the induced coil of the first apparatus is replaced by two smaller coils in the form of a cross. Thus he has produced an electrical sound of small diameter which can be introduced into wounds or incisions.

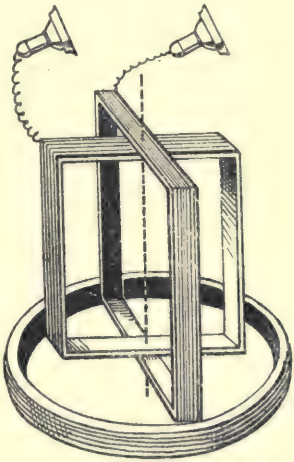


Fig. 223.—Chilowsky's modified apparatus showing the three coils perpendicular between themselves and the telephonic receivers.

Apparatus of this type is only efficient when the bodies to be found are not deeper than one to two centimeters. Their use is therefore very limited.

The "searcher-localiser" invented by M. François has a more important range of action. It comprises essentially:

(1) A first group, called *fixed group*, formed of two identical coils placed in the prolongation of one another on a stand bearing also the devices for regulating the sensibility and the various connecting terminals. One is fixed, the other one mobile. The mobile coil represents one of the two essentials for regulation. The other one consists of a small metal ball surmounting a rod fixed on the stand by a joint link which allows the ball to be approximated or withdrawn from the coils.

(2) A second group of coils wound one at the side of the other which constitutes the exploring element, the properly so-called searcher-localiser, the weight of which is very small, about 350 grammes.

(3) A telephone receiver mounted on a head-clamp with a metal spring.

(4) A small box containing a non-polarisable three-element battery and a trembler interrupter intended to

produce a rapid succession of makes and breaks of the primary circuit (fixed group).

The outfit can be used in a very simple way.* After having placed the stand carrying the fixed group on a non-metallic support, and having removed the searcher from the field of regulating coils and the box containing the battery and the interrupter, so that the noise of the trembler does not interfere with the sound heard in the telephone, the operator puts on the headpiece. Should he hear a noise it shows that the balance is not in equilibrium; he therefore proceeds to regulate it which after a little experience can be done in a few seconds.

In order to localise the projectile in the tissues the surgeon passes the searcher lightly over the region supposed to contain it, being careful to maintain it as far as possible perpendicular to the surface of the body. As soon as the instrument approaches the metal object sufficiently near to develop induction currents the telephone starts ringing. The sound heard in the receivers is the more intense as the axial line of the searcher approaches the projectile; by passing the instrument in every direction, we shall find the point where the intensity of the sound is at its maximum.

According to their size splinters of steel, iron or cast iron are discovered by the searcher at more or less great depths. Other metals such as copper (French bullet), lead, bronze, gold, silver, aluminium, etc., influence the apparatus at depths which are also in relation to the size. It is however evident that the more magnetic a metal is, the larger the distance at which it reacts on the exploring coil.

A close determination of the depth may be obtained with the searcher. We effect it by comparing the sound produced by the projectile in the telephone with the sound produced by a small piece of the same metal. This piece is brought more or less near to the searcher, and it is made to slide on a small graduated rule placed in the axis of the apparatus. A good and exercised ear determines as easily the instant when the intensity of the two sounds are equal as a musician is able to pitch two strings of the same tonality; all that is necessary to do afterwards is to read

* See the communication of M. François to the Academy of Medicine and the articles already mentioned, by Messrs. Lebon and Albert-Weil.

on the rule the distance which separates the metal object from the searcher in order to know the approximate depth of the projectile in the tissues.

We may close the series of appliances based on the Hughes induction balance by mentioning the finger-stall

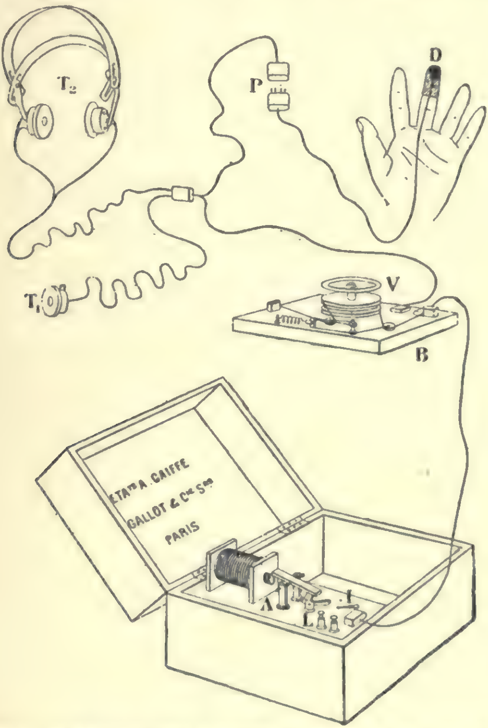



FIG. 224.—The audioscopic finger-stall by M. A. de la Baume-Pluvinel (Gallot & Co.). We see on the diagram the four principal parts of which the appliance consists. (1) The source of the vibrating current constituted by a coil ($A$) with a rapid trembler ($L$) (fed by two dry batteries) contained in a box which also is used for transporting all other accessories. (2) The compensator ($B$) which must be placed on a wooden support not containing any metal part and which is regulated by means of a fly-wheel ($V$). (3) The telephone receivers ($T_1$, $T_2$). (4) The finger-stall ($D$) (which is placed on a finger which is little used normally, say the middle finger of the left hand) and which contains the exploring coil in the shape of a pastille.

of M. A. de la Baume-Pluvinel (Gallot & Co., manufacturers) the object of which is to provide the extremity of the surgeon's finger with a small appliance which would enable him, by exploring the interior of the wound, to recognise the direction in which it is best to open the tissues in order to reach the foreign body in the most direct possible way. His apparatus gives the desired effect under excellent conditions and seems to us to be by far the most original, the most attractive, as well as the most useful of the instruments of this series.

It is in reality the exploring coil of the Hughes balance; only the surgeon places it on one of his fingers (instead of fixing it on a sleeve as the François sound) preferably on the top of the middle finger of the left hand and maintains it in place by means of a finger-stall of sterilised rubber. He thereupon introduces the finger into the wound or the incision and turns it round in order to explore the walls. This appliance has the advantage of being easily handled owing to the mobility of the finger. However, its shortness does not give it great sensibility. The metal body must not be further than one to two cm. from the extremity of the finger in order that the operator should be usefully guided, but in this case the distance is quite sufficient as the surgeon is generally very near the projectile which he does not feel with the finger.*

§ 76. B. **Electric Explorers and Detectors.**—Although the metals mostly used in the manufacture of projectiles are magnetic it is not the case with all of them; they are however all conductors. The processes of detecting metal projectiles based on the latter property seem to contraindicate their general use. They have the great inconvenience of necessitating actual contact, that is to say they can only be used after incision or during the exploration of a wound.

We are going to review them rapidly by quoting textually, as in the foregoing paragraph, from the article published by Dr. H. Lebon in *Science et la Vie.*

*Electric Explorer-Extractor by Trouvé.*—This instrument is one of the first invented of those which take advantage

* A variation of this appliance intended for exploration before the intervention and having a greater sensibility has just been devised by the same constructors for M. de Gontant-Biron.

of the conductive property of metals constituting the projectiles to close an electric circuit having appeared first in 1867. For a certain period it formed part of regulation military and naval medical equipment. The apparatus consists essentially (Fig. 225) of a stylet formed of two small rods of steel, insulated from one another at the lower end and attached at the other end to a small electro-magnet contained in a case in the form of a watch called the revealer fixed to the top of the stylet. This is connected at the other end to the extremities of a battery, and will be traversed by the current whenever the points of the stylet both touch a metallic body thus closing the circuit. It will thus attract the vibrating plate. If we quickly raise and lower the stylet alternately there will be produced a series of makes and breaks of the circuit and the vibrating plate of the electro-magnet revealer will be heard. A body of metal only will be conduct sufficiently to close the circuit as the contact with a splinter of a bone or with any fragment of tissue will not cause any error. But the contact with the projectile is necessary. The instrument may however also be joined to forceps, the insulated branches of which take the place of the rods of the stylet. The metal body when found can thus be easily extracted.

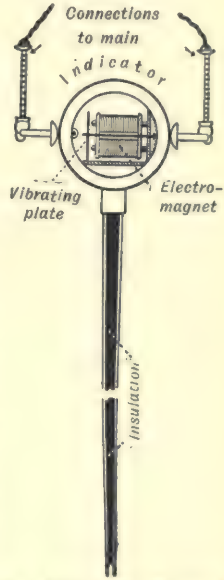


FIG. 225.—The Trouvé electric explorer.

Guilloz of Nancy wished to render the Trouvé apparatus more practical and to that effect he modified it very successfully. His electric trocar is an ordinary trocar the central needle of which, insulated except at its bare extremity, moves inside another metal hollow needle. The two needles are inserted in the circuit of a battery and of a galvanometer or of a bell. The point of the central needle always projects a little beyond the extremity of the hollow needle, owing to an antagonistic spring placed in the handle of the apparatus ; if the surgeon meets a hard body in the wound the surgeon must press the handle of the trocar so as to overcome the resistance of the spring which prevents the retreat of the central needle ; the two needles come then into contact with the hard body, and if the latter is of metal it establishes a contact between the two points and then the galvanometer or the bell will immediately reveal its presence. Guillot has also designed, on the same principle, an electric needle-carrier explorer which enables one to carry out analgesic injections. He uses instead of the hollow needle of the trocar described above a needle by Pravaz joined to a syringe and pierced by holes lengthwise in such a way that the liquid is instilled into the tissues.

Both the Guilloz apparatus as well as the Trouvé apparatus must be provided with a double contact in order to reveal the presence of a metallic foreign body. The telephonic line by Graham Bell, described about fifteen years ago, requires only one contact. This instrument consists of an ordinary telephone receiver, provided with two conducting wires ; one of these is joined to a silver spoon or even to a simple platinum spiral and the other is fixed to a copper or steel rod of small diameter. The patient places a part of the spoon or of the spiral into his mouth and the surgeon explores the wound with a metal rod, holding at the same time near his ears a telephone receiver which may be replaced with advantage by Hedley's ultra-sensitive double listening headpiece, which enables the surgeon to have the free use of both his hands. As soon as the probe comes into contact with the projectile a sharp characteristic noise is heard in the telephone. Dr. H. Henrard, the very eminent radiologist of Brussels, has replaced the spoon by a lead plate covered with compressed gauze soaked with a saline solution and he fixes this by means of a bandage to the surface of the patient's skin. A conductor joins this plate of lead to a telephone receiver mounted on a headpiece ; this receiver is joined to a probe, bistoury, needle of a hypodermic syringe or forceps which can be introduced into the wound. In either case (spoon or lead plate) the voltaic couple which produces the current required for making the telephone sensitive is obtained without a proper battery : in the first case the saliva of the patient serves as an electrolyte, as the silver of the spoon and the copper of the probe play the part of anode and of cathode; in the second case the saline solution on the one hand, the lead of the plate and the metal of the exploring instrument on the other hand, fulfil the same object.

To the Henrard telephone apparatus which is accessible to every physician even in a country place, we may add a battery and an electrolytic detector similar to that of Colonel Ferrié, used in wireless telegraphy, in order to improve the audibility of the sound in the receiver. This has been accomplished by Messrs. Mauclaire and Garin. A buzzing or fizzing noise is then produced in the receivers during the whole length of the contact of the surgical instrument with the foreign metal body. In order to find the contact in an irregular course, Messrs. Mauclaire and Garin propose the use of a probe in the interior of which pass two conductor lines, one being joined to the positive pole of the battery and the other to the negative pole through the detector, ending at the metallic projections placed at the extremity of the sounding line. It is however recognised that with this apparatus as well as with any other contact probe we may obtain negative results, owing to the deposit of blood or of fatty or serous liquid which forms an insulating cover round the projectile.

Finally the Cambridge Scientific Instruments Co. has recently constructed on the same principles an instrument in which the telephone is replaced by a strong and transportable though sensitive galvanometer. The errors produced by the buzzing in the telephone receiver are thus avoided. Two conductor wires lead to the galvanometer and are connected one to the exploring probe proper and the other to a "contact" of the same metal as the probe and which is fixed in a corner of the wound. No difference of potential would be established between the probe and the contact, as both are constituted of the same metal. But as soon as the explorer has come into contact with another metal in the wound, the voltaic element is formed and the galvanometer deviates. Its sensitiveness is such that a metal fragment of only 1 millimeter in diameter causes the needle to deviate by 10 to 20 degrees (about 3 centimeters on the scale).

To sum up, we see that if the electro-vibrator, the induction balance and the telephone probe are capable of rendering occasionally good service, they only constitute particular methods which cannot replace X-ray examination and the extraction by means of the intermittent control and that their use can only be restricted to hospitals which have no X-ray installations. These hospital units become less and less frequent; we therefore find that the use of these methods does not extend, but on the contrary becomes daily restricted.

However, it is as well to know of their existence in order to be able to use them in case of necessity when nothing better is available.

## CONCLUSION

We live now in such times that the memories of the pre-war epoch become more and more blurred. To-day we must imagine that there was such a time when surgeons were trying to find projectiles without having X-rays at their disposal.

We have shown here what services they are rendering us daily in the search for projectiles known or suspected.

Very often a projectile which has not been detected persistently causes inexplicable symptoms; but the rays detect it and the operation is carried out without difficulty.

Very often also a radioscopic examination discovers by chance the existence of ignored and inert projectiles. There is no doubt that these have remained from former wars and nevertheless many of these wounded recovered. This tolerance of the organism must not be forgotten. It is therefore a matter of dispute whether inert projectiles should be extracted. It should only be taken into consideration if the damage caused by the operation is going to be less than the inconveniences felt by the patient.

But how can we appreciate the possible damage unless the rays have enabled us first to localise the projectile, then to estimate its exact depth, and to locate its precise anatomical situation? It is only in the light of this knowledge that the advantages or inconveniences of the extraction of the inert projectiles can be properly weighed.

Finally the rays do still more. They guide the surgeon in his search, they lead him to the metal body by the most direct and most favourable way, according to his choice, with the smallest damage and without any risk of failure.

We have seen the real aid which may be given to us by electro-vibrators, but also the very frequent cases in which they are not successful. The rays are an infinitely truer and surer guide.

The first idea which must have come to the surgeon was to look himself at the screen, and to put on himself the fluoroscope, to go and grasp with forceps which he saw a projectile which he also saw. But then he was working in the dark and was receiving harmful rays to a great extent. The simplicity of the process is only apparent and the surgeon has no right to risk damaging his hands to no purpose.

Thus, from the very beginning of the war, it became apparent that only the intermittent control could supply exact information without interfering with the success of the operation itself and without any danger of dermatitis: these controls were effected by the radiologist who became the collaborator of the surgeon.

It is the radiologist who sees and points out. Sometimes he fixes the memory of the position of the projectile with a compass, and during the intervention he utilises it in order to control, in an indirect and intermittent way, the direction of the route of access. The compass is a mediate indicator; the indication supplied by it is second hand; the apparatus remembers only after having been placed in the presence of markings the place of which is determined by a graphic method. The position of the projectile thus supplied is relative only, dependent on the position of the marking points.

On the contrary, the radiologist looks at the projectile directly on the screen and shows it with the end of his needle: "That is where it is," he says. The information is immediate and first hand. Its value is absolute and not only relative. It is not the control with two degrees of the compass, it is direct control.

It is the second mode of intermittent control which we consider superior to all others, because it is simple, because it avoids all causes of errors, because it is without danger: *cito, tuto et jucunde.*

It does not matter that some people use it exclusively, that others continue to make use of the compass, but operate on a radiological table, ready to utilise the intermittent control of the screen in case of failure: it nevertheless remains a fact that only that last system of control gives the surgeon a complete guarantee against an unsuccessful operation.

For many long months we have been trying to perfect and to make its method of working more precise. Numerous and eminent surgeons have come, sometimes from very far, to see us operate. All have recognised the advantages which our method of working presents.

It seemed to us that we would do useful work by describing this method in a more lengthy way than in our various communications and by publishing to-day this volume where we have condensed what we have learned at the hospital of the Descartes Lyceum during our radio-surgical collaboration.

# INDEX

*Printed in Great Britain by Hazell, Watson & Viney, Ld., London and Aylesbury.*

*Extract from*

*the Introduction by the General Editor,*

*Sir Alfred Keogh.*

THE special interest and importance, in a surgical sense, of the great European War lies not so much in the fact that examples of every form of gross lesion of organs and limbs have been seen, but is to be found in the enormous mass of clinical material which has been presented to us and in the production of evidence sufficient to eliminate sources of error in determining important conclusions. For the first time also in any campaign the labours of the surgeon and the physician have had the aid of the bacteriologist, the pathologist, the physiologist and indeed of every form of scientific assistance in the solution of their respective problems.

The achievements in the field of discovery of the chemist, the physicist and the biologist have given the military surgeon an advantage in diagnosis and treatment which was denied to his predecessors, and we are able to measure the effects of these advantages when we come to appraise the results which have been attained.

But although we may admit the general truth of these statements it would be wrong to assume that modern scientific knowledge was, on the outbreak of the war, immediately useful to those to whom the wounded were to be confided. Fixed principles existed in all the sciences auxiliary to the work of the surgeon, but our scientific resources were not immediately available at the outset of the great campaign; scientific work bearing on wound problems had not been arranged in a manner adapted to the requirements, were not fully foreseen; for the workers in the various fields were isolated or had isolated themselves pursuing new researches rather than concentrating their powerful forces upon the one great quest.

However brilliant the triumphs of surgery may be, and that they have been of surpassing splendour no one will be found to deny, experiences of the war have already produced a mass of facts sufficient to suggest the complete remodelling of our methods of education and research.

The series of manuals, which it is my pleasant duty to introduce to English readers, consists of translations of the principal volumes of the "Horizon" Collection which has been appropriately named after the uniform of the French soldier.

The views of great authorities, who derive their knowledge from extensive first-hand practical experience gained in the field cannot fail to serve as a most valuable asset to the less experienced, and must do much to enable them to derive the utmost value from the experience which will, in time, be theirs. The series covers the whole field of war surgery and medicine, and its predominating note is the exhaustive, practical and up-to-date manner in which it is handled. It is marked throughout not only by a wealth of detail, but by clearness of view and logical sequence of thought. Its study will convince the reader that, great as have been the advances in all departments in the services during this war, the progress made in the medical branch may fairly challenge comparison with that in any other, and that not the least among the services rendered by our great Ally, France, to the common cause, is this brilliant contribution to our professional knowledge.

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2. How to instal the *material organisation* which permits of the application of this treatment; and how to recognize those conditions which prevent its application.

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The authors review, in succession, the Clinical details, the Epidemiology, and Prophylaxis of *Dysenteries*, *Cholera*, and *Typhus*. In the section dealing with *Prophylaxis*, in particular, will be found practical advice as to the special hygiene possible in the case of large collections of people placed in conditions favourable to the development of these diseases.

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Of all the infections which threaten our wounded men, tetanus is that which, thanks to serotherapy, we are best able to prevent. But serotherapy, when it is late and insufficient, may, on the other hand, tend to create a special type of attenuated and localised tetanus ; in this form the contractions are as a general rule confined to a single limb. This type, however, does not always remain strictly monoplegic ; and if examples of such cases are rare this is doubtless because physicians are not as yet very well aware of their existence.

We owe to MM. Courtois-Suffit and R. Giroux one of the first and most important observations of this new type ; so that no one was better qualified to define its characteristics. This they have done in a remarkable manner, supporting their remarks by all the documents hitherto published, first expounding the characteristics which individualise the other atypical and partial types of tetanus, which have long been recognized.

The preventive action of anti-tetanic serum should not cause us to disregard its curative action, the value of which is incontestable. However, a specific remedy, even when a powerful specific, cannot act upon all the complex elements which constitute a disease ; and tetanus presents itself, in the first place, as an affection of the nervous system. To contend with it, therefore, a symptomatic medication should come to the aid of a pathogenic medication.—*Professor Widal.*

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