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ON GUNSHOT INJURIES
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ON GUNSHOT INJURIES TO THE BLOOD-VESSELS

Founded on experience gained in France during
the Great War, 1914–1918.

BY 

GEORGE HENRY MAKINS, G.C.M.G., C.B.,

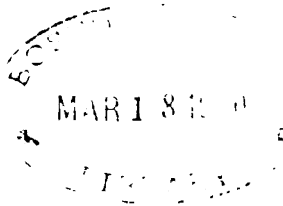
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British Expeditionary Force in France.*

NEW YORK:
WILLIAM WOOD AND COMPANY
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**TO
MY SURGICAL COMRADES OF
THE GREAT WAR**



PREFACE.

A GLANCE at this essay will suffice to show the lines upon which it has been prepared.

The General Section consists of an amplified and revised edition of several papers already written upon the subject, while the Special Section furnishes the material from which the views expressed have been deduced.

No attempt has been made to deal with the literature of the subject, since it has seemed to the author that the individual practical experience of one surgeon might be of greater value than opinions drawn from an examination of the work of others.

It remains to express the author's thanks to the many surgeons who afforded him the opportunity of examining their cases—to Captain Bashford for his aid in the description of the histological details; to Captain L. W. Shelley for his continuous help in keeping up the records of the cases; to Captain Z. Mennell, for help with the cases in London; to Sir W. Morley Fletcher, Lieutenant-Colonel Elliott, and Dr. M. Young, for the valuable aid given on behalf of the Medical Research Committee in obtaining both recent information and later information as to the ultimate results of cases; to Messrs. A. K. Maxwell, S. A. Sewell, and J. R. Ford, for the beautiful illustrations they have prepared for the book; and, lastly, to Mr. S. H. Rouquette for kindly reading most of the proof-sheets.

49, UPPER BROOK STREET,
March, 1919.



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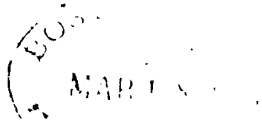
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GUNSHOT INJURIES TO THE BLOOD-VESSELS.

CHAPTER I.

INTRODUCTION.

WOUNDS the main importance of which depends upon implication of the large vascular trunks, and their consequences, have been a subject of special interest in the treatment of gunshot injuries for all time. Knowledge as to the general behaviour exhibited by these lesions has undergone little material change. Their special features, consisting in the tendency to spontaneous cessation of primary hæmorrhage even in the presence of very extensive damage to the vessel involved; the frequency with which such forms of injury are the occasion of secondary hæmorrhages; and the large proportion of them which are followed by the development of one of the several forms of traumatic aneurysm, have been maintained.

The chief information gained during the present war will be found to consist in a more accurate knowledge of the signs of injuries to the arteries; such as the indications to be gleaned from an examination of the peripheral and vasomotor nervous system; the value of auscultation, both local over the artery, and of the precordial region; and as to the actual mode of development of some of the consequences of arterial injuries. Further, opportunity has been afforded of judging of the effect of obliteration of the main vessels upon the vitality of the parts supplied by the peripheral branches affected, the latter observations being far from exhaustive at present. An increase in exact cognizance of the nature of the primary anatomical lesions of the vessels, and the arrangement of the vessels in relation to the various forms of traumatic aneurysm, has been acquired. Lastly, experience has been gained as to the relative advantages attained by obliteration of the main vessels by ligature, by simultaneous occlusion of artery and vein, and the attempt to maintain their viability by suture, respectively. In the latter particular military practice has been affected, as in so many other fields of surgery, by the limitations imposed by the septic nature of the wounds to be dealt with. Hence primary or early suture, which method was



Fig. 1.—Lateral wound of common carotid, partly closed by clot. Complete division of internal jugular vein. *Peninsular War, Mr. Guthrie. Museum of Royal Army Medical College.*

looked forward to with enthusiasm in the early part of the war, had to be abandoned for a considerable period, and has only been resorted to with greater frequency since improvements in general treatment of wounds have been attained.

Fig. 1 is inserted to illustrate an injury received during the Peninsular War, which differs in no material respect from hundreds of those which are being met with in the present campaigns. The clean, complete division of the internal jugular vein, now closed by an organizing thrombus; the irregular lateral wound of the common carotid artery with thickened margins, almost occluded by a firm fibrinous clot; and the fact that the patient from whose body the specimen was removed died on the twenty-fourth day as a result of repeated secondary hemorrhages from an infected wound, first occurring on the thirteenth day, form a sufficiently familiar picture of conditions which more active primary treatment is happily reducing steadily to greater rarity.

The long period of peace antecedent to the South African campaign of 1899-1902 had greatly limited personal experience of gunshot injuries to the great vessels, this being for the most part confined to occasional pistol or rifle bullet wounds and the somewhat similar lesions produced by stabs by sharp instruments. The advent of the Boer War, however, again brought a considerable number of vascular injuries into the purview of the military surgeon. The Lee-Metford and Mauser bullets, as a consequence of their outline, stability and velocity of flight, proved themselves pre-eminently capable of effectuating clean perforations or limited local lesions of narrow structures such as the blood-vessels. This capacity, indeed, was shown to be so great as to allow the perforation of such vessels as the tibials, themselves of considerably smaller calibre than the bullet which traversed the artery.

Fig. 2 illustrates a series of injuries of this class obtained during the Russo-Japanese war in Manchuria. It should be observed that the specimens from which the illustrations were taken are those of vessels excised secondarily; hence the margins of the openings are infiltrated and thickened, and the perforation shown in (*a*) has acquired the rigid rounded outline characteristic of the opening communicating with the cavity of an aneurysmal sac. If exposed in the recent state while the artery still retains its normal longitudinal elasticity and freedom from fixation to surrounding structures, such a perforation is much more likely to assume the appearance of a simple vertical slit, or the entry wound may be rounded and the exit of slit form, as is the case with wounds of the skin when a limb is traversed.

In the present war the employment of every ancient form of

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missile; the introduction of high explosives and the consequent influence on the outline and velocity of flight of fragments of shells and bombs; together with the comparative instability of flight of the modern pointed rifle and machine-gun bullet; have considerably modified the nature and severity of the vascular lesions met with. The chief alterations in character are found in an augmentation of the degree and extent of contusion, and an increase of the number of what may be considered incised and lacerated wounds.

It is convenient in this introduction to give a brief account of the manner in which the material upon which the present essay is founded was obtained, and as to how far the conclusions arrived at are supported by facts.

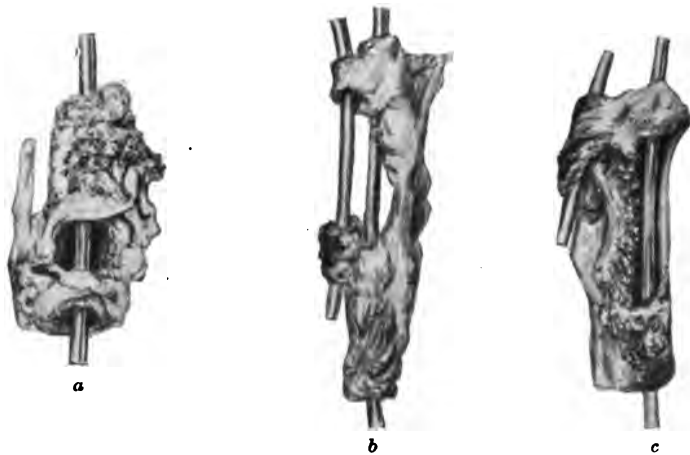


Fig. 2.—Bullet injuries. (a) Perforation of anterior tibial artery. (b) Lateral wound of brachial artery, vein divided. (c) Lateral wound of brachial artery and vein. *Brentano*.

The small number of reports dealing with the primary treatment of arterial wounds have been furnished to me by the kindness of surgeons working at casualty clearing stations. They would have been much more comprehensive had it not been for the unfortunate accident that a large number went astray during the change which took place in the British line in March, 1918. None the less I owe a debt of gratitude to the officers who gathered the information, and to Lieut.-Colonel T. R. Elliott and the Medical Research Committee, who provided the necessary forms and organized their collection.

The results given in these reports are of an immediate nature only, and, as a rule, the period for which the cases were under continuous observation did not average more than a week or ten

days. It has not been possible to trace the further course of these patients.

The whole of the rest of the material has been collected by myself with the aid of Captain L. W. Shelley in hospitals on the lines of communication, and during the past five months at a base hospital in London. The cases included have therefore, without exception, come under my personal observation, although in a number of them I have been in no way responsible for the methods of treatment adopted.

For information as to ultimate results I am again indebted to the Medical Research Committee, and the aid of Dr. Matthew Young.

It follows from this account that the difficulty common to all surgical observations made during war, which can never be fully avoided—that of not being able to watch the progress of individual cases from beginning to end—has been in some measure overcome; and that, although the ideal has not been attained, yet a fair general review of the course taken by the injuries and the results of treatment has been secured. In the matter of pure statistics relatively small reliance can be placed upon the data furnished; yet, as the experience of an individual surgeon they may have their use, and it has seemed well to include such numbers as are available, adding a caution as to the manner in which they have been collected.

One further remark seems necessary. This refers to the influence which extended experience on the one hand, and improvement in wound treatment generally on the other, have exercised on the course taken by the cases. In January, 1916, I published a short review of the vascular injuries observed by me during the first twelve months of war, and I have quoted these in places where they differ materially from those of the more extended series now dealt with.

CHAPTER II.

DISTRIBUTION AND ANATOMICAL CHARACTERS OF GUNSHOT INJURIES TO THE BLOOD-VESSELS.**CONDITIONS WHICH AFFECT THE ACTUAL FREQUENCY WITH WHICH THE INDIVIDUAL LARGER ARTERIES SUFFER INJURY.**

AN accurate determination of this question is not easy, because lesions of the great vessels which undergo treatment are recorded in large numbers, while those of the smaller ones, even of the magnitude of the tibials, are more frequently passed over as of minor importance. Again, the paucity of recorded examples of wounds of the great arteries of the trunk, independently of the visceral vessels, affords eloquent testimony to the gravity of such injuries and their frequent fatal issue. With regard to the large vessels of the neck and limbs material does exist, both as to the individual arteries and to the portions of the vessels most likely to be implicated.

In a series of 169 traumatic aneurysms which developed in connection with wounds of the larger arteries collected by me in 1913, the numbers are as follows. In this series it must be remembered that all the injuries treated by primary ligature have been eliminated.*

Common carotid	7	per cent
External carotid	3	4.1
Internal carotid	1	1.59
Subclavian	4	0.59
Axillary	23	2.8
Brachial	21	13.6
Femoral	77	12.4
Profunda	5	45.5
Popliteal	28	2.9
Total	169	16.5

A valuable comparison with these numbers may be drawn from the next table, recording the number of injuries to individual blood-vessels dealt with at a casualty clearing station during the early days of the first battle of the Somme, collected by Captain Hey, and published by Sir Anthony Bowlby.†

* Bradshaw Lecture, "Gunshot Wounds of the Arteries," 1913, p. 32.

† *British Medical Journal*, 1917, June, vol. i, p. 707.

DISTRIBUTION AND ANATOMICAL CHARACTERS 7

					per cent
Carotid	5	..	..	..	1·8
Vertebral.. .. .	2	..	..	..	0·7
Subclavian	2	..	..	..	0·7
Axillary	15	..	..	..	5·4
Brachial	39	..	..	..	14·2
Radial	18	..	..	..	6·4
Ulnar	8	..	..	..	2·8
External iliac	2	..	..	..	0·7
Femoral	51	..	..	..	18·4
Popliteal	31	..	..	..	11·1
Anterior tibial	16	..	..	..	5·7
Posterior tibial	58	..	..	..	20·9
Various	30	..	..	..	10·8
Total .. .	277				

The most striking difference in these two series is the large number of injuries to the posterior tibial vessels included in the second table. In the next table the small number of injuries to this artery will again be noted, and it is obvious that this discrepancy depends on the fact that injuries to the posterior tibial are, with few exceptions, dealt with in the primary stage, and most often in connection with compound fractures or large open wounds.

					per cent
Aorta	2	..	..	..	0·4
Carotid	87	..	..	..	17·5
Vertebral	3	..	..	..	0·6
Subclavian	30	..	..	..	6·0
Axillary	61	..	..	..	12·2
Brachial	47	..	..	..	9·45
Common iliac	1	..	..	..	0·2
External iliac	3	..	..	..	0·6
Internal iliac	1	..	..	..	0·2
Femoral	175	..	..	..	35·2
Popliteal	87	..	..	..	17·6
Total .. .	497				
Tibials *	26	..	..	..

These numbers demonstrate sufficiently the influence of length, calibre, and location in exposed positions on the proportionate incidence in the various vessels.

Factors of equal importance determine the more frequent location of injury to definite segments of the individual arteries. These factors are found in the relative degree of fixity of the vessels in different parts of their course, and in their relation to neighbouring bones. First, with regard to local fixation of the vessels, this depends upon: (1) The width and capaciousness of the vascular cleft, and the amount of loose connective tissue situated therein; (2) The position of branches, especially those taking a direct course from the parent artery at a

* The injuries to the tibial vessels are not included in the percentage calculation for reasons given above.

wide angle, or those at once acquiring a firm connection with a bone; and (3) On the passage of the vessel under a firm fibrous structure. Examples of contrast of the first condition are found in the relative fixity of the femoral vessels in Scarpa's triangle and Hunter's canal respectively; yet in Scarpa's triangle the artery has an important anchor where the profunda dips sharply beneath the adductor longus, and is further immobilized by the origin of the circumflex branches. Familiar examples of the second condition are the circumflex branches of the axillary artery, and the upper articular and azygos branches of the popliteal artery. The third condition is met with where the femoral vessels leave Hunter's canal to become popliteal, and again when the posterior tibial passes beneath the fibrous arch in the origin of the soleus. The close relationship of a large artery to the neighbouring part of the skeleton is again nowhere better exemplified than in the case of the termination of the femoral and the commencement of the popliteal to the femur.

Any of the foregoing conditions, as limiting or rendering impossible displacement of the vessel by the expanding force exercised by the travelling bullet, may be an all-important factor in preventing the escape of the vessel from a wound or serious contusion.

CONTUSIONS OF THE BLOOD-VESSELS CAUSED BY GUNSHOT INJURY.

Of the experience gained in the present war, that regarding the frequency of occurrence of contusions, and the significance of this form of injury in the causation of thrombosis, secondary hæmorrhage, and traumatic aneurysms, is perhaps the most novel; for any accurate knowledge that we possessed on this subject previously was founded mainly on experimental studies.

That the condition was familiar—as is the case with so many observations made in this war—to military surgeons in older times, is sufficiently illustrated by a specimen preserved by Mr. Guthrie, now in the museum of the Royal Army Medical College (No. 34.5). This preparation shows the femoral vessels to be totally occluded as the result of the passage of a bullet by a track coursing immediately behind them. It was perhaps too commonly assumed that the thrombosis in such cases was a secondary result accompanying suppuration, but the condition was well known in civil practice independent of infection. Thus I have seen both popliteal arteries occluded as a result of the passage of a cart-wheel over the limbs, the injury being followed by gangrene of one leg necessitating amputation, when the condition was confirmed by direct investigation.

The following description is founded in part on clinical observation, and in part on the beautiful histological preparations made for me by Captain Bashford.

The degree and extent of damage to the walls of the vessels may vary greatly, and it is most important to remember that mere inspec-

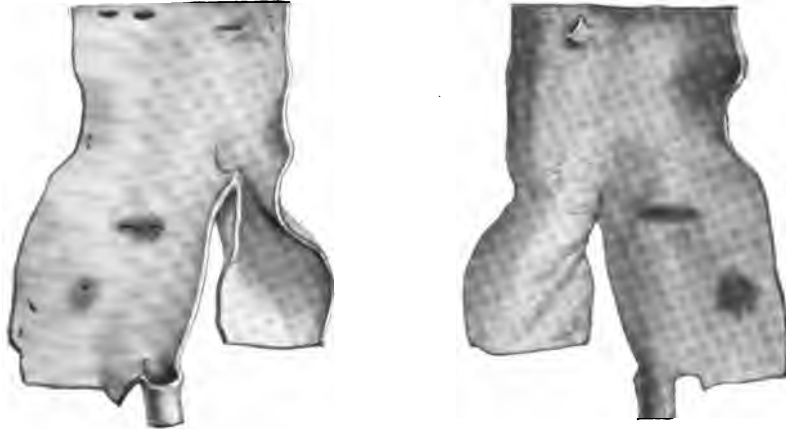


Fig. 3.—Contusion of right common iliac artery: internal and external surfaces. Linear rupture of the intima and minute perforation. *Captain Adrian Stokes.*

tion of the exposed vessel often gives but little idea of the structural disintegration that has been effected, and also that the mischief may

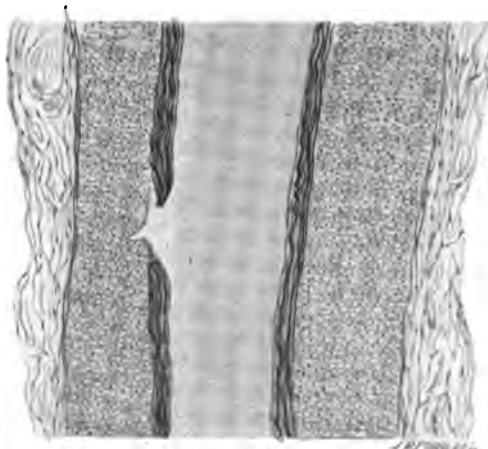


Fig. 4.—Section of radial artery, showing a rupture of the intima involving the muscularis, discovered one inch from a small contused perforating wound. *Specimen prepared by Captain Pringle.*

extend widely within the vessel from the spot where the external indications are strongest.

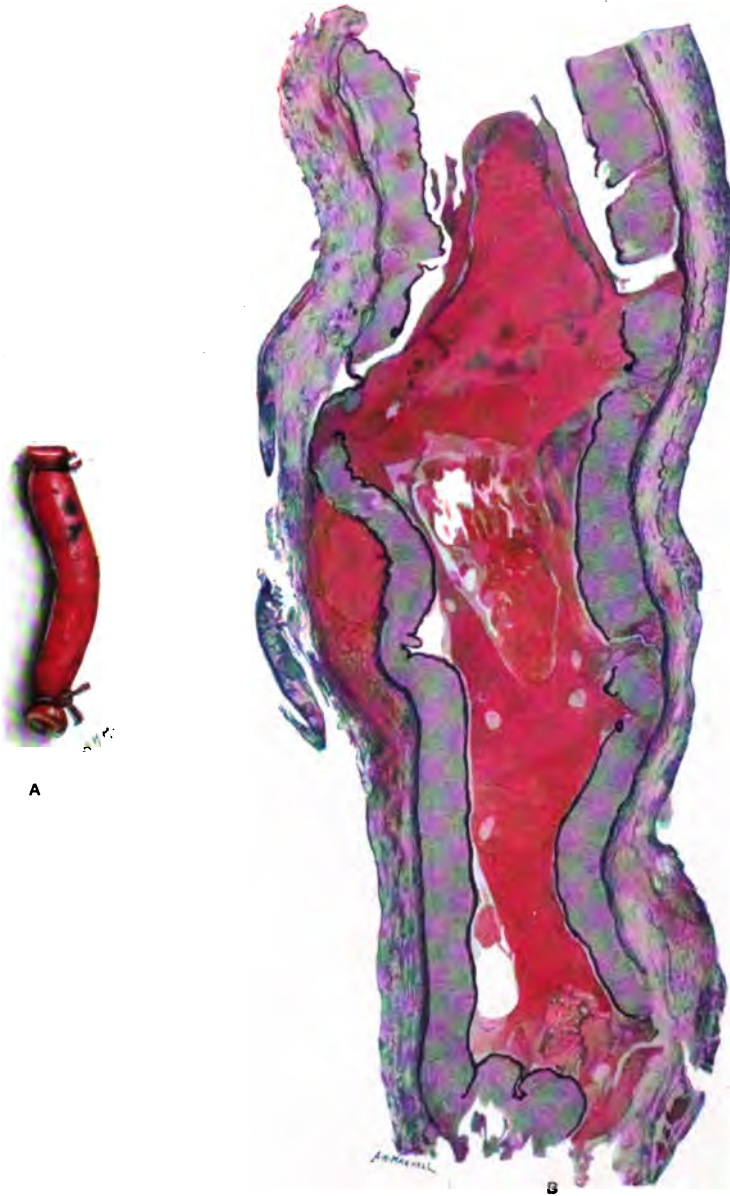
Figs. 3 and 4 exhibit what may be regarded as the most limited degree of structural damage. In *Fig. 3* two ecchymosed areas are visible on the outer aspect of the common iliac artery, while on the inner aspect a linear rupture of the intima, probably also involving the muscularis, is visible. In the recent state, when removed by Captain Adrian Stokes from the body of a man who died as a result of injuries to the abdominal viscera, the neighbourhood of the rupture was clothed by a delicate network of clot, forming a thin lateral thrombus.

Fig. 4 shows a lesion consisting of a linear fissure involving the intima, the internal elastic lamina, and half the depth of the muscularis. The rupture was associated with a perforating lesion situated an inch lower down in the course of the vessel, and no external indication of its presence existed. It will be observed that even the microscopic section affords no evidence of local blood extravasation into the walls of the vessel. The specimen is illustrative of the fact that remote ruptures of the intima and underlying coats may be due to stretching of the vessel consequent on forcible displacement from its bed rather than to local contusion.

Plate I (A) gives an external view of a thrombosed segment of the superficial femoral artery excised by Major Hope from the floor of a large open wound on the anterior aspect of the thigh. Secondary hæmorrhage occurred on the tenth day, and necessitated this operation. At the upper part of the drawing two small dark spots are seen; these correspond to the points of maximal structural injury, and at one of them the artery had given way and allowed the bleeding to take place. *Plate I (B)*, from a section carried through the clot across these spots, shows well how very much more extensively the coats of the vessel are damaged than could have been estimated from external inspection alone. Every degree of structural disintegration which may accompany severe contusion is exhibited—thus, disappearance of the endothelium from the portion of the vessel occupied by the clot, rupture of the elastic lamina, fissuring of the muscularis to varying depths, and one fissure completely dividing the muscularis and allowing the escape of blood into the adventitia. No evidence of infection of the clot could be detected.

All these changes are illustrated in greater detail by *Plates II and III*, made from preparations by Captain Bashford, to whom I am indebted for the histological particulars. The vessel, an anterior tibial artery still pervious and pulsating, was excised by Captain Hartley from the floor of an open wound in the front of the leg as a precautionary measure, since it had obviously been damaged. *Plate II* is of a slightly oblique transverse section of the vessel. The adventitia is normal at the lower part of the figure except for some

PLATE I.



(A)—Thrombosed segment removed from superficial femoral artery. The upper of the two dark spots corresponds with the point from which secondary hæmorrhage took place. The lower of the two dark spots is the outward manifestation of the extensive hæmorrhage within the destroyed or necrosed adventitia, a portion of which is shown displaced in the figure. In several other sections it was found to be continuous with the tissue above and below by a thin membrane covering the extravasated blood.

(B)—Longitudinal section through the contused vessel shown in (A). Multiple ruptures of the intima and media. Extravasation into the adventitia. At one point the adventitia has necrosed and given way and allowed the occurrence of secondary hæmorrhage.

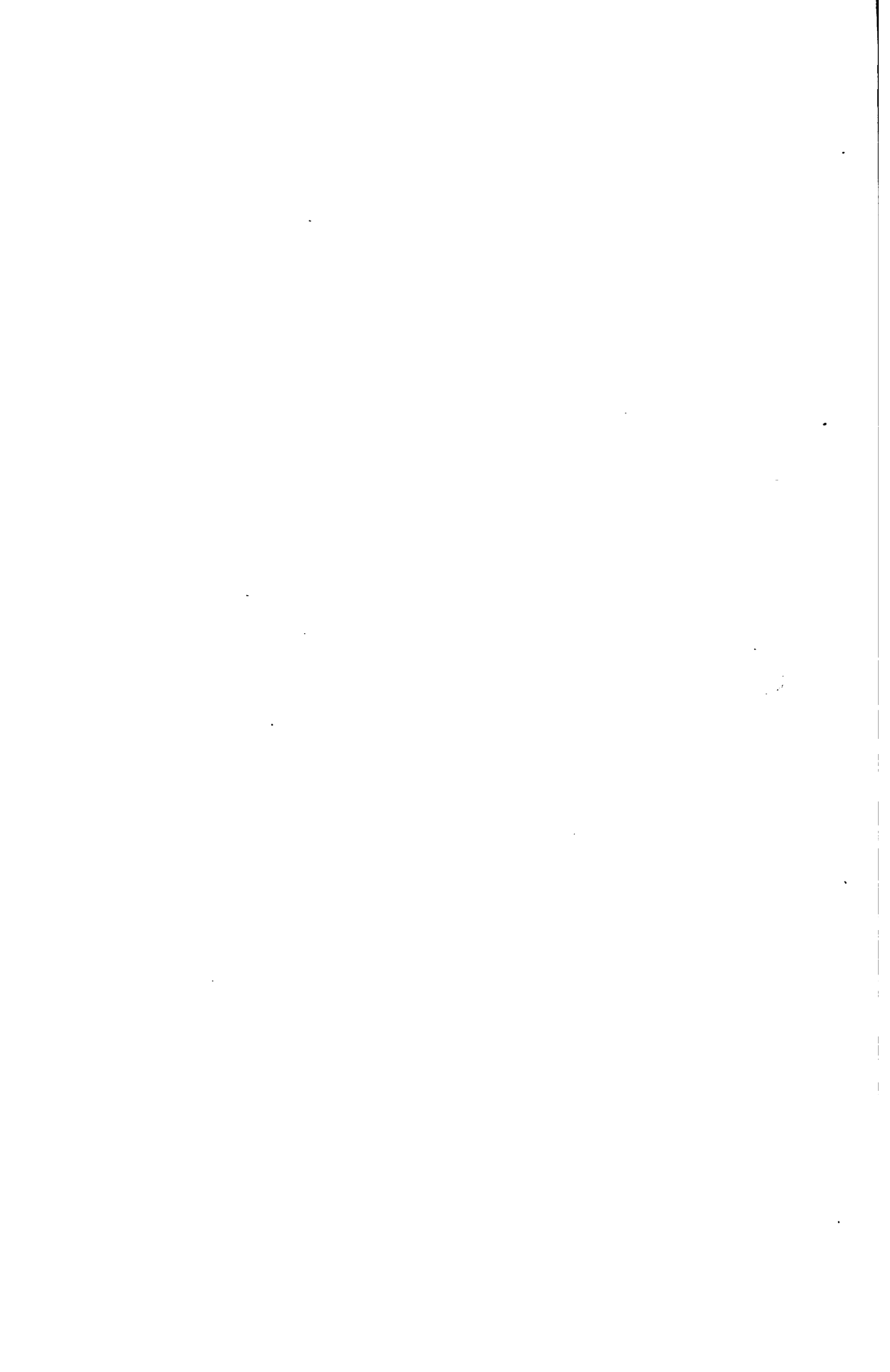
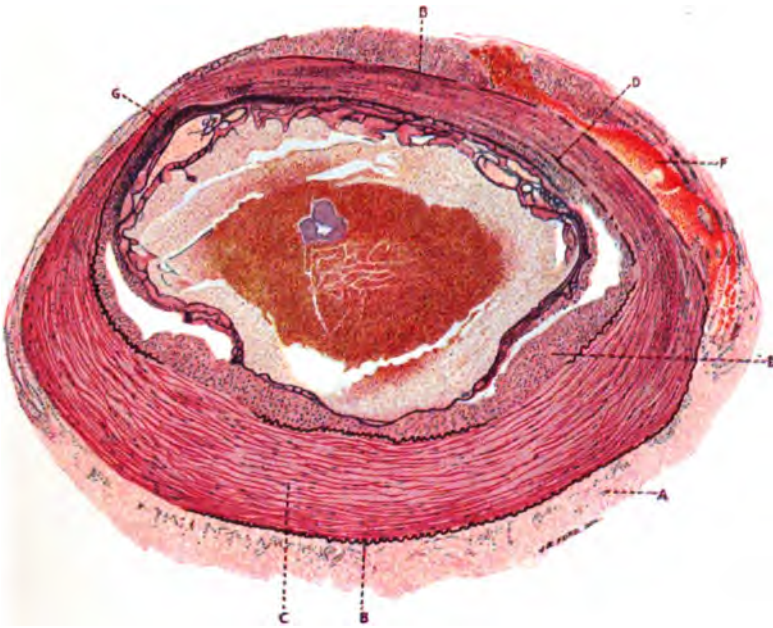


PLATE II.



Slightly oblique transverse section across a contused artery. A, Adventitia; B, External elastic lamina; C, Media.; D, Internal elastic lamina, destroyed in upper part of figure; E, Thickened sub-endothelial layer; F, Hemorrhage into adventitia; G, Extreme thinning of media at point of maximal injury.

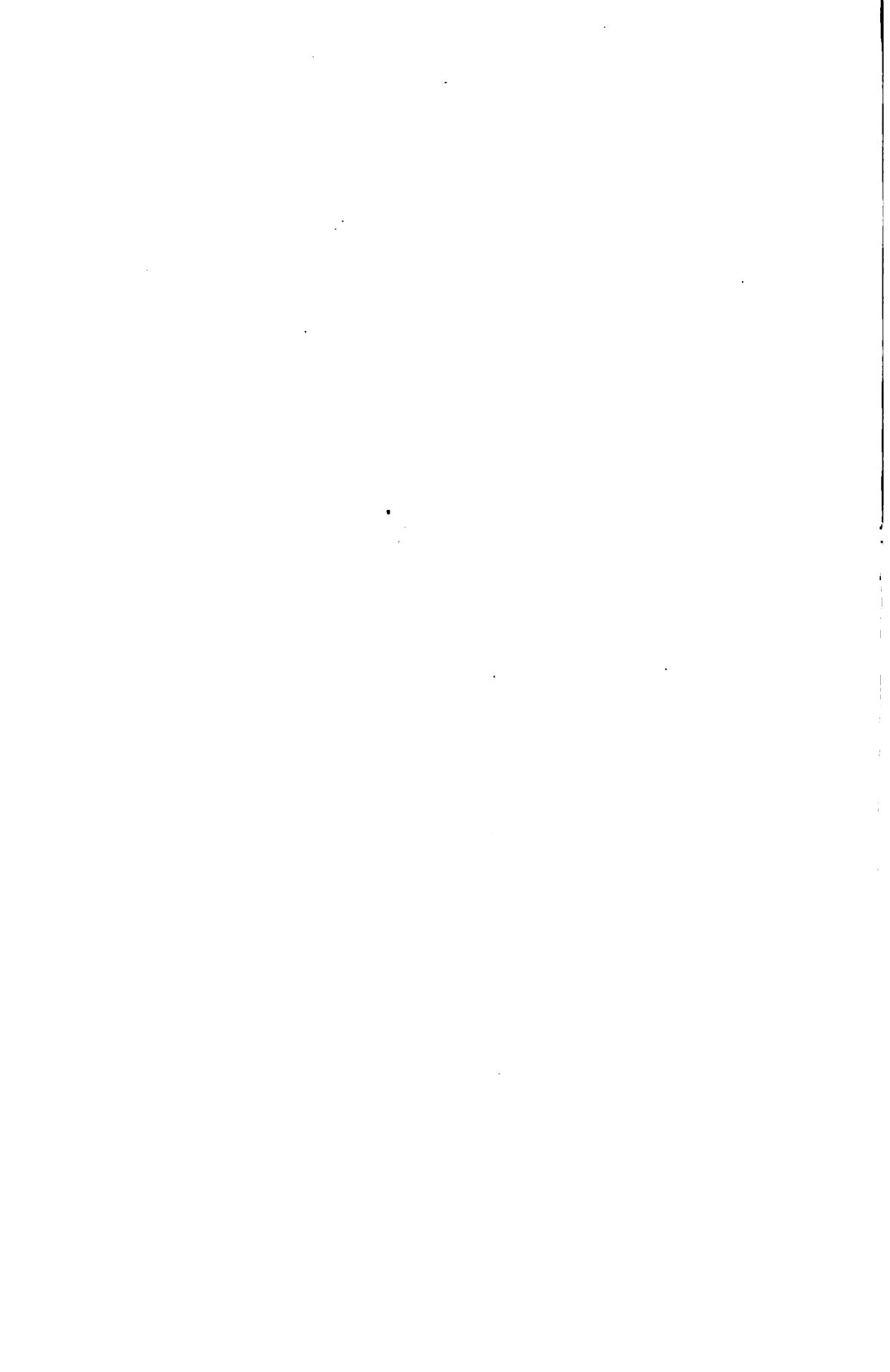
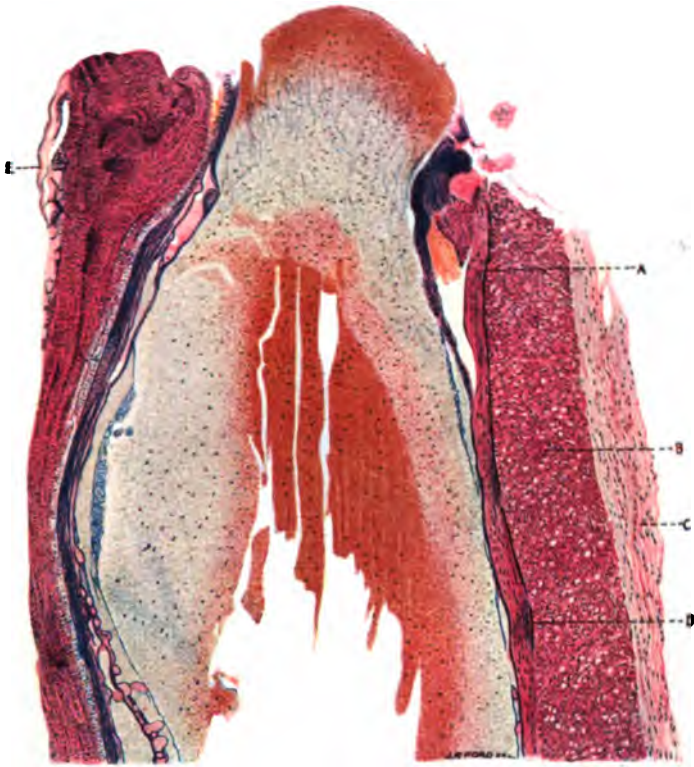
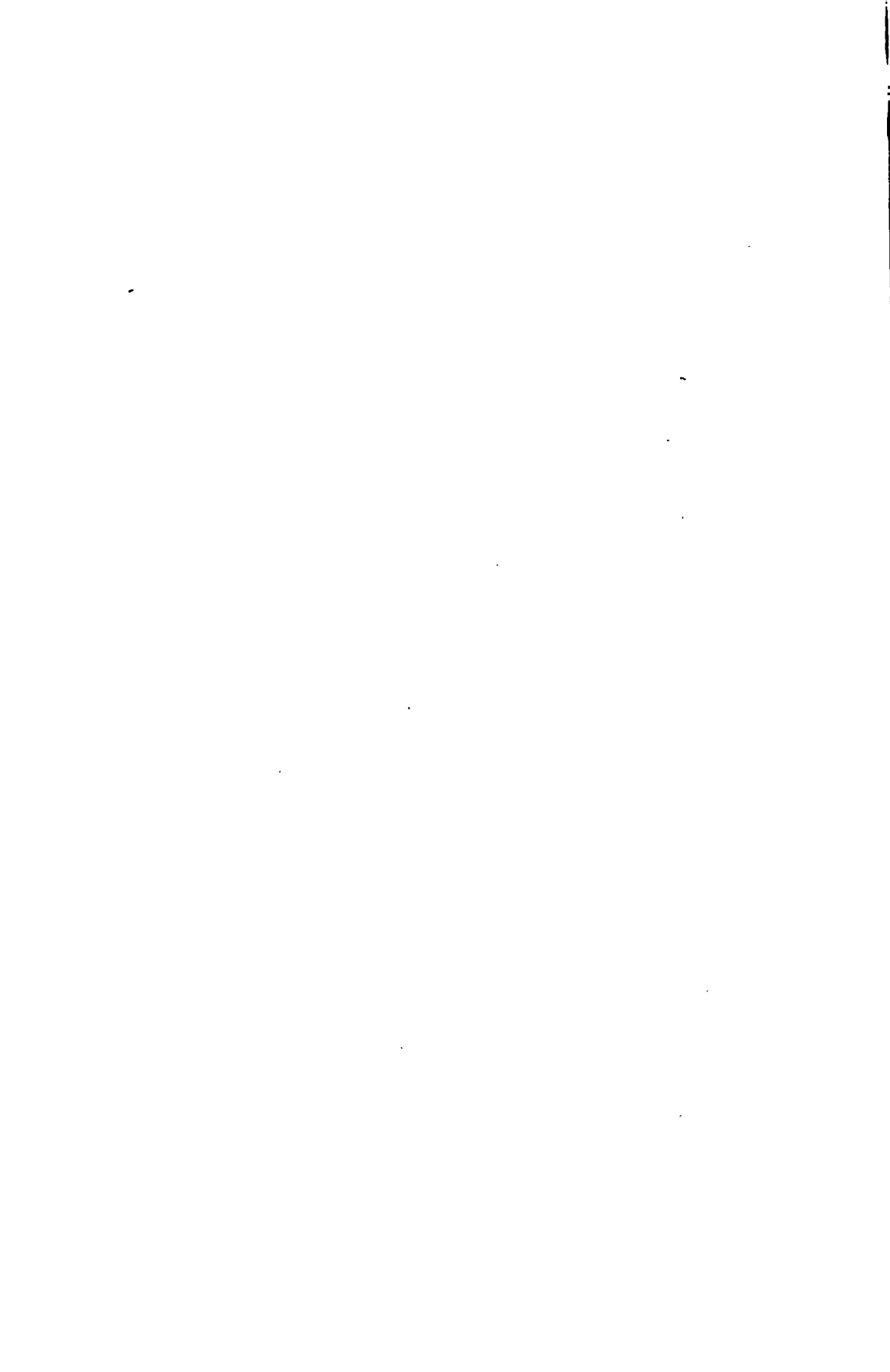


PLATE III.



Longitudinal section of the same artery shown in *Plate II*. Complete disorganization of wall of vessel on left side. F, Remains of adventitia infiltrated with leucocytes. Right side: A, Internal elastic lamina. B, Irregular nucleation and some vacuolation of cells of media. C, Normal adventitia.



leucocytic infiltration, and an interstitial blood extravasation in the upper part. Both the external and the internal elastic laminae are fairly intact in the lower part of the section, showing their normal curves, but in the upper half the elastic tissue is stretched, straightened out, and fissured. The muscular coat gradually thins from the normal part to the point of maximal contusion (G), where it has almost disappeared, and in the upper part of the section a considerable amount of leucocytic infiltration has taken place. The sub-endothelial layer is irregularly thickened, and the endothelial lining is gone. The lumen of the vessel is occupied by a clot, the peripheral layers of which are evidently of slow formation, while the central portion consists of clot of more rapid formation, which encloses a small cavity occupied by blood platelets and fibrin.

A vertical section of the vessel, the lower end of which corresponds with the level at which the transverse section was made, is shown in *Plate III*. It will be noted that the adventitia is completely disorganized on the left side of the figure; it is, in fact, only recognizable at the upper part, and is heavily infiltrated with leucocytes and some fibrin. On this side of the artery both the elastic laminae are completely destroyed, and an extensive deposit of fibrin takes the place of the endothelium and sub-endothelial tissue. The right-hand wall of the vessel is less damaged, and its normal structure is fairly well retained. The adventitia is normal; the cells of the media show some vacuolation and disarrangement of the nuclei, but are not seriously affected. The internal elastic lamina is recognizable throughout: as fibres below, but its membranous structure is recognizable above. The sub-endothelial tissue is thickened and irregularly nucleated, and the place of the endothelium is taken by a layer of fibrin. The central clot exhibits the same characters already described in the oblique section.

The common sequence to contusion of the wall of the vessel is a rapid thrombosis; this may remain localized, or it may extend progressively in a peripheral direction. It is, however, remarkable that rapid thrombosis is by no means an inevitable consequence, even when the contusion is of the degree depicted in *Plate II*. In this artery pulsation was still present on the fourth day following the injury, although the vessel was exposed and its external appearance led the surgeon to tie it and excise the injured portion. The section shows what had really taken place—the immediate formation of a thrombus not sufficiently large to obstruct the lumen of the vessel, and, later, the deposition of a more fibrinous layer of clot upon this. A later figure (*Fig. 21*, p. 58) depicts a central cylindrical thrombus in connection with a wound in the wall of the vessel, which was only sufficiently capacious partially to obstruct the lumen, and *Fig. 5* shows

a lateral firm thrombus, also not causing complete obstruction. The significance of such thrombi in relation to the possible detachment of emboli is obvious. No doubt the tendency of these thrombi is to become completely obstructive. The common course is for them to remain local in extent ; less frequently the clot may extend widely in a peripheral direction, and some instances of this will be referred to later, especially in connection with the carotid artery.



Fig. 5.—CONTUSION OF THE BRACHIAL ARTERY, WITH INCOMPLETE LACERATION OF THE WALLS OF THE VESSEL.

The adventitia is ruptured, the muscularis almost intact, and the intima broken. Over the damaged portion of the intima a local lateral thrombus has developed.

It is evident, in the case of the partially obstructing thrombi figured, that the process started from the most seriously damaged portion of the vessel, and should the whole circumference suffer, the formation of a completely occluding clot is more rapid ; but even in such instances the clot may by no means tightly fill the vessel, and in spite of its presence blood may escape in small quantities. Thus in one case a very severely damaged artery is described by Major Copeland as looking “as if it had been rubbed by a nutmeg grater,” and blood was slowly escaping at several distinct spots.

A point of some importance is illustrated in *Fig. 21*, with regard to the possibility of persistency of the lumen of a vessel primarily completely occluded by a thrombus. Sir A. Wright, many years ago, pointed out the small proportion of the corpuscular element and the abundance of fibrin in the clots, also the tendency to rapid contraction of the fibrinous network and shedding of the retained red blood-corpuscles. Early firm adhesion of the clot occurs only at the site of the wound or contusion of the wall of the artery, and the clot contracts towards this anchored point. Hence the lumen becomes in part re-established, and in the absence of renewed deposition of clot viability of the vessel may be more or less completely regained.

The tendency to rapid clotting may no doubt differ in association with conditions of the blood, but that slow progressive occlusion is a common occurrence seems to be indicated by the gradual manner in which occlusion may follow the operation of suture, although, on the other hand, a thrombus may form before a suture operation has been completed by closure of the main wound. It is doubtful also

whether the varying rapidity with which a Tuffier's tube becomes occluded, altogether corresponds with the technical capacity with which it has been introduced.

The accidents liable to follow arterial thrombosis in gunshot injuries are identical with those common to the condition under other circumstances. Primary rapid occlusion may give rise to anæmic gangrene, which may be immediate, and is strictly comparable with that which follows the interruption of the blood supply by ligation of the vessel. The occurrence of gangrene is naturally favoured in cases in which the clot formation extends peripherally. This accident has been most commonly observed to take place in the carotid, femoral, and popliteal arteries. When the process of occlusion is partial or less rapid in nature, time is allowed for compensatory changes in the collateral circulation, and the effects are less serious; but still the vitality of the parts situated in the area of the peripheral distribution of the vessel may suffer in the same manner as after the application of a ligation. Definite ischæmic changes may develop, or the muscles lose considerably in volume and contractile power. These changes are naturally most marked when an associated injury to the nerves is present, but they occur in some degree whenever the peripheral circulation is interfered with.

The occurrence of embolism in these injuries must be considered quite apart from the question of septic infection and disintegration of the clot: portions of soft recent clot may become detached and cause trouble from the sudden and complete anæmia produced. The same remark applies to the occurrence of secondary hæmorrhage, the bleeding being the result of the normal separation of the devitalized area of tissue in the vessel wall. The clot in the case illustrated in *Plate I* was not infected, and the tissue of the arterial wall shows little sign of reactionary changes.

There can be no question that injuries of the nature of contusions and non-perforating lacerations are not infrequently the explanation of the late formation of aneurysms or hæmatomata. The correspondence of the date at which pulsation and swelling appear in many cases, with that at which secondary hæmorrhage is common, is in itself suggestive. Beyond this, however, many operators have observed local bulging of arteries at the time of explorations for hæmorrhage. A characteristic description is given in a report by Captain Cowell in which he says the inner coats of the artery bulged through a defect in the adventitia, like an inner bicycle tube projecting through a hole in the cover. Small local bulges may also indicate injury to the inner layers of the wall. *Fig. 6* depicts such a bulge in the femoral artery above the opening of an arterio-venous communication. Dilatation of the entire lumen may also result in the early stages of

an arterial injury. *Fig. 53* shows an early stage of aneurysm formation from a leak in the centre of a contused area of the brachial artery.

Thrombosis as a result of contusion is still more commonly seen in the veins than in the arteries. The condition is often met with during the performance of operations on wounded arteries, and the observation that pre-existing blocking of the vein in no way prejudiced the results of ligation of a main artery, was one of the circumstantial facts which supported the introduction of the practice of ligaturing both vessels when occlusion of the artery is necessary.



Fig. 6. — Lateral suture of superficial femoral artery. Small aneurysmal dilatation. Ligation of femoral vein.

The existence of a contusion of the arterial wall is not readily determined, in the absence of ocular demonstration. The sign which commonly suggests its occurrence, obliteration of the peripheral pulse, may equally denote a contused lateral wound or even complete severance of the artery. Cases have also been recorded* in which explorations suggested by absence of the peripheral pulse have revealed no appreciable lesion.

Veau ascribes this occurrence to a state of general vaso-constriction of the arteries of the limb, and designates the condition arterial stupor. It would seem to correspond to the condition of local shock which accounts for the temporary loss of sensation and power in a limb the subject of a gunshot injury. Its chief interest seems to lie in affording a possible explanation in some cases of the absence of hæmorrhage from completely divided arteries lying exposed in an open wound, and such a condition might possibly be concerned in the occurrence of the immediate cerebral symptoms which may follow injury to, or ligation of, the carotid arteries.

The subject of arterial thrombosis cannot be left without mention of the very serious influence which rapid blocking of the main artery, or even of minor branches, may exert on the rapid progress of anaerobic gangrene. This subject has been ably dealt with by Captain Bashford† in his paper on the general pathology of acute bacillary gangrene arising in gunshot injuries of muscle, which supplies both clinical and histological evidence of the manner in which the rapid extension of the process is favoured by vascular obstruction. The

* MM. VEAU, VIANNEY, LACOSTE, AND FERRIER, *Presse Médicale*, 1918, No. 46, Aug. 15, p. 425.

† *British Journal of Surgery* vol. iv, No. 16, p. 587.

influence of blocking of the visceral arteries upon the organs concerned has also been dealt with by Captain Bashford* in a paper on the histology of the tissues immediate and remote from the point of injury in gunshot wounds; and by Colonel Andrew Fullerton† in the case of the kidney.

GUNSHOT WOUNDS OF THE BLOOD-VESSELS.

Wounds of either arteries or veins may be divided into three classes: (1) *Lateral wounds*, transverse, vertical, or oblique; (2) *Perforations* traversing the lumen of the vessel; (3) *Complete severances of continuity*. Practically every one of these lesions is of a contused, or contused and lacerated, character. Mr. Shattock‡ has pointed out that in no instance amongst a large series of wounded vessels, could any evidence of explosive effect be detected.

Lateral Wounds.—These lesions may be of the most insignificant character, or, on the other hand, may be of a more serious nature than even a complete division.

The least serious lesions are those caused by punctures by minute fragments of metal, such as may be derived from portions of the mantle of a fragmented bullet, or small particles of bombs. The fragment may enter the lumen, be arrested in the opposite wall of the vessel, or pass into the blood-stream. No doubt many such lesions undergo spontaneous repair, and their occurrence may not even be suspected; but instances occur in which the opening remains patent and an aneurysm develops. Inspection from within the cavity of the sac in such cases arouses surprise that patency could have been maintained. The possession of a minute orifice of entry such as this no doubt explains some of the cases of spontaneous cure of traumatic aneurysm which occur.

A foreign body, even of the size of a bullet, may enter by a lateral wound and thence travel in the interior of the vessel. An instance in which a bullet, entering by the thoracic aorta, passed on to be arrested in the right common iliac artery is quoted on p. 115. In another remarkable case a shrapnel ball lying in the lumen of the inferior vena cava was apparently maintained in position below the opening in the diaphragm by the force of the blood-stream.

Fig. 7 illustrates an incomplete lateral wound, or it might be regarded as an attempt at perforation, abortive as a consequence of want of force on the part of the missile. In this instance a fragment

* *British Journal of Surgery* vol. iv, No. 15, p. 433.

† *Ibid.*, vol. v, No. 18, p. 248.

‡ *Proceedings of the Royal Society of Medicine* 1918, vol. xi, No. 9, July, p. 116.

of shell now lies impacted within the lumen of the axillary artery and completely obstructs it. It is probable that in the initial stage the small missile failed to perforate the intima, and pushed this before it until the blood-stream was completely interrupted. Subsequently the media and adventitia have healed spontaneously over the outer aspect of the piece of metal, and the intima has perished, leaving the foreign body surrounded by organized thrombus within the lumen of the vessel.



Fig. 7.— Impacted foreign body in the axillary artery. (Colonel Charters Symonds.)

The types and degrees of lateral lesions are portrayed in the various examples included in *Fig. 8*. All were drawn from arteries removed after a sufficient lapse of time to allow of stiffening and fixation from infiltration of the wall of the vessel; hence the orifices are patent and gaping. In a more recent condition the openings gape less widely, the margins are generally irregularly shredded, the tattered adventitia projecting around the stoma, while the muscularis and intima are more or less retracted. Histological examination shows the structure of the adjacent part of the wall of the artery to have suffered injury similar to that described under the heading of contusion, extending over a variable area. A number of illustrations of lateral wounds will be found in the sections devoted to the special vessels.

The specimen lettered *c* in *Fig. 8* illustrates diagrammatically a type of wound met with on one occasion; its form, that of a lateral flap, is of some importance with regard to the possibility of the restraint of hæmorrhage by pressure of extravasated blood-clot on the artery from without. This wound, as also those marked *a*, *b*, and *e*, may be regarded as examples of more or less purely incised wounds produced by the passage of small sharp fragments of metal. Given satisfactory local and aseptic conditions, all are eminently suitable for treatment by suture. In dealing with such lesions, however, it has to be constantly borne in mind that the structural damage to the wall of the artery may be much more extensive than the external appearances would seem to warrant, since, beyond the visible laceration, remote injuries to the muscularis and intima may have resulted from contusion and stretching at the time of the accident. The actual patent opening may in fact lie in the centre of an area of the wall of the vessel, in which contusion has led to widespread structural disintegration such as is portrayed in *Plate III*. These remote injuries, although perhaps not sufficient to cause failure of union of the line of suture, are yet capable of vitiating the final result of the

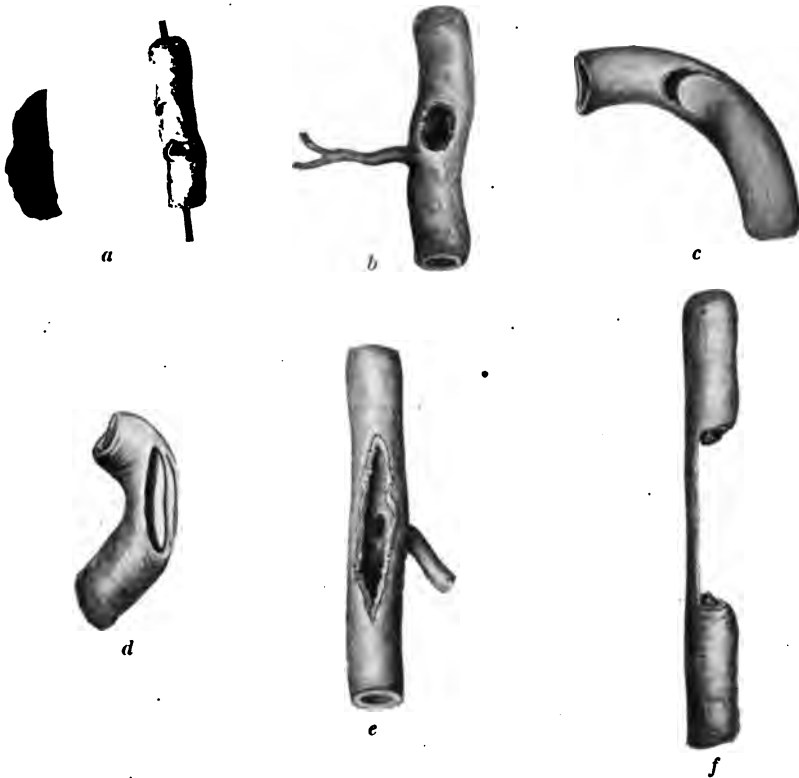


Fig. 8.—TYPES OF ARTERIAL WOUNDS.

a. Small portion of the femoral artery removed at the time that the aneurysm was extirpated and the vessel ligatured, with the piece of shell which produced the injury. The regular outline and smooth margins of such an incised wound at the end of ten days are well shown.

b. Oval wound of superficial femoral artery. The wound is in immediate proximity to a lateral branch fixing the artery. Shell injury.

c. Diagrammatic representation of a flap-like wound of subclavian artery. Large mass of primary clot; no aneurysmal sac formed; secondary cellulitis of neck; secondary hæmorrhage. Shell injury.

d. Oval wound of superficial femoral artery. The thin strip of arterial wall between the main opening and the lateral slit shows this to have been actually a perforation. Secondary hæmorrhage appears to have taken place through the lateral slit. The specimen has become bent during the process of preparation. Bullet injury.

e. Unusually long lateral wound of axillary artery. Note the branch arising immediately opposite the centre of the wound.

f. Diagrammatic representation of a three-fifths division of the femoral artery. This form is frequent, and amounts practically to a complete division of the vessel. It is, however, a more serious injury, since the remaining bond of union prevents free retraction and contraction of the ends, and hence spontaneous thrombosis and closure of the vessel is less likely to take place.

It will be noted that all these vessels were exposed from three to ten days after the infliction of the wound; hence the margins of all are more even and rounded than in the recent stage of the injuries.

operation by favouring the occurrence of thrombosis and ultimate occlusion.

When a larger proportion of the circumference of the vessel is involved, or if actual loss of substance has been extensive, the degree of retraction of the open ends of the artery is often very great, reaching a maximum in such injuries as *Fig. 8, f*. In such circumstances the conditions are further distorted, as has been pointed out by Sencert,* by a change in the axis of the remaining strand of the wall of the vessel. This band forms a salient angle at the extremities of which the open ends of the vessel point in the same diverging line. As a result of this arrangement, the open ends of the vessel deliver the stream of blood in a false direction, while the connecting strand prevents their retraction into the tissues, and thus hæmorrhage is favoured. When the degree of retraction is less, the wound itself forms the blunt apex of the salient angle. In a later stage the open ends of the vessel cicatrize, the intima and adventitia uniting over the retracted media, and a rounded smooth opening is formed communicating with a false aneurysm (see *Fig. 42, p. 159*). I believe it is rare for spontaneous closure of the vessel to take place in injuries of this class.

Consideration of the series of wounds illustrated above and the accompanying remarks on their anatomical characters, makes it evident that no useful practical distinction can be drawn between wounds of the arteries caused by bullets or fragments of shells as far as indications for treatment are concerned. It is clear, on the one hand, that a shell wound may be either limited and incised in character, or a severely contused and lacerated injury; on the other, that while the modern pointed bullet, given direct and exact impact, may cause a limited and strictly localized lesion, it is also capable, in consequence of its inherent instability of flight, of adding an extensive area of contusion around any opening it may effectuate. Each injury, in fact, requires to be judged on the actual condition disclosed on direct examination, and not upon the nature of the agent which produced it, always bearing in mind the greater probabilities of serious infection of the neighbouring soft tissues in lesions produced by fragments of shells.

Perforations.—This denomination is reserved for those injuries in which the missile traverses the vessel, and bilateral openings are produced. Except that the openings tend to partake of the characters of entry and exit apertures, that of entry being of a punched-out nature, and that of exit stretched and everted, little practical distine-

* *Les Blessures des Vaisseaux* (Horizon Series), p. 4.

tion can be drawn between them and many of the lateral wounds already described. This form of injury may be caused by either bullets, or fragments of shells, or bombs. The modern change in outline and balance has rendered pure perforations by bullets of less frequent proportionate occurrence. The diminution has, however, been in great measure made up for by the increase in number of perforations effected by small fragments of metal from shells and bombs propelled by high explosives.

Perforations made by the passage of Mauser or Lee-*Metford* bullets are usually small and gape little; this may also be the case with the pointed bullet if it strikes exactly and with a low degree of velocity (see skiagram, *Fig. 16*); but more frequently the margins of the opening in the vessel are considerably contused, and larger in

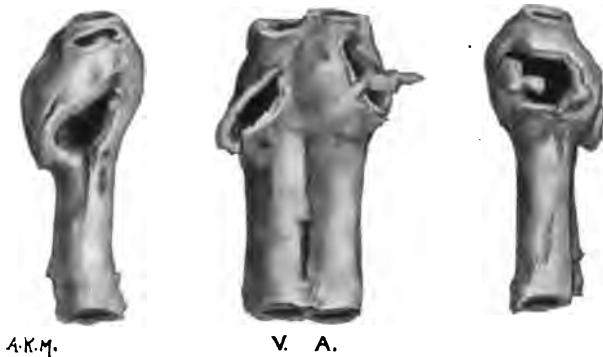


Fig. 9.—Perforating wound of femoral artery and vein. Adhesion of the opposing sides of the vessels has established a direct arterio-venous communication. Opening in artery with irregular shredded margins, that in vein more incised in character. Shell injury.

diameter than the bullet which produced the injury. The actual amount of gaping may be materially influenced by the degree of local fixation of the vessel and the relative capacity allowed for longitudinal stretching. The varying character and outline of the openings may be gathered from inspection of *Fig. 9*, and in general they may differ little from many of the single lateral wounds.

A remarkable asymmetrical perforation produced by a bullet is illustrated by *Fig. 8, d*; in this the separation between the two openings is represented by a very narrow strip of the arterial wall. The lesion obtains somewhat special importance in that the presence of the narrow strip was held by Colonel Gordon Watson to be responsible for the separation of the wall of a traumatic aneurysmal

sac at its attachment to this point, and a consequent secondary hæmorrhage.

Fig. 9, depicting a traversing perforation of the femoral artery and vein effected by a fragment of shell, offers an excellent example of the contrast between the anatomical characters exhibited by wounds of arteries and veins respectively, and the greater tendency of the former to be torn and shredded. A free flap like that here depicted may sometimes be met with projecting into an arterio-venous communication. I have seen this on more than one occasion. Reference to *Fig. 28*, which shows a projecting flap of muscularis still unhealed in the margin of an arterio-venous communication, explains the long persistence of this condition.

Complete Division of the Vessel.—Complete severance of continuity of the vessels is not uncommon. In large lacerated wounds the condition is easy of explanation; but the frequent occurrence of complete solutions of continuity met with in simple bullet wounds, with typical apertures of entry and exit on the surface of the body, was one of the surprises attendant upon the introduction of the bullet of small calibre.

The anatomical characters exhibited by the vascular wounds are inconstant. Severances effected by rifle bullets sometimes offer an appearance difficult to distinguish from those made by the knife of the surgeon, the ends of the vessel appearing sharp and even. In many of these lesions division of the vessel is followed by prompt retraction of the free ends, and spontaneous cessation of or entire escape from hæmorrhage occurs, the accident being followed neither by the escape of blood nor the formation of a hæmatoma.



Fig. 10.—Complete division of popliteal artery and vein. The proximal end of the artery is thrombosed, but was still leaking. The vein is completely occluded, but the thrombus does not reach its free extremity.

Completely divided arteries have often been found in the course of explorations made with a view to dealing with injured nerve trunks in which no evidence of previous hæmorrhage has been detected, beyond at most a certain amount of cicatricial tissue; moreover, it is often impossible in practice to determine from clinical evidence

whether an absent radial pulse at the wrist depends on contusion and thrombosis of the axillary artery, or complete severance of the trunk. This difficulty may arise in wounds traversing the area occupied by any of the great vessels at the root of the neck, the axilla, or elsewhere, and it arises with some frequency.

Completely divided vessels, even of the size of the femoral, are often found in large open wounds also, the free ends contracted in calibre for a short distance, and pulsating freely above, while no escape whatever of blood is taking place.

Fig. 10 depicts the condition of a completely divided popliteal artery and vein found exposed in a large wound. In this case the proximal extremity of the artery is filled by a cylindrical thrombus which projects from the open lumen. The clot is seen to increase gradually in calibre from above downwards, and the free extremity is dome-shaped. The form of the thrombus depends upon the fact that it did not firmly occlude the artery, and hence leaking hæmorrhage caused a gradual increase in its size. The satellite vein is filled by a more efficient thrombus, the situation of which is indicated by a fusiform enlargement seen above the free extremity. It will be observed that no essential difference in appearance exists between the lines of section effected by the bullet and the knife of the surgeon respectively.

A striking contrast to these neat injuries is not infrequently met with in the contused and lacerated wounds caused by rough fragments of shells. In these the free extremities of the vessel may be irregularly torn and tattered, the division of the individual coats departing from the ordinary rule, and considerable lengths of the artery may have been actually carried away by the passing missile. An example is offered in *Fig. 11* of the thoroughly atypical manner in which the coats of the artery may be destroyed, for here we find a more or less intact tube of intima projecting from the irregularly torn, retracted, and rolled-up muscularis and adventitia.

Speaking generally, from the point of view of danger from



A.M.

Fig. 11.—Complete division of femoral artery. Laceration of adventitia and media. Intima projecting with intact circumference and regular margin.

Captain Adrian Stokes.

hæmorrhage, complete severance of the vessel may be regarded as a less serious accident than a three-quarter severance such as is depicted in *Fig. 8, f*, since in the latter the bond of union acts as a check to the normal process for spontaneous closure of the lumen. It may, moreover, be pointed out, that lesions of the latter class are apt not infrequently to be regarded as complete divisions when met with in operations for arterial hæmatoma or false traumatic aneurysm, because the connecting band, as a result of infiltration and fusion of the remains of the artery with the surrounding tissues, becomes difficult of definition and recognition.

WOUNDS OF THE VEINS.

What has been said regarding wounds of the arteries holds good, in general, for those of the veins also. Such variation as exists depends on the more delicate and tenuous structure of the walls, and on the greater tendency to thrombosis.

Many of the figures illustrate these points, notably *Figs. 9, 10, 12, and 13*. *Fig. 10* furnishes an example of a very clean transverse division, while in *Fig. 12* a more frayed and tattered tear is depicted; in the case of the latter the condition is exaggerated by the adhesion of the infiltrated perivenous areolar tissue, as this specimen was removed after an interval of some days from the reception of the injury, and secondary changes have taken place.

The differences dependent upon the smaller proportion of muscular tissue, and the lesser degree of resistance offered by the vein to the passage of the missile, are perhaps still better illustrated by the characters exhibited by traversing perforations. These are well shown side by side in *Fig. 9*, while *Fig. 13*, drawn from a specimen obtained by Captain Adrian Stokes, affords an excellent example of a simple traversing wound of the common iliac vein in which little secondary change took place prior to the death of the patient. The openings in this drawing gape widely, but when the slits are vertical the tendency during life is for the vein to collapse somewhat and the margins of the wound to fall together. Many instances of perforations or rents of the great veins at the back of the abdominal cavity have been recorded, in which hæmorrhage was arrested spontaneously or by the aid of the surgeon, where recovery from the injury followed. A good instance of such an injury to the portal vein treated by forcipressure has been recorded by Captain Romanis.* During the course of an abdominal operation, a lateral wound half an inch in length

* *Lancet*, 1916, Oct. 14, p. 679.

was discovered in the portal vein from which blood was gushing freely. Two artery forceps were clamped on the side of the vein in a longitudinal direction, and the hæmorrhage was controlled. The forceps were left in position until the third day, when they were removed.

Fig. 12.—INJURED POPLITEAL ARTERY AND VEIN, FOLLOWED BY GANGRENE OF THE LEG.

The vein has suffered complete severance as a result of the passage of the bullet. The ragged, frayed ends of the vein are well shown. The amount of separation of the ends is less than the average distance, a fact readily explained by the firm nature of the connection normal to this particular artery and vein. The lower end of the vein is still occupied by a thrombus.

The artery, which has suffered a severe contusion, presents a fusiform enlargement occupied by a thrombus opposite the gap between the ends of the severed vein. Both above and below the thrombosed spot the calibre of the vessel is notably diminished, a condition usually seen when the normal arterial circulation is arrested either by a thrombus or a large wound involving the lumen. *Under the care of Capt. W. G. Mumford.*



No further hæmorrhage took place from the vein, but on the eighth day the patient had an attack of severe hypogastric pain, vomited twice, passed bloody urine, and died. The cause of death was secondary hæmorrhage from an injury to the right renal artery. At

24 GUNSHOT INJURIES TO THE BLOOD-VESSELS

the autopsy, the lumen of the portal vein was found to be patent, and the position of the wound occupied by a sound scar. Reference will be made later to the frequency with which wounds of the veins of the limbs heal spontaneously, especially by the aid of adhesion to neighbouring structures.

The histological details met with in a wound of the popliteal vein twenty-four hours after its infliction are portrayed by Captain Bashford in *Fig. 14*. It will be noted that very little injury has been suffered by the wall of the vein in the neighbourhood of the wound. The endothelial lining of the vein has been shed, and its



Fig. 13.—Recent perforation of common iliac vein. *Capt. Adrian Stokes.*

place taken by a layer of fibrin deposited on the inner surface of the internal elastic lamina. At one spot at the lower side of the section, separation of the muscularis from the intima has taken place, and opposite to this the internal elastic lamina has lost its natural curves, while beneath it some fibrin and red blood-corpuscles have been deposited. This specimen is from a comparatively slight injury, but serves well to illustrate the characters which have been described above.

PROCESS OF REPAIR OF THE INJURED VESSELS.

There is no evidence to lead to the opinion that any variation from the normal process is noticeable in the method of repair of vessels, either contused, or wounded by gunshot. The same sequence of prompt contraction, retraction of the inner coats, and provisional thrombosis followed by endothelial proliferation at the injured spot, and final organization of scar tissue, is observed. Any special features lie in the severity of the primary injury to the tissues, the frequent irregularity of the process as far as symmetry is concerned, and the length of the segment of the vessel which the subsequent cicatrization may implicate.

When the vessel has suffered complete division, the customary contraction of the terminal segment of the free extremity, retraction of the muscularis and intima within the confines of the adventitia, the formation of a provisional thrombus within the lumen, and sometimes the capping of the free extremity by a convex blood-clot, are observed. The process is in fact identical with that which follows



Fig. 14.—Section of recently wounded popliteal vein. All the coats of the vessel are divided at one spot on the right. There is little damage to the wall of the vessel around the opening. The endothelium is shed, and a layer of fibrin and blood cover the internal elastic lamina. At the lower part of the figure the media is seen to be separated from the intima. Opposite this spot the elastic lamina is stretched and its normal curves are obliterated, and a deposit of fibrin and red blood-corpuses separates the coats of the vessel; this is shown more highly magnified in B. *Specimen by Capt. Bashford.*

the division of any healthy artery by a blunt instrument, and can perhaps properly be compared to that which follows surgical torsion of a vessel.

The conditions are less satisfactory when the wound is a lateral one and hæmorrhage continues, either externally, or into the surrounding tissues. It is under these circumstances that the process of

spontaneous healing does possess special features rarely met with in injuries produced by other forms of violence. If the opening be of the nature of a minute puncture caused by a tiny fragment of metal, or of the limited extent produced by a bullet of small calibre, there is no doubt that it may heal spontaneously by the normal process. I think the first instance of spontaneous healing of perforations caused by a bullet to an artery of the magnitude of the abdominal aorta, was observed by Brentano* during the Russo-Japanese War. In this case the bullet traversed the aorta just above the origin of the renal vessels, and then passed through the liver. The patient died on the seventieth day from the results of a subphrenic abscess which developed in connection with the wound of the liver. At the autopsy the cicatrized entry wound was visible on the external aspect of the vessel, presenting an appearance like the proximal stump of a small branch which had been cut off. The scar of the exit wound was slit-like in character. The surface of the vessel was coated with a layer of plastic lymph, quite separate from the suppurating blood-clot which lay around. When the vessel was opened, at first glance the healed wounds were hardly visible on the inner surface, and both were firmly closed. Since the period of that observation, closure and consolidation of perforations has been observed with some degree of frequency during the performance of operations, particularly for the cure of arterio-venous aneurysms. A still more striking example of a wound of the abdominal aorta will be found on page 119.

A second classical case, that of Majors Johnston and Freyer, may be mentioned. A patient who had received an antero-posterior perforating wound of the thigh implicating the femoral vessels, died fifteen days later from enteric fever. At the autopsy the wound of entry into the artery was closed by a small firm clot embedded in the sartorius muscle, the small circular exit wound was attached to the corresponding opening in the underlying vein, while the wound of exit in the posterior wall of the vein was 'nearly cicatrized.' This case is quoted as illustrating an early stage of a course of events often met with, in which both the apertures on the non-contiguous aspects of the vessels close spontaneously, while those from which blood can pass readily from one vessel to the other remain patent. This method of spontaneous control of hæmorrhage or extravasation has now become a matter of common experience, and it will be referred to again under the heading of aneurysmal varix. It is mentioned here, as it may be but a step in the complete spontaneous cure of an arterio-venous injury, since the orifice

* "Ueber Gefässschüsse," *Archiv. für klinische Chirurgie*, 1906, Bd. 80, s. 304.

connecting the lumen of the artery and vein may occasionally contract and eventually close.

Spontaneous healing of vascular wounds may be aided by the lateral adhesion of other structures than satellite vessels—thus, to muscles or nerves which take a parallel course. The part which may be taken by large nerve trunks is most strikingly illustrated in the case of the axillary artery, where the conditions are more favourable than in any other region of the body. It has also been met with not infrequently in injuries to the brachial artery.

Fig. 15 depicts the ultimate condition of an axillary artery in which spontaneous healing has been effected. A considerable extent of the wall of the artery was implicated, principally upon one aspect. It is seen in the drawing that the muscular coat of one side of the vessel is practically normal; on the other side it is absent for a considerable stretch, its place being taken by cicatricial tissue. The remaining muscle, where it lies alongside the organized thrombus, is very highly vascularized. A striking feature in this section is the great amount of sub-endothelial thickening seen opposite the site of maximal injury, the new tissue extending right across the lumen of the artery. The organized permanent thrombus contains a large number of blood-vessels, suggesting a very early stage of possible 'canalization.'

During the South African War a curious instance of the closure of an opening in the brachial artery by the insertion of a loop of the musculospiral nerve was recorded by Sir William Stokes. This observation is interesting in relation to the question of temporary or permanent closure of the wound in the vessel by foreign bodies of other nature. Temporary restraint of hæmorrhage from wounds of large vessels by persisting firm impact of bullets or other fragments of metal is a familiar condition, as also the less agreeable experience of furious hæmorrhage from large vessels such as those of the neck or the thigh, following the removal of a



Fig. 15.—Spontaneous healing of axillary artery, and occlusion of lumen. Specimen prepared by Capt. Greenfield.

retained foreign body. *Fig. 7*, already referred to, demonstrates the possibility of permanent control being established by similar means. A striking instance of temporary control of hæmorrhage from a wounded popliteal artery is furnished by the skiagram, *Fig. 16*.

Many cases have been recorded which illustrate the capacity of



Fig. 16.—SKIAGRAM SHOWING THE BONES OF THE THIGH AND LEG OPPOSITE THE POPLITEAL SPACE.

An impacted bullet is seen lying transversely in the popliteal space. The point of the bullet, after traversing the popliteal vein, is lodged in the popliteal artery without penetrating the anterior wall. Removal of the bullet some days after its entrance was followed by free hæmorrhage, necessitating ligation of both vessels. *Under the care of Major Stoney Archer.*

wounds of the large veins to cicatrize spontaneously, even when the point of entry has been the heart. One case of this kind, under the care of Captain Gregory, which came under my own observation, may be mentioned. In this instance a skiagram taken in the supine position showed a shrapnel ball in the lower part of the chest. A second skiagram taken in the erect position showed the shrapnel ball

at the brim of the pelvis. The ball was eventually removed from the external iliac vein. The patient died later, and little trace of the point of entry of the missile was found; it was decided that it had descended from the right auricle. It had seemed possible that the ball might have entered the vena cava from the hepatic vein, as there was a large track in the liver, but examination of the hepatic vein afforded no definite evidence that a wound had existed.*

It may be added that a remote cure of an arterial wound may be effected by solidification of a traumatic aneurysm. Many cases have been observed in which this sequence of events occurred, most frequently in the case of the lower end of the femoral or of the popliteal artery.

Fig. 44, p. 170, affords a remarkable bond of union formed between the ends of a divided carotid artery. A solid column of young connective tissue, simulating a completely thrombosed artery retaining its normal calibre, connects the two parts of the vessel. This tissue has been laid down in the cavity occupied by a Tuffier's tube which was retained in the neck for four days. The tube was removed four weeks prior to death; had the patient survived, no doubt progressive cicatrization would have reduced the column to the condition of a narrow connecting cord.

* CAPT. GREGORY, *British Medical Journal*, 1917, vol. 1, p. 482.

CHAPTER III.
**SYMPTOMS AND SIGNS
 OF GUNSHOT WOUNDS OF THE BLOOD-VESSELS,
 AND THE TREATMENT OF HÆMORRHAGE.**

THE evidences of a gunshot injury to the blood-vessels are *general* and *local*: in some cases the general symptoms may be absent and the local signs so trivial as to create the impression that injury to a vessel of any importance is improbable. In the latter case the diagnosis may only be formed as a result of the development of subsequent manifestations, such as lowering of the vitality or even gangrene of the parts supplied, or one of the forms of traumatic aneurysm. It will be convenient in this place to deal with the general symptoms and initial local signs, reserving the consideration of the consequences for Chapters IV and V.

It is unnecessary to deal at any length with the general symptoms due to the loss of blood. It suffices to say that these are evidences of a pure acute anæmia, often to a certain extent influenced by the phenomena of wound shock—thus, initial psychic syncope, pallor and anxiety of countenance, bodily weakness, increase in rapidity and compressibility of the pulse, combined with loss of volume, increased rapidity and diminished depth in the respiratory movements, vertigo, roaring noises in the ears, and thirst, often extreme. In cases of the gravest nature all these symptoms tend to augment, pallor becomes extreme, restlessness develops, the pulse becomes progressively weaker until it flutters out, sweating occurs, the bodily temperature falls, the pupils dilate, and the patient becomes sleepy or unconscious. Occasional deep gasps of ‘air hunger’ interrupt the slowly failing respiration, restlessness and perhaps muscular twitchings increase, and death may be preceded by relaxation of the sphincters.

The physical signs denoting injury to the large blood-vessels may be shortly summarized as follows :—

1. External hæmorrhage.
2. Internal hæmorrhage, the extravasated blood collecting within the tissues of the body. This may give rise to a local swelling, exaggerated by œdema from pressure on the veins which may involve an entire limb. The condition may or may not be accompanied by superficial ecchymosis.

3. Evidence of interference with the peripheral circulation, indicated by diminution in strength or actual abolition of the distal pulse, and a fall in the distal blood-pressure.

4. The development of a systolic bruit over the wounded spot in the artery, or the development of a continuous venous roar with systolic exacerbations, when both artery and vein are implicated and communicate with each other. These bruits, especially when the lesion is situated in the lower extremity, may be in some cases audible in the precordial area.

5. Signs of disordered nervous function, even when no direct injury has been sustained by the peripheral nerve trunks.

6. Signs of lowered vitality or of gangrene in the area supplied by the injured vessel.

7. The subsequent development of an arterial hæmatoma, a traumatic false aneurysm, or an arterio-venous communication.

LOCAL TREATMENT OF PRIMARY HÆMORRHAGE.

It will be convenient to proceed first to the general question of hæmorrhage—primary, recurrent, or secondary—and its treatment.

It may be premised that death from primary hæmorrhage accounts for a very large proportion of the fatal casualties of battle, although the circumstances under which the deaths take place preclude the collection of accurate statistics upon this important point. The remarkable feature of primary hæmorrhage following gunshot injuries lies in the experience that so large a number of wounded men escape death when the vascular lesions present would have seemed to render a fatal issue inevitable.

The most striking instances of escape from the consequences of wounded arteries are seen in the case of large lacerated wounds in which the continuity of large trunks has been completely interrupted; but in these—as has been already shown—the nature and extent of the violence exerted on the walls of the vessel are such as especially to favour spontaneous control of the bleeding. The type of injury, in fact, resembles in a close degree that seen when a limb is totally avulsed, in accidents of which category the escape from the consequences of a ruptured artery is also a classical observation.

In the second favourable form of gunshot wound as far as escape from the dangers of primary hæmorrhage is concerned—the narrow traversing track—new factors beyond the contused nature of the arterial wound are introduced. These consist first in the shifting in relative position of the various planes of the structures of the body traversed, and consequent interruption of direct continuity in the patency of the track, due to assumption of an altered position of the

part of the body implicated subsequently to reception of the wound. Change of position, an almost invariable sequence to the blow of the missile, develops irregularity and an increase of intricacy in the track, and thus obstructs the passage of blood to the surface. Further, if hæmorrhage continues into the tissues, pressure consequent upon this irregularity of the track is exerted upon the wounded spot in the vessel, and a second hæmostatic influence is brought into play.

Whenever hæmorrhage persists and gives rise to danger, either from direct loss of blood, or from increasing pressure due to collection of blood within the tissues of the wounded part, the classical procedure of ligature of the vessel at the wounded spot is to be followed should the circumstances permit. If it be necessary to maintain temporary control, modification of the same principle should be made use of, and the pressure exerted directly over the wound in the vessel.

If a vessel be so situated as to be capable of being grasped and controlled by an artery forceps, but the application of a ligature is impracticable, the artery forceps should be left in position and the wound lightly filled with gauze. The tissues should not be too firmly grasped, and then the forceps may remain in position for several days before removal, or be left until the clamped end of the vessel separates spontaneously.

The application of a proximal ligature should be reserved for very exceptional cases of urgency; and in every instance, if the main trunk *must* be occluded, the ligature must be applied in as close proximity to the wound as possible. The seat of election is theoretically and practically the most unsuitable spot to choose, since it does not eliminate the collateral supply of blood to the parts between the point of ligature and the original wound, although by the greatly decreased supply which it leaves for the wounded area it seriously diminishes the protective power of the tissues against infection.

When the source of the hæmorrhage is from small vessels not readily reached, or when the bleeding is actually parenchymatous in character, the wound may be plugged after proper mechanical cleansing. A method somewhat extensively employed, especially by French surgeons, consists in provisional suture of the wound over the hæmostatic plug. It may be pointed out that if the primary cleansing and preparation of the wound has been efficient, neither of these measures prevents secondary closure of the wound, at a date varying from three or four to ten days, provided the conditions are favourable as to the size of the wound and the means of caring for it.

The last resource for temporary control of bleeding, the application of a tourniquet, is a vexed question not easy of solution. Every surgeon would gladly eliminate this dangerous and clumsy procedure from his practice. Yet circumstances do occur when the use of the

tourniquet is unavoidable, such as the absence of skilled assistance, want of time, the position in which the patient may find himself situated, or the nature of the surroundings. It can only be said, therefore, if the tourniquet be the sole available means of temporarily arresting the hæmorrhage, that every precaution must be taken to make sure that the band is released at the earliest possible moment : further, that no patient be subjected to transport without being specially marked, so that the presence of the tourniquet be not overlooked. Even when the latter precaution is observed, the evil effects of too tight or too prolonged application of the tourniquet are unhappily far from unfamiliar. Naturally the most frequent instances of the evil effect of the tourniquet are seen in patients who have either constricted their own limbs, or in whom the tourniquet has been applied by a fellow soldier.

When the hæmorrhage is internal, and no urgent signs of loss of blood or of danger from pressure are present, we are faced with a question which has given rise to much discussion. We know that in a large proportion of such cases the bleeding will undergo spontaneous arrest, either as a result of natural processes effected at the wounded spot in the vessel itself, or by the pressure of the blood already extravasated into the tissues and unable to escape to the surface of the body by the original track produced by the missile.

It has been argued that certain knowledge of the presence of a wound in a large artery should be at once followed by resort to the normal procedure, that is to say, suture or ligature of the vessel at the bleeding point. This view is supported by the self-evident fact, that if this course be taken and prove successful, the following risks are at once eliminated, and a prolonged course of subsequent treatment is avoided : recurrent or secondary hæmorrhage ; gangrene dependent on pressure exerted by extravasated blood-clot upon both the main vessel and its neighbouring collateral branches ; and the remote formation of any of the various forms of traumatic aneurysm. In fact, by adopting the proper method the surgeon not only relieves the patient from the immediate dangers of the condition, but also removes from the future all risks of a sequence of serious complications, and enormously reduces the duration of the course of treatment required.

On the other hand, difficulties have been raised to the adoption of the ideal method of treatment proper to this class of injury at advanced stations on the line. It has been asserted that most recent gunshot wounds are already infected, and further, that an operation incision made at an advanced post is practically certain to become so. Hence it has been argued that suture is an impracticable and ligature a dangerous procedure. Further, it has been said that if an interval be allowed to elapse between the receipt of the injury and

the permanent occlusion of the main vessel, valuable time is gained in which compensatory enlargement of the collateral circulation makes progress; thus, the dangers attendant on sudden local anæmia are reduced, and gangrene is less likely to supervene. The last serious objection to immediate operation is one which obtains in all cases of whatever nature, the danger of subjecting to any operation whatever a patient who has recently lost a large quantity of blood, especially if a general anæsthetic be necessary.

During the present war some general changes of opinion have taken place, but they are rather in the nature of compromise than in the acquisition of experience which fully justifies any attempt to lay down invariable rules for treatment.

With regard to immediate radical treatment, it has been proved that, in the absence of bleeding, little harm can result from the delay attendant upon the removal of wounded men to the line of special units equipped for operative work, or to the casualty clearing station which, under the conditions of the warfare of the first three years, assumed the functions of the stationary hospital on the lines of communication.

It has also been proved that within a period of six to twelve hours, wounds properly cleansed by mechanical methods coming far short of complete excision of the walls of the cavity, may be promptly closed and may heal permanently by primary union, provided that a proper interval of rest can be assured prior to further transport of the patient.

Thus the primary cause of failure in the earlier periods of the campaign has been eliminated, and—given conditions and surroundings such as obtained during the winter of 1917-18, when the casualty clearing stations were able to carry on their work practically unmolested—the treatment of wounded arteries falls into line with that of other serious wounds, such as those of joints or even severe compound fractures of the bones of the limbs. If such conditions can be assured, then the cardinal rule of surgery that a wounded vessel shall be secured at the earliest possible moment can be followed, and the advantages already enumerated will be gained.

During active military operations, however, combined with the necessity of shifting the situation of the operating centres and the rapid evacuation of wounded men, times will always occur when conditions unfavourable to the performance of operations will obtain. In this case the following rules would seem appropriate :—

1. Bleeding vessels in an open wound should always be secured at the earliest possible moment.
2. When injured vessels, and especially those of large calibre, are visible in open wounds, they must be ligatured whether bleeding is taking place or not.

3. When a large vessel is exposed in an open wound and has obviously suffered contusion and is thrombosed, the vessel should be ligatured above and below the thrombosed segment, and the latter excised. This procedure obviates the subsequent danger of secondary hæmorrhage, which is incalculable from external inspection of the vessel alone, as has been seen from the section devoted to contusion of the arteries.

4. When evidence exists that a large vessel has been wounded in the course of a track traversing the body or limbs, unless the conditions are favourable, it is not advisable to interfere primarily if no signs of progressing hæmorrhage are forthcoming, nor indications that the vitality of a distal portion of the limb is becoming endangered. In all such cases, although an arterial hæmatoma and subsequently a false traumatic aneurysm may result, yet the later treatment of either of these conditions under favourable circumstances for operation is to be preferred to the risks attendant on a primary operation.

RECURRENT AND SECONDARY HÆMORRHAGE.

Recurrent Hæmorrhage.—The occurrence of recurrent bleeding in a large number of those patients in whom it had ceased spontaneously under the influence of shock and rest, either when the patients are moved, or when the wounds are disturbed for the purpose of being cleansed and dressed, is not a matter to cause surprise. The treatment of this accident differs in no particular from that of primary hæmorrhage, and needs no further mention here.

Secondary Hæmorrhage, either from the systemic or visceral vessels, is unhappily still a frequent sequence to those gunshot wounds which it has been impossible to preserve from the sinister influence of infection. The experience in the earlier stages of the present war recalled those of the pre-Listerian era, and even under the increasingly favourable conditions of more recent times the occurrence of this accident has been deplorably common.

Beyond the all-important factor of septic infection, others enter into the category of causes of this complication—thus, the nature of the primary injury which, beyond inflicting a number of perforating wounds in vessels scattered widely in all parts of a very extensive wound, may also occasion multiple vascular lesions of great severity, but not actually perforating the walls of the vessel at the time. The first circumstance favours the escape from the attention of the surgeon who is called upon to deal with the case primarily, of individual perforations which may lie more or less hidden in remote extensions of the wound, and may also perhaps have spontaneously ceased to bleed. The second obtains a still greater

importance from the fact that sepsis is not an inevitable factor in the causation of secondary hæmorrhage, but the injured wall of the vessel may give way as a result of the final separation of a portion of tissue which is completely devitalized although temporarily continuous with the still living tissue. If septic infection does supervene, tissue much less seriously injured may have had its vitality lowered to such a degree as to fall an easy prey to the ravages of micro-organisms.

Certain peculiarities in the normal anatomy of individual vessels also exercise an influence on the occurrence of secondary hæmorrhage; the most important of these is mechanical fixation, especially to the bones. The significance of this factor has already been alluded to in relation to the manner in which it may affect the possibility of the escape of a vessel, or account for the relative degrees of damage, as evidenced by the infliction of contusion, non-perforating laceration, actual perforation, or complete division respectively. Anatomical fixation has a further action in preventing the normal retraction and contraction consequent upon the stimulus of injury to an artery; hence the wounded vessel may be retained at the surface of a wound, and perhaps with a patent orifice. The conditions, indeed, bear a strong resemblance to those consequent on the fixation resulting from infiltration and inflammatory induration on the vessels contained in the tissues. A few of the arteries influenced by such anatomical arrangements, and from which secondary hæmorrhage frequently takes place, may be mentioned—thus, the circumflex branches of the axillary as they pass around the neck of the humerus, the several scapular arteries where they are held in close connection with the borders of the bone, the gluteal artery as it emerges from the pelvis, the circumflex branches of the profunda femoris and the parent trunk itself as it dips beneath the adductor longus (the fixation here depending on relation to muscles and not to bone), the superficial femoral as it leaves Hunter's canal, the articular branches of the popliteal as they lie on the surface of the lower end of the femur, and the anterior tibial artery as it pierces the interosseous membrane and where it is attached to the anterior surface of that membrane.

Attacks of secondary hæmorrhage are often heralded by a rise in the bodily temperature, and an increase in rapidity and irritability in character of the pulse. This may be regarded as an indication that secondary hæmorrhage often follows an increase in the degree of infection. The immediate onset may be accompanied by pain, but in many instances the bleeding, although furious, may come on insidiously and only be detected by the patient or attendant by the discovery of blood in the dressings or the bed. The classical sequence of one or more insignificant hæmorrhages is, however, the most common course of events, and one of which the import should never be discounted or disregarded.

When the secondary hæmorrhage is of the internal variety, pain resulting from tension and separation of the tissues is usually the first indication.

Treatment of Secondary Hæmorrhage.—The routine procedure in all cases of secondary hæmorrhage consists in the application of a ligature to the bleeding point. This may prove a matter of extreme difficulty, either by reason of the anatomical position of the vessels from which the bleeding proceeds, or the unsatisfactory state of the walls of the vessels themselves and of the surrounding tissues.

It is rare indeed that proximal ligature of the main trunk supplying the wounded area is justifiable. This operation involves the collateral vessels more extensively, is much more dangerous to the future vitality of the tissues, perhaps to a limb itself; and in a very large percentage of instances is but a temporary expedient, since recurrence of the secondary hæmorrhage is a common event. Only one exception to this general statement appears to be justified by practical experience, and that is in the case of ligature of the internal iliac artery or its posterior division, when bleeding is taking place from one of the vessels of the buttock close to the point at which it emerges from the pelvis. I have seen a number of patients in whom proximal ligature has been successful in these circumstances, but success in the case of any other trunk is rare. Even in the case of the internal iliac, gangrene of the tissues of the buttock has been observed occasionally. Proximal ligature of the main artery at the seat of election is therefore to be condemned, and may only be resorted to when no other course is possible. Further, should it be considered necessary to deal with a main trunk, the ligature should be applied in as close proximity as possible to the actual wounded spot, difficulties of access being disregarded as far as possible. The latter procedure is perhaps most useful when hæmorrhage from an amputation stump has to be dealt with. It has here the advantages of rendering unnecessary free handling and disturbance of flaps which may have in great part united, and of avoiding having to deal with a softened artery, to tie which effectively the vascular cleft must be followed up to an undesirable extent; it allows a comparatively healthy portion of the vessel to be dealt with at the bottom of a fresh wound, and at the same time does not encroach unduly upon the blood-supply of the flaps by collateral vessels.

As a general rule, should the application of a ligature or forcipressure prove unsuccessful or impracticable, the wound must be plugged. Plugging may prove successful even when large arteries provide the source of the bleeding; it is frequently so when smaller vessels are at fault in the wounds of patients suffering from toxæmia or septicæmia, or if the hæmorrhage is of the parenchymatous class.

If, however, this practice be resorted to, the surgeon must be content to risk the condition of the wound as far as dressing is concerned, and allow the plug to remain in position for several days, or a week or more if necessary. In adopting this plan it must be kept in mind that in granulating wounds, any blood which escapes tends for the most part to remain in, or escape externally from, the cavity, and not to infiltrate and dissect up the limb as it may do in a recent injury. Even in recent wounds, the experience of the salt pack as recommended at one time by Colonel Gray, and the safety with which wounds anointed with Mr. Rutherford Morison's compound of bismuth, iodoform, and paraffin may remain undisturbed, support the justifiability of leaving a plug in position for prolonged periods. It seems almost unnecessary to add, that in introducing plugs which are intended to rest for a prolonged period in a wound from which secondary hæmorrhage is occurring, the utmost care must be exercised that every extension and crevice of the cavity be efficiently filled; for upon this precaution the success or failure of the procedure will ultimately depend. A hastily and imperfectly introduced mass of gauze may prove worse than useless for the purpose intended.

The final resort in secondary hæmorrhages from the limbs lies in amputation.

A few words may be added as to the general treatment of patients who have suffered from severe hæmorrhage. The usual precautions of removal of tight clothing, the arrangement of the patient with the head low, the insurance of complete immobility and rest, will at once follow the local arrest of the bleeding. On these precautions should follow the application of warm coverings, and additional heat obtained by the application of warm bottles, or if circumstances permit, in bad cases, some form of warm-air bath.

Even in secondary hæmorrhages the internal administration of drugs cannot be relied upon to afford any useful aid; in both primary and secondary hæmorrhage an increase in the total volume of fluid in the vessels is the main object to be striven after.

The Replacement of Blood.*—While it may be stated that blood is the best fluid with which to replace lost blood, yet in practice this course may be impossible or unnecessary. With a moderate hæmorrhage there is no need to replace the lost blood artificially. If the bleeding has been more severe, the loss can be made good by a more easily obtainable fluid, i.e., Bayliss's 6 per cent gum-arabic solution. A still more severe hæmorrhage will demand blood.

* W. M. BAYLISS, F.R.S., Medical Research Committee's Memorandum, No. 1, on *Intravenous Injections to Replace Blood*; OSWALD ROBERTS, Med. Res. Comm. Mem., No. 4, on *Blood Transfusion*.

A precise indication as to when blood transfusion is imperative is still wanting, and much to be desired. Most observers are agreed that a critical point has been reached when the total hæmoglobin content is as low as 80 per cent. In primary hæmorrhage it is unfortunately not possible to calculate the hæmoglobin value without an elaborate procedure which is not easily carried out. Other aid must therefore be sought. Clinical signs are of a certain value, but very often it is hard to determine from a patient's appearance how much blood has been actually lost, and ocular demonstration of the amount is usually wanting.

In these circumstances the blood-pressure is a valuable guide. A systolic pressure determined by the auscultatory method, which remains below 80 mm. of mercury for hours, is an indication that help is required.

The question to be settled is what the nature of this aid should be. The changes that take place after a hæmorrhage give some useful indications. Directly blood is lost, fluids begin to pass into the circulation from the tissues. The resulting dilution of the remaining blood continues for some days until the blood volume is restored or exceeded. Further, the manufacture of hæmoglobin and red blood-cells begins, and proceeds until the normal is attained.

The first want therefore is fluid. This can be supplied either by the mouth or by the rectum, provided that the patient can take and retain fluid by one of these channels, and the call is not imperative. If these methods be ineffective, impossible, or too slow, fluid may be introduced directly into the circulation. The best artificial fluid for this purpose is Bayliss's 6 per cent solution of gum arabic in normal saline. If introduction of this fluid fails to produce the required result and to raise the blood-pressure, recourse must be had to transfusion of blood.

The matter may be shortly summed up as follows :—

1. *Primary Hæmorrhage.*— In sudden and abundant hæmorrhage, immediate transfusion is indicated.

2. In less severe cases, Bayliss's gum-arabic solution should be tried, and followed by transfusion of blood if no permanent effect has been produced.

3. In milder cases, an attempt to restore the blood volume may be made by the administration of large amounts of fluid by mouth or by rectum. If necessary these attempts may be followed by 2.

Secondary Hæmorrhage.—In this case the hæmoglobin content is most likely already depressed to the critical point. Consequently, even a moderate hæmorrhage will reduce it to a point incompatible with an efficient natural recovery; hence immediate transfusion of blood is the safest course. The beneficial effect to be hoped for from

transfusion is greatly lessened in patients the subjects of general infection.

Signs of Interference with the Distal Circulation.—Inspection of the part affected may reveal pallor when the artery alone is wounded, or congestion and cyanosis when both artery and vein are affected. The part may also be cold to the touch. The evidence furnished by examination of the pulse to the distal side of the injury is important both as denoting to some extent the gravity of the local lesion, and also as indicating the sufficiency of the collateral supply to the part. Many factors, however, combine to render it no more than a contributory aid; thus interference with the pulse may be due to temporary pressure exerted by a fragment of bone, a displaced bone, a retained foreign body, or extravasated blood. Again, it may be due to thrombosis, or the pulse may be impalpable simply as a result of the general depression of the blood-pressure when only slight local obstruction exists. These factors are to be remembered in deciding upon the necessity of any intervention, and especially that of amputation. In the latter case absence of a distal pulse cannot be accorded the weight in forming a decision which used to be given it, except when gross infection of the wound in general by anaerobic organisms is suspected or known to exist. As a sign of an arterial wound its value is slight compared with the evidence to be obtained by the use of auscultatory methods.

A comparative fall in the distal blood-pressure of the part is a sign of some constancy, but not of any great practical utility in dealing with the early stages of these injuries. It gains more importance in the consideration of the proper treatment to be adopted in aneurysms, and will be dealt with when this subject is reached.

EFFECTS OF WOUNDS OF THE ARTERIES ON THE GENERAL CIRCULATION.

Wounds of the large blood-vessels are commonly attended by apparent enlargement and excited action of the heart. These signs are fairly constant in the early stages following the injuries, but vary in degree and mutual relationship, tending to subside with rest in the recumbent position and with development of the gradual compensation which follows when the opening in the arterial wall has remained patent for some time.

In a large proportion of cases of injury to the larger arteries the apex of the heart will be found in the nipple line, less frequently outside that line even to the extent of one to two inches, and sometimes raised above the normal level. The pulse-rate averages from 90 to 120. The degree of either enlargement or excitement may

vary with individual idiosyncrasy and the psychic influences so common in gunshot injuries, and both are more marked when primary loss of blood has been great or toxæmia is a factor. Allowing full weight to these general factors, however, no doubt can exist that a simple defect in the arterial wall, in communication with a lateral chamber in which the blood is constantly circulating, demands increased cardiac effort to maintain the flow of blood. This effort must be the greater, since the circulation of the blood through the cavity does not receive the normal aid afforded by the elastic wall of the blood-vessel, and the blood contained within the cavity is not controlled by the proper vasomotor mechanism, and meanwhile the imperfectly supplied distal portions of the body call for their normal supply.

The call on the cardiac muscle is probably greatest during the period in which a simple arterial hæmatoma—that is, a pool of fluid blood in direct continuity with the arterial blood-stream—is still present. Following the ordinary physical law, this large collection of blood will be maintained at a pressure equal to that of the general circulation, and the force for this extra duty must be furnished by the heart, the local resistance offered being merely that of the surrounding tissues of the limb, in place of the highly regulated support of the arterial wall.

When an arterio-venous communication has been established, the obstruction to and disturbance of the circulation are still more serious. In these circumstances, the arterial flow diverted from its normal course is driven into and disturbs the slower reverse current in the vein. The walls of the vein, as a result of the increased intra-vascular pressure to which they are subjected, stretch, and thus a great bay is formed in which a swirling eddy is established. In this way obstruction is offered to the current in the distal segment of the vein, while a varying proportion of the arterial blood destined to the supply of the peripheral portion of the body passes directly backward to the heart.

That an arterial leak acts practically as an actual obstruction to the circulation appears obvious from the immediate fall in the distal blood-pressure which takes place. This fall coincides for a prolonged period with that observed when the main artery supplying a limb is occluded by the application of a ligature. Thus, in twenty-three cases of traumatic aneurysm of recent development, the average difference in the peripheral blood-pressure between the normal and the injured limb amounted to 21.4 mm. of mercury when tested by the manometer.

The amount of fall, in the case of an untreated aneurysm, probably decreases with time and development of the collateral

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circulation; thus, in a case of aneurysmal varix of the superficial femoral of seven months' standing, the distal pressure had risen to nearly normal, again falling after an operation for the cure of the condition.

Support to the belief that an obstruction in the arterial circulation throws increased strain on the central organs is also afforded by the experience of the frequency with which the operation of ligature



Fig. 17.—Wound of popliteal vessels. Position of heart during inspiration.
Skiagram by Capt. Stone.

of an artery for the cure of a spontaneous aneurysm in the limbs is followed by the development of one in the thorax.

With regard to the evidence of cardiac dilatation afforded by determination of the position of the apex; of 37 cases in which cardiac murmurs accompanied the presence of an aneurysm, in 24 the apex was in the nipple line, in 4 within that line, and in 9 it was from half an inch to two and a half inches outside. In the majority

of instances the vertical level tended to be raised, often into the fourth interspace.

Radiographic examinations have been made in a few cases during the early stages of treatment, and the illustrations (*Figs. 17, 18, 19, 20*) are highly interesting. *Figs. 17* and *18* depict the size and position of the heart in inspiration and expiration respectively. They



Fig. 18.—Same case as *Fig. 17*. Position of heart during expiration.
Skiagram by Capt. Stone.

were taken from a patient with a popliteal varix of four days' standing, in whom the position of the apex had been determined by palpation as being in the nipple line. It will be observed that this position during expiration is more than confirmed, while during inspiration, except for a slightly increased extent of the shadow to the right of the sternum, nothing abnormal is to be observed. In the investigation of another case, it was pointed out to me by Captain McIlwaine

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that an exactly similar condition had been observed by him in a certain number of the patients sent to the base with the service diagnosis 'disorderly action of the heart.' *Figs. 19 and 20* were taken from such a case by Captain Crymble, and the striking resemblance of the two sets of skiagrams is obvious.

Captain Mellwaine further kindly undertook the cardiographic



Fig. 19.—Case of 'disorderly action of the heart.' Position of heart during inspiration.
Skiagram by Capt. Crymble.

investigation of four patients suffering from wounds of the vessels, and furnished me with the following brief reports of the cases.

Femoral Arterial Aneurysm.—Wounded, July 5, 1916. Examined, July 18. There was marked pulsation visible in the 3rd and 4th interspaces. The beat of the heart was forcible and diffuse, not heaving. The apex beat was felt in the 4th and 5th spaces just outside the nipple line. No murmurs were present. The electro-

cardiogram was normal, showing no right or left ventricular preponderance. General blood-pressure: systolic, 140; diastolic, 75.

Femoral Arterio-venous Aneurysm.—Wounded, Aug. 15, 1916. Examined, Sept. 3. Visible pulsation was present. The apex beat was in the 4th space just round the nipple. It was forcible, but not heaving. A systolic murmur was present at the apex and in the

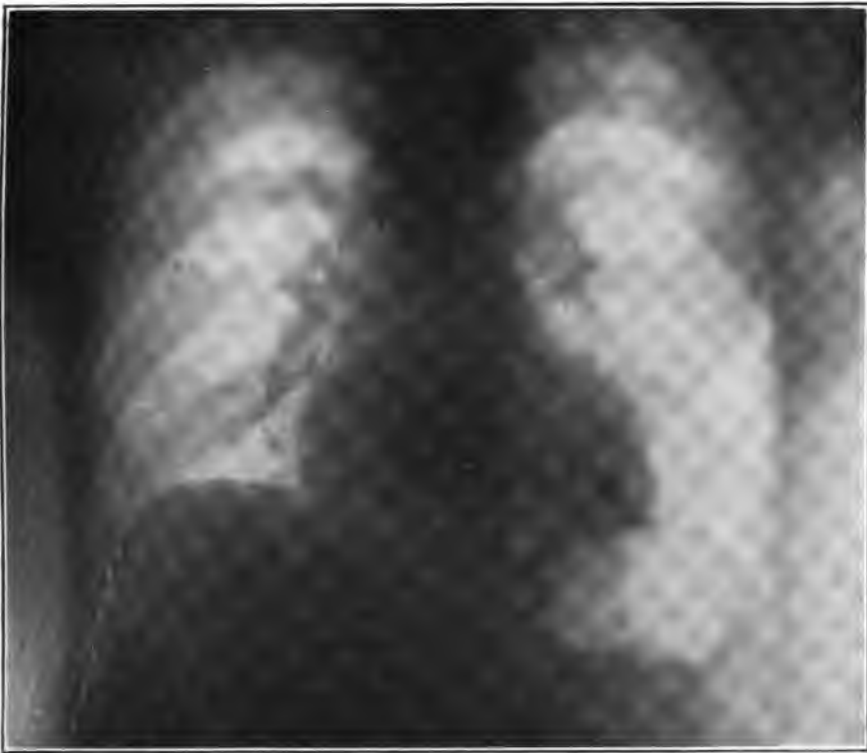


Fig. 20.—Same case as *Fig. 19*. Position of heart during expiration.
Skiagram by Capt. Crymble.

pulmonary area. The apical murmur was not conducted towards the axilla: it was modified by respiration. Blood-pressure: systolic, 120; diastolic, 60. The electrocardiogram showed no evidence of any ventricular preponderance.

Femoral Arterio-venous Aneurysm.—Wounded, June 5, 1916. Examined, Sept. 12. The apex was in the 5th space half an inch inside the nipple line. Over the præcordia there was a forcible beat, not

heaving. This pulsation was visible. There was a well-marked systolic murmur at the apex, not conducted outwards. There was also a systolic murmur at both areas at base, the aortic area murmur being the louder, and a loud aortic second sound. Blood-pressure : systolic, 155 ; diastolic, 70. The electrocardiogram showed no definite evidence of any ventricular preponderance. The heart did not appear enlarged in the skiagram taken.

Femoral Arterial Aneurysm.—Wounded, Sept. 27, 1916. Examined, Oct. 9. There was a visible wave of pulsation over the 3rd and 4th spaces. The apex beat was in the 4th space just inside the nipple line. A deep inspiration caused the beat at this point to disappear, and the most forcible beat appeared in the 5th space half an inch inside the nipple line. There was an apical and basal systolic murmur, modified by respiration, best heard during expiration. The skiagram showed that the cardiac shadow was markedly altered by respiration, being pear-shaped in deep inspiration and a flattened lateral oblong in expiration. There was no evidence in the electrocardiogram of any ventricular preponderance. Blood-pressure : systolic, 122 ; diastolic, 60. There was a loud knock in the artery.

These observations seem opposed to the view that actual dilatation of the heart was present. In fact they rather suggest that a want of tone in the heart muscle—and hence a condition favourable to an exaggeration of the changes of shape of the organ accompanying the respiratory movements—accounts for the outward displacement of the cardiac apex.

It is a striking fact that the cardiac conditions so nearly resemble those met with in some of the unwounded men sent down from the front with the diagnosis 'disorderly action of the heart.' Yet it does not seem reasonable to assume that the subjects of arterial wounds in whom such signs are so frequently present were already suffering from 'disorderly action of the heart' when they received their wound ; but rather, that the vascular injury has led to the development of the condition.

The patients in whom these cardiac disturbances are present do not suffer from præcordial distress, rapid respiration, or any pain. On inspection, the apex beat is observed to be displaced and abnormally visible, while diffuse pulsation is frequently apparent over the whole præcordial area. Acceleration of the pulse is a constant sign, the rate varying from 80 to 120, with a mean average of about 100. An irritable character is common, and in some cases the 'knocking' type, more freely discussed below, is found. The symptoms, while not constant, are extremely common in connection with arterial wounds, although their prominence does not always coincide with the importance of the vessel implicated. Without doubt cardiac

idiosyncrasy, temperament, and perhaps indulgence in tobacco may be contributory causes, and the phenomena are certainly in part dependent on loss of blood. It may be well to emphasize that they have been observed during the first few weeks after reception of the injuries, and tend to diminish with time. With all these reservations, however, definite evidence exists to support the statement that disordered cardiac action follows and results from wounds of the large arteries and the formation of false aneurysms.

What is known as to the ultimate course of arterio-venous aneurysms and varices tends to support the view that extra strain is thrown upon the heart by their formation, and that subsequent changes take place in the peripheral circulation. Sir W. Osler,* while pointing out that the changes may not be so great in the case of vessels of the upper as in those of the lower limb, says, "In the majority of cases venous stasis forms the most serious sequel of the disorder. The changes in the arteries on the proximal side of the lesion are less striking, but sooner or later sclerosis occurs with dilatation, and sometimes with sacular aneurysm opposite the orifice of the communication. Even within two months of the injury the femoral artery may be felt to be larger and with stronger pulsation." Observation during the course of operations of the exposed vessels in a number of recent cases in the present war has not impressed me with the occurrence of early proximal dilatation; on the other hand, distal contraction has been a constant feature, either in pure arterial injuries or in arterio-venous lesions, as will be referred to below. It is obvious, however, that in the early stages, during which the patient is kept at rest in the recumbent position, any considerable arterial dilatation is unlikely to develop. During the performance of operations undertaken at a later period, the artery on the proximal side of a traumatic aneurysm is generally found to be thickened and dilated, but it may be remarked that a similar condition is found also when the lesion is purely arterial in character.

It is of much interest, in view of the early cardiac conditions above dealt with, to quote again from Sir W. Osler; he says, "One of my patients died from heart disease, which may have had some connection with his long-standing lesion." Again, "In an arterio-venous communication in the middle of Scarpa's space established in 1898, at the time of death, in 1911, the dilated arteries extended from the bifurcation of the common iliac to the lower third of the thigh. Hypertrophy of the heart followed, and death from progressive failure of the circulation." In rare instances signs and symptoms

* "Remarks on Arterio-venous Aneurysms," *Lancet*, 1915, i, 952.

of cardiac disease, in which respiratory distress and general œdema are marked features, have been observed to develop a few weeks after the primary injury, such cases ending fatally. I have never witnessed this result myself.

Cardiac Murmurs.—A matter of interest, which has apparently escaped previous recognition, lies in the frequent transmission of the local systolic arterial bruit to the heart, and hence the presence of cardiac systolic murmurs of a pronounced character accompanying wounds of certain of the blood-vessels.

The nature and explanation of these murmurs is not altogether simple, for they are temporary, inconstant in occurrence, and heard especially in connection with certain vessels. The last fact introduces some difficulties as to the actual mode of their conduction or transmission; hence it may be as well to deal with one question as a preliminary—namely, whether the cardiac bruits are purely hæmic in nature.

That hæmic cardiac murmurs are not infrequent as a result of serious loss of blood is a well-recognized fact, and has been verified in many cases; moreover, in one, a loud apical systolic murmur accompanying a local bruit over the site of a wounded posterior tibial artery, was replaced by a soft hæmic murmur which persisted for twenty-four hours after the wounded artery had been occluded by ligature. This observation suggests that in some instances a compound of factors may account for the presence of the cardiac murmur; but the above was an isolated experience, and in other observed cases ligature of the wounded vessel has been followed by immediate disappearance of the cardiac bruit. When the experiment is made of trying to abolish the cardiac bruit by pressure on the vessel proximal to the wound, it is found that absolute suppression of the blood current is required to banish the bruit entirely.

In pure arterial injuries the murmur is loudest at the cardiac apex, or often over the base of the left ventricle, and the sound is not conducted towards the axilla or the neck. When present, the murmurs are loud and distinct as a rule, and are indistinguishable in character from those present in mitral valvular disease. It is remarkable that in some cases the cardiac bruit may be much louder than the local murmur indicating the wounded spot in the vessel. This feature is the more surprising, in that the local arterial murmur is commonly conducted more widely in the distal than in the central direction.

In arterio-venous aneurysms or aneurysmal varices the venous hum is continuous, while the systolic element is commonly the more pronounced, and possibly accentuated by a prolongation of the diastolic phase. In femoral arterio-venous aneurysms the venous

roar is sometimes absent, and when the communication is situated in the neck or axilla, the continuous venous roar is usually the only element. The conveyed murmurs are only common when the vessels of the lower extremity are concerned, and are then generally most pronounced over the base of the heart. When the murmurs commence to fail in strength, the systolic element is usually the first to disappear.

Amongst 180 cases of arterial lesions in which a routine examination was made with the object of searching for cardiac murmurs, these were present in 37; 18 of the lesions were arterio-venous, 19 purely arterial.

The date of appearance of the murmurs is early, probably as a rule immediate, but in some instances a day or two may elapse before they become evident. Four cases of delayed appearance are included among the numbers given above. Considerable variations in strength and tone may occur from day to day, but the general tendency is towards diminution and disappearance of the sounds. The longest period in which any murmur was noted to persist in men recently wounded was seventy days, but many patients in whom the arterial wound was untreated returned to England with the bruit still audible.

Experience has shown, however, that the conveyed murmurs may persist for a long period; also that, after subsiding during a period of rest, they may return with the resumption of active life. Thus, a brachial arterio-venous communication of six years' standing was detected as a result of the discovery of an abnormal cardiac bruit during an ordinary routine examination made for medical purposes; and I have seen other instances in which a primary diagnosis of cardiac disease needed to be revised in consequence of the discovery of a local vascular lesion in the limbs. It is in this last respect that the conveyed murmurs acquire their chief practical importance, since it is obvious that their discovery may lead to the detection of a lesion that might otherwise be readily overlooked, especially in the subjects of multiple small gunshot wounds.

Local Vascular Murmurs.—The characters of the typical local murmurs are well known and recognized, but some remarks on the conditions which may affect the sounds in individual cases may not be out of place. Moreover, it is not perhaps even now generally recognized, that a local systolic murmur is the most certain and easily obtained proof of a wound of a deeply situated artery.

Considerable variations of tone and character are met with. Thus, the arterial wound may be indicated by a soft 'bellows' murmur (especially when there is great swelling of the limb), a loud 'rushing' sound, or a musical whistle, the latter commonly in the later stages when cicatrization is advanced. In the presence of an arterio-venous

communication, either the systolic bruit or the venous roar may be the more prominent element; in some cases the buzzing sound, compared to the noise made by 'a bee in a bag,' is the salient feature; in others the venous roar assumes the character of a deep pedal note. No characteristic differences have been observed between the murmurs accompanying the contused wound produced by the bullet and the often comparatively cleanly-cut opening produced by sharp fragments of shells or bombs. Neither does the loudness of the sound correspond with the size of the vessel concerned, although a superficial position of the vessels is of much importance in this respect.

A number of factors, to which it is difficult to assign the proper relative import, do, however, doubtless affect both the character and strength of the bruit produced. Thus, the nature of the aperture may be mentioned: in some cases marginated by a ragged ring of the media, in others by a thin sharp margin of bare intima from which the media has been stripped, while in still others a ragged tongue of media may project across an arterio-venous opening. Again, the timbre of the bruit tends to change in accordance with the stage of stiffening from infiltration or cicatrization which has been reached. Lastly, the depth of tone and resonance of the sound is affected by the length of the column of blood, the size of the cross-section of the vessels, the presence of a large collection of fluid blood or clot in connection with the wound in the vessel, and the general conformation of the patient himself. It is obvious that the mass, strength, and degree of tension of the structures of a limb are of importance as resonating factors, and these are still more evident when the wounded vessel is situated over the chest wall, or in the close vicinity of hollow viscera.

In connection with the comparative resonance of different limbs, an observation made in employing percussion to elicit the tympanic note present when a limb is deeply infiltrated with gas is of some interest. This sign, to which considerable importance is rightly allotted, may be vitiated by the presence of either a large wound defect or the existence of a considerable collection of effused blood in a limb, especially around a fracture. Either of these conditions may accompany a wounded artery, and the altered acoustic conditions will no doubt affect the character of a murmur.

Certain other features are worthy of further consideration; but before proceeding to them, the occurrence of systolic arterial bruits independent of an open arterial wound should be mentioned. These may depend upon obstruction to the arterial lumen, due either to cicatricial contraction of the vessel itself, or to pressure from without. Such murmurs are distinctly rare in my experience. I have auscultated many hundreds of arteries in the search for wounds, and among these may be particularly mentioned a series in which the distal pulse was

diminished or absent in injuries about the root of the neck and shoulder. In such cases complete severance of the vessel, obstruction from thrombosis, or external pressure by displaced fragments of bone is to be expected; but in very few instances has a murmur been detected, and this a 'whistling' at a late stage after the injury, probably due to cicatricial changes.

A local vascular murmur may be very considerably modified by pressure exerted by the bell of the stethoscope; this may accentuate it as well as alter the timbre. In an instance in which a pure systolic bruit was audible over a traumatic aneurysm of the femoral artery, pressure by the stethoscope produced a soft cooing sound, somewhat resembling the musical sigh often heard among trees in a soft breeze at night.

It is not uncommon for a murmur to be audible over the site of a sutured arterial wound, when either the lumen is narrowed for a considerable longitudinal extent, or when a sudden narrowing is present. These bruits closely resemble those accompanying the presence of an open wound. A somewhat striking experimental proof of the capacity of incomplete obstruction to the arterial lumen to give rise to a murmur audible in the heart, is afforded by an observation made during the use of Tuffier's arterial tubes. In two such cases a systolic bruit was audible at the apex of the heart after the introduction of the tube, disappearing with its removal.

Another not infrequent phenomenon is the presence of a systolic bruit, audible throughout the great vessels of the body, developing in consequence of a severe secondary hæmorrhage. Its interest depends upon its resemblance to the hæmic cardiac murmurs so much more commonly present under like circumstances, and thus it brings the two conditions into accord. It is remarkable that in one instance in which this general arterial bruit was well developed, no similar murmur was audible over the heart; but it may be added that the patient at the time of examination was within a few hours of death.

A much more common occurrence as a sequence of hæmorrhage is the development of a general arterial bruit of the 'pistol shot' or 'water hammer' type. The assumption of this type may again be quite independent of an arterial wound, but it gains interest in this relation from the fact that it materially modifies the character of the murmurs audible over an aneurysm when it is present. This 'pistol shot' character has been referred to by Sir W. Osler,* and I adopt the term from him, as much more nearly describing the sound than the term 'slamming' I was accustomed to make use of. As a

* *Loc. cit.*, p. 953.

generalized phenomenon it is often heard in its most pronounced form in patients dying from acute toxæmia, or in patients at the end of a long and trying operation during which much blood has been lost. In this form the sound suggests the falling of drops of water in an empty tube, and causes an actual shock to the tympanic membrane of the auscultator with each beat of the heart. The probability of its presence is indicated with some certainty by the character of the pulse on palpation, a similar 'knock' being felt. When this generalized sound is present, it naturally accentuates and modifies the local murmur audible over an arterial aneurysm or an arterio-venous communication; but it is an interesting fact that the local murmur may assume the same character when it is not present in the arteries generally.

This type of sound can be readily reproduced experimentally by lowering the diastolic pressure in an artery of an extremity by applying the arm band of an ordinary manometer; in fact, as pointed out to me by Captain McIlwaine, by the ordinary auscultatory method employed in determining the blood-pressure. When the band has been tightened for some seconds, and is then relaxed, the early beats of the artery distal to the compressing band are audible, and of the true 'pistol shot' type. By this observation definite support is afforded to the view that the diversion of a portion of the blood-stream through an abnormal opening lowers the distal blood-pressure and interferes materially with the blood-supply of the limb beyond the wound, conditions calling for increased effort on the part of the heart to maintain the vitality of the limb. The fact that the local phenomenon is inconstant is readily explained by the condition commonly observed when wounded arteries are exposed for the purpose of ligation or suture. In these circumstances the portion of the vessel distal to the wound is found to be considerably contracted, and this to an extent approximating to that seen when the vessel has been completely severed. I have noted this condition as late as seven months after the reception of a lateral wound of the femoral artery which took part in an aneurysmal varix, so that the compensating contraction may be more or less permanent. This contraction is no doubt sufficient, in a great number of cases, to correspond with the diminished amount of blood able to reach the artery; hence a sufficient diastolic pressure is maintained to obviate the occurrence of the 'pistol shot' sound. If, on the other hand, the compensatory contraction is insufficient as a result of the large amount of blood diverted from the normal current, or possibly as a consequence of disturbance of the normal vasomotor reaction causing actual peripheral dilatation, the 'pistol shot' character is assumed by the aneurysmal murmur. This view is further supported by the observation that the 'pistol shot'

sound is far more common in arterio-venous than in arterial aneurysms; and this because a much larger amount of blood can be diverted into the lumen of the vein—whence it can readily pass onwards with the reverse circulation—than can be possible in the case of the cavity of an arterial aneurysm, which is of more or less constant dimensions.

In connection with the general explanation offered above of the mode of production of the 'pistol shot' sound, it may be suggested that when in arterio-venous lesions this is local only, the 'knock' may be produced by the direct passage of the powerful arterial stream into the dilated venous channel, in which the pressure is comparatively low.

Mode of Transmission of Local Aneurysmal Murmurs to the Heart.—Before proceeding directly to the consideration of the mode of conduction of local vascular murmurs to the heart, it may be convenient to recall that the conduction of the murmurs in the limbs themselves varies considerably both in extent and distribution.

In purely arterial lesions the murmur is loud, and can be heard more widely in the distal than in a central direction. Centrally it is rare to be able to trace the sound more than a few inches. Further, the murmur is practically limited in distribution to the line of the vessels themselves and the area of the limb occupied by the aneurysmal sac, if one is present.

In arterio-venous lesions, the murmurs are conducted in both directions, the double bruit often the entire length of the limb, while in the central direction the venous roar is always conducted widely. In some instances the conduction is limited to the line of the vessels, in others the vibrations are transmitted to the whole mass of the tissues of the limb, and audible in whatever position the stethoscope is applied. This latter phenomenon is no doubt explained by the comparative strength of the vibration caused by the meeting and mixing of the currents, which is further indicated by the palpable thrill commonly present over the vessels. Perhaps to a lesser extent it may be influenced by the tone, tension, and strength of the individual limb. In relation to the inconstancy of the transmission of the vibrations to the limb generally, it may be remarked that the sign of 'purring or bubbling thrill' is very variable both in strength and occurrence. In some cases it is difficult to determine, and in all it is a very uncertain guide to the exact location of the arterio-venous communication. The same may be said when the vein is exposed; thus, the wall of the internal jugular vein may in some cases be seen to 'shiver'; in others the vibration is not visible. Definite vibration on the surface of the neck is also occasionally seen. Venous pulsation is not often visible independently of the arterial pulsation except at

the root of the neck. Of the entire number of cases I have seen, in only two instances in the limbs—(a) where the brachial artery at the bend of the elbow was in communication with the median basilic vein; and (b) when the cephalic vein had been laid bare by incision of the pectorals for exploration of an axillary arterio-venous aneurysm—was independent venous pulsation palpable and visible.

It is a remarkable fact that conduction of the local systolic murmur to the heart is uncommon unless the wounded vessel is situated in the lower extremity; and the same remark applies in a lesser degree to the arterio-venous bruits, with the definite reservation of the cases in which the tissues generally conduct the murmur to the cardiac area. Amongst a large series, the murmur accompanying a local injury to the artery alone was audible in the heart in 6 out of 24 axillary aneurysms, and in only one instance of arterial aneurysm of either the neck or arm. On the other hand, amongst 94 cases of arterial aneurysm in the lower extremity, the systolic murmur was conducted to the heart in no less than 31 instances. Moreover, the murmur is equally loud and pronounced whether the local injury is situated in the vessels of the thigh or the leg. Again, as has been already remarked, the loudness of the cardiac murmur in no way corresponds with that heard over the wounded spot in the vessel or the aneurysm, for the latter may be soft while the conducted murmur in the heart is loud and pronounced.

It does not appear easy to explain this difference in regard to transmission of the local murmur from the vessels of the lower extremity and those of the remaining parts of the body. It is difficult to assume any other path of conduction than the vessel wall and the column of blood contained by it, and this path is uninterrupted in the case of all. It is clear that the comparative distance of the lesion from the heart exerts little or no difference, unless the resonating power of the column of blood be increased by its length; and if this be the case there seems no reason why the systolic arterial murmur should not be audible in any part of the column of blood and vessel wall connecting the lesion with the heart. Another explanation to hand, lies in the direct transit by vessels which make no turns and gradually increase in size from their termination to their origin in the heart. These conditions are present in the vessels of the lower extremity, while in the case of the upper, a fairly sharp bend is made as the vessels emerge from the thorax, and both in these and the vessels of the neck a very sharp contrast of calibre exists where they originate from the aorta. This difference in direct course and continuous gradual increase in size seems, therefore, a ready, if not an entirely convincing, solution of the question. In relation to the influence of direct proximity of the arterial lesion to the heart, it is

of interest to note that in the only case observed of wound of the internal mammary artery, a systolic murmur was loud beneath the third left costal cartilage, but no trace of it was to be detected in the heart.

The fact that the systolic murmur accompanying arterial injuries is transmitted in the opposite direction to the arterial blood-stream suggests that the vibrations may be mainly conducted by the arterial wall; and if this be the case, the influence of change of direction and sudden increase of calibre may be more readily intelligible. In the case of the arterio-venous bruits this question is not of equal importance, but transmission by the wall of the vein is still more easy to accept. The most probable explanation is that in either case the sounds are conducted by the venous current.

When arterio-venous communications are met with in the neck or axilla, the continuous murmur is commonly audible over the whole cardiac area, but the normal cardiac sounds can usually be heard quite distinct from the adventitious bruit. In these instances, however, the murmur may be continuously traced from the seat of the vascular lesion to the præcordial region, usually diminishing in strength as the heart is reached. This phenomenon therefore rather resembles that of the general conduction of the arterio-venous murmur to the mass of the tissues of the limbs, the advantage of the sounding-board provided by the chest wall facilitating the transit and intensifying the strength of the musical vibrations. When the arterio-venous lesion is more distantly placed, the difference between the very limited central conduction of the local systolic arterial murmur, and the long extent which intervenes between the cessation of this and its reappearance in an even intensified form in the heart, is very striking; the only explanation which comes ready to hand lies in the fact that in the vein the direction in which the sound is conducted corresponds to that of the blood-stream, while the arterial murmur requires to be transmitted in an opposed direction. This view gains support from the not infrequent observation that in arterio-venous communications situated in the neck or axilla, it is the venous roar alone that reaches the præcordial area, the systolic element being either masked by the valvular sounds, or being suppressed. Again, even in the case of arterio-venous communications in the lower extremity in which a double murmur is transmitted to the heart, the systolic element, often at first the more pronounced, fades more rapidly, and often becomes quite inaudible or disappears, while the venous roar persists.

Signs of Disordered Nerve Function accompany many arterial injuries, and should be mentioned here, although they are seldom of diagnostic significance in the early stages of the injuries. They acquire

their real importance as one of the consequences of arterial injuries, and will be dealt with at greater length in Chapter V.

There can be little doubt that these signs are for the most part a direct result of interference with the peripheral blood-supply, although in some of the recorded instances it is not possible altogether to exclude the implication of the peripheral nerves by the injury; but, as Captain Burrows has pointed out, cases do occur where the injuries to the vessels are of a partial nature, in which disturbances both of motor action and sensation appear to follow a purely vascular lesion.

Captain Burrows, in an interesting paper,* has drawn a definite distinction between the character of the signs which he considers are purely ischæmic in origin, and those which he suggests are 'reflex' in nature. In the former, anæsthesia of the glove or stocking type, subjective sensations, and muscular paralysis accompanied by a hard inelastic condition of the muscles on palpation, are met with, the abnormalities of sensation being confined to the portion of the limb distal to the injury. In the reflex type, widespread cutaneous anæsthesia, sometimes extending well above the level of the wound and corresponding with no definite nerve distribution, is combined with motor paralysis in which the muscles are soft and flaccid. For the reflex type he suggests the name 'angiotic paralysis.'

Leriche† attributes the signs of disturbance of nervous function accompanying vascular lesions to injury to the perivascular sympathetic nerves contained in the arterial sheath, and supports this view by a number of cases in which he has obtained improvement in the symptoms by performing at a later date what he terms perivascular sympathectomy, i.e., excision of a short portion of the sheath and contained nerves.

* *British Medical Journal*, 1918, i, Feb., p. 199.

† *Lyon Chirurgicale*, 1917, xiv. No. 4, July, p. 754.

*CHAPTER IV.***ARTERIAL HÆMATOMA AND TRAUMATIC FALSE ANEURYSM.**

APART from external hæmorrhage, the common sequence of a gunshot wound of a large artery is the development of an arterial hæmatoma, usually a large pulsating collection of blood lying at first diffused in the tissues, its line of extension being dependent on the anatomical arrangement of the part concerned. The most characteristic are those which develop in connection with comparatively superficial vessels such as the common femoral or the third part of the subclavian; in these the hæmatoma is commonly accompanied by widespread ecchymosis of the overlying integument. When the deeper vessels are wounded ecchymosis is rare, the soft fluctuating local swelling is replaced by a tense general swelling of the limb, and no definite limitation of the extent of the cavity can be at first determined.

The earliest secondary change consists in coagulation of the effused blood at the circumferential part of the cavity, which process tends to check primarily any further extension of the extravasation. As the process of coagulation proceeds, shrinkage of the resulting clot takes place, with the result of producing a definitely localized, pulsating swelling which may project boldly from the surface of the part of the body affected. The extent to which coagulation may proceed varies; in a minor proportion of the cases the central portion of the effusion remains fluid in direct continuity with the contents of the wounded artery, and the condition of arterial hæmatoma persists for some time. This class of case is that most liable to suffer from the effects of infection of the surrounding tissues, which may result in secondary extension into the tissues, or secondary hæmorrhage from the external wound. It is most frequently met with in situations such as Scarpa's triangle or the anterior triangle of the neck, in which the blood effusion is afforded but slight support by the surrounding structures.

In other instances, particularly in the case of vessels well supported by the surrounding structures, the entire effusion may become metamorphosed into a firm clot, and the primary systolic bruit produced by the wound in the artery may disappear completely. If a primary bruit disappears, we may assume a limited lateral wound

of the artery to be likely (*Fig. 21*). The further progress of such cases varies; a large hard clot is a primary cause of danger, since it tends to exert very firm pressure on the main and the collateral vessels, and hence gangrene of the peripheral part of the limb is apt to occur, especially if the femoral or the popliteal artery has been wounded.



Fig. 21.—Wound of the right common carotid artery. The interior of the vessel is occupied by a cylindrical clot starting from the wounded spot and extending peripherally. The contracted thrombus is not of sufficient calibre completely to obstruct the blood-stream. Without the vessel a solid mass of clot is attached to the wall. A condition of solidified hæmatoma exists which might be followed (*a*) by spontaneous healing of the wound of the wall of the artery, or (*b*) by the delayed development of a false aneurysm.

able, since the old irregular blood cavity is gone and is replaced by a distinctly new formation. In *Fig. 22, c* and *d* show examples of two such sacs, developed in connection with the posterior tibial artery; both were wiped out of the deep layers of the calf through

A more common result is the secondary development of a false aneurysmal cavity. The impact of the blood-stream opposite the defect in the arterial wall tends to hollow out a rounded space in the recently coagulated blood, or to regularize the form of any residual space remaining in the clot. The resulting cavity acquires a boundary formed by the deposition of well-marked layers of laminated clot, resembling that met with in typical spontaneous aneurysms. The sacs when small and recent are readily separable from the surrounding mass of conglomerate primary clot. At a later date the primary coagulum is completely absorbed, and then a typical false aneurysm remains. The wall of the provisional sac is thickest at the point most distal from the arterial wound, becoming gradually thinner as it approaches the opening in the artery, to the edges of which it is united by a comparatively tenuous layer. When laid open, the smooth, shining, inner surface of the sac suggests the presence of an endothelial lining, even at an early stage of development. When this stage has been reached the designation of arterial hæmatoma ceases to be applicable, and the term false aneurysm is prefer-

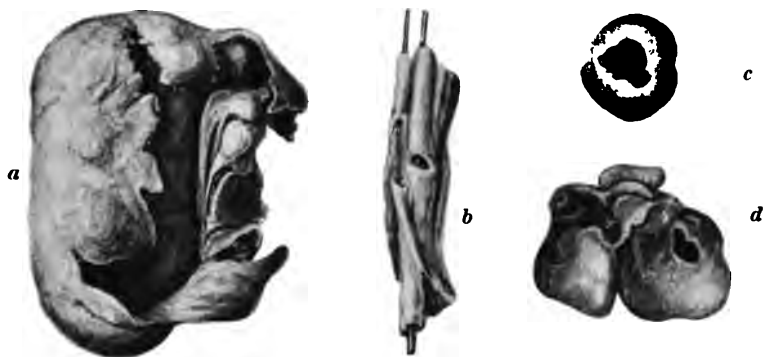


Fig. 22.—THREE SMALL FALSE ANEURYSMAL SACS DEVELOPED IN CONNECTION WITH WOUNDS OF THE POSTERIOR TIBIAL ARTERY IN THEIR EARLY STAGE.

The largest and most irregular (a) has beside it the artery (b) showing a small lateral wound and one of the venæ comites also wounded. The patient from whom it was removed had a compound fracture of the leg, the wound accompanying which was badly infected. Pulsation and a purely arterial bruit were not noted until the tenth day. On the fifteenth day secondary hæmorrhage occurred, and the limb was amputated. *Under the care of Lieut.-Colonel Butler.*

The smallest sac (c) is fairly symmetrically globular; the hole by which the wound in the artery communicated with it is well shown, also the tenuous nature of its margins. A magnified section of the wall of this sac is seen in Fig. 23. *Under the care of Captain Clementi Smith.*

The third sac (d) resembles the two others in character; the small hole communicating with the lumen of the artery is seen. The whole structure is somewhat tripartite in outline, but the two secondary masses contain only a small cavity, and consist mainly of solid clot. *Under the care of Captain W. G. Mumford.*

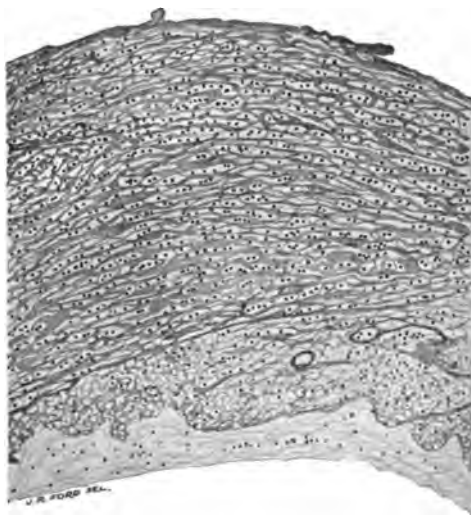


Fig. 23.—A SECTION OF THE WALL OF THE SMALL ANEURYSMAL SAC SHOWN IN Fig. 22 c, MAGNIFIED TO DEMONSTRATE ITS STRUCTURE ($\frac{1}{2}$ objective).

The wall is formed by interlaced concentric laminae of fibrin and, within the meshes of the network, blood-corpuscles. No fibrous tissue has yet been developed.

incisions made to evacuate large masses of clot with which their connection had been severed.

In the case of larger vessels, when hæmorrhage necessitates an early operation, similar cavities are found in the clot and in connection with the open wound in the artery; but the main wall of clot varies much in thickness and regularity, and the cavity may be still incomplete, the laminated portion of the clot endowed with a smooth surface being more dome-shaped in outline and extent, and hardly reaching the actual lips of the arterial wound.

I believe this process occurs whenever a false aneurysmal sac is eventually developed, since such cavities, whenever they have existed for a short period, are roughly or symmetrically spherical in form, while the original space occupied by the arterial hæmatoma is usually extremely irregular. The subclavian aneurysm depicted in *Fig. 47* is a good example, the original collection of blood having occupied the whole posterior triangle of the neck. Again, when the femoral artery is wounded by a bullet traversing Hunter's canal, the original blood effusion travels into the posterior compartment of the thigh through the opening made by the missile in the adductor muscles. Yet the cavity of a traumatic aneurysm developed in this position is in my experience practically invariably a rounded sac limited to the anterior aspect of the adductor muscles, and not an hour-glass sac extending from the front to the back of the limb. The great mass of primary blood-clot is in fact quite independent of the eventual cavity of the aneurysm.

When the aneurysmal sac has reached its full development, a strong fibrous wall is formed, from which the overlying structures may be readily stripped, the interior being usually strengthened by a variable thickness of blood-clot still not decolourized, although usually firm and tough in consistence. When the sac is opened in the course of operation, or after removal, this passive clot may occupy the half or more of the potential cavity; its presence is an indication of the continuing tendency to spontaneous cure, and its value as a buffer interposed between the full force of the blood-stream and the fibrous boundary of the cavity is considerable. The size of the opening connecting the lumen of the vessel with the interior of the sac obviously depends on the extent of the original injury, but it is remarkable in some instances how small this may be and yet allow the stoma to retain its patency.

One peculiarity in the structure of these sacs, dependent on their mode of causation, is of great practical importance. I refer to the fact that they may be in part formed from neighbouring structures. When these extraneous elements are derived from adjacent nerve trunks, the greatest care is necessary should the sac require to be

excised. A partly damaged nerve is often spread out widely in the wall of the aneurysm, and unless this is appreciated an important nerve may be needlessly sacrificed by the operation.

In some instances the original large common space occupied by the hæmatoma becomes loculated, and the circumferential part may become cut off. This was the case in the subclavian aneurysm depicted in *Fig. 47*, p. 182. The fluid contained in the superficial loculus in the posterior triangle had already become decolourized at the time of operation, and was quite independent of the deeper aneurysmal cavity beneath the remains of the scalenus anticus. In this case the loculus was a development of much importance, since the thinning of its walls, with the consequent apparent increase in size in the swelling to which pulsation continued to be communicated, was regarded as indicating the necessity for prompt operation.

This mode of spontaneous cure may be even more direct. Thus, in an officer under my care for an injury to the nerve trunks in the axilla accompanied by extinction of the radial pulse at the wrist, during an operation for the relief of the nerve lesions performed by Colonel Percy Sargent, a spherical sac containing two ounces of straw-coloured fluid was found attached to the proximal termination of the severed artery.

A somewhat special feature of false traumatic aneurysms following gunshot injuries of the arterics accompanying injuries to the bones, consists in the deposition of bone in the wall of the sac consequent on the diffusion of small fragments of bone and freed bone-cells in the track made by the missile. I saw one instance in the case of a femoral aneurysm operated upon by Major Littler Jones in France. A still more striking observation of a bony wall has been published by Major Lawford Knaggs,* in which the original walls of the aneurysmal sac were afforded by the upper part of the shaft of the humerus itself, the aneurysm later becoming diffused into the tissues in the neighbourhood of the shoulder. The specimen is included in the War Collection at the Royal College of Surgeons.

An account will be found on p. 116 of an arterio-venous aneurysm of the innominate vessels in which the sac was formed by an old tuberculous cavity situated in the apex of the right lung.

Behaviour of Surrounding Tissues. — It must not be assumed that the processes of diminution of size and solidification of the walls of the aneurysmal sac depend solely on the absorption and contraction of the primary clot, the hollowing out of the interior, and the deposition of fibrinous laminæ capable of later development into

* *British Journal of Surgery*, 1917, vol. v, No. 18, p. 243.

fibrous tissue. Nor do these things alone ensure the limitation and final solidity of the aneurysm. A not less important part is played by the surrounding tissues, which react in a remarkable manner to the stimulus afforded by the presence of the blood-clot in their midst. The connective tissue of the vascular cleft, the intermuscular spaces, and the muscles themselves, become infiltrated with serum and an abundance of leucocytes destined to take part in the subsequent absorption of the clot.

A considerable part of the mass of the tumour in the early stages consists of this surrounding infiltration, and the gradual disappearance of the latter and of the œdema accounts for much of the diminution of the apparent size of the tumour. It is this induration which affords support to the original blood-clot, and tends to prevent further extension of the aneurysm.

The occurrence of this change in the surrounding tissues is also an important element in influencing the surgical treatment of the aneurysm. Even the process of exposure and delimitation of the sac is rendered more difficult by the swollen, indurated condition of the connective tissue, and the separation and displacement of muscles is interfered with by the firm adhesion between them and their sheath. Still more difficult in the earlier stages is the freeing of the blood-vessels themselves, since they are embedded in a mass of tissue like firm bacon, from which they can only be cleared by the use of the knife. It is this infiltration which renders operations for the suture of the vessels so difficult and unsatisfactory at this period, because it interferes not only with the insertion of sutures, which readily cut out, but also renders it a troublesome task to free the vessels sufficiently to approximate the ends without tension, if any loss of substance has occurred.

Before passing on to a consideration of the signs and symptoms of traumatic aneurysm, the question of tardy development should receive some notice. It is a striking fact that in so many cases the existence of an aneurysm is not noted until days, weeks, or even months after the reception of the original injury. No doubt in many cases this is due to the small size of the sac, and to imperfect observation in consequence of the haste with which many patients with small wounds are necessarily evacuated. Giving due weight to this explanation, it is an undoubted fact that the development is sometimes a late one, and mention of the significance of incomplete lesions of the vessels in this relation has already been made in the section dealing with contusion of the vessels. Another explanation of the tardy development of the aneurysm, however, is undoubtedly to be found in the secondary giving way of an originally perforating lesion in which the process of spontaneous healing commences and eventually

fails. The most striking instances are afforded by the cases in which the original hæmatoma has been evacuated without the discovery of any bleeding point, and the wound has been allowed to heal. In connection with arteries, even of the magnitude of the external iliac, which were actually exposed during the process of clearing out the hæmatoma, a secondary aneurysm has been seen to develop several days later while the patient has remained under observation.

In the section on arterio-venous communications, an instance of early and apparently permanent disappearance of a continuous murmur will be found, no doubt due to early closure of an opening in the vessels; while reference to *Fig. 1* shows how nearly an opening in the arterial wall may reach complete closure and yet eventually give rise to secondary hæmorrhage, or under other conditions to a late aneurysm. *Fig. 21* also furnishes suggestive information. Here the wound is closed by an internal cylindrical clot not completely obstructing the lumen of the vessel, joined by a narrow band to a larger clot deposited in the tissues of the neck, both external and internal clot being most likely of a temporary nature. Another not uncommon occurrence is the complete extinction of local pulsation by pressure exerted on the main vessel owing to the rapid transformation of the effused blood into a firm coagulum. This pressure may suffice to prevent any passage of blood through the arterial wound, and thus lead to the extinction of the bruit, and may also obstruct the circulation to an extent involving loss of vitality of the limb (see *Fig. 26*, p. 72). Yet no sign of an aneurysm will be present, although such may readily appear at a later date when the absorption of the original blood-clot has allowed of sufficient dilatation of the lumen of the vessel for the restoration of the circulation.

Signs and Symptoms.—The cardinal local signs of an arterial hæmatoma or a false aneurysm—the presence of a localized pulsating swelling, the pulsation being capable of control by pressure exerted on the artery on the proximal side, need no further description; but a few additional remarks may be devoted to two points—the characteristic arterial bruit, and the effect on the general circulation. The presence of this bruit indicates an incomplete solution of continuity, that is to say a wound in the wall of the artery; it is in fact a sign of a wounded artery rather than of an aneurysm.

The systolic murmurs vary greatly in intensity, depth of tone, and musical character. As a rule, during the first few days they tend to be shrill and loud, and are audible along a considerable length of the vessel on the peripheral side of the wound. It is not common for the bruit to be conducted for any material distance centrally, and frequently it is scarcely audible a couple of inches above the situation of the wound. The character of the bruit depends on the force of

the circulation, and upon the size and shape of the opening in the vessel and the degree of irregularity of its margins. As the process of rounding off the ragged margins of the arterial wound progresses—a species of incomplete repair—the murmur tends to become softer and deeper in tone. The effect of diminution in size and increased regularity of surface of the blood cavity may also be a factor in the production of this change of character. It may be remarked that at the same period the heart's action is commencing to recover somewhat from the disturbance caused by the wound of the vessel and the resulting interference with the distal circulation, hence the pulse is less rapid and forcible. As already mentioned, complete coagulation of the effused blood of the hæmatoma may cause a temporary or permanent cessation of the murmur; in the latter case it may be assumed that a chance of closure of the arterial wound exists. In cases where hard clot forms early, the consequent pressure on the arterial wound may not only prevent the further escape of blood, but also the production of a bruit. In these a murmur may develop later; hence the importance of repeated examinations.

Reference to the fact that systolic arterial bruits may be transmitted to the apex of the heart and the base of the left ventricle has been made elsewhere (p. 48).

The importance of auscultation as a means of determining the existence of a patent opening in the wall of an artery cannot be too strongly urged, since it is the only method of forming a certain diagnosis in some cases, for instance in a swollen thigh or calf in which no pulsation is detectable. I do not believe that the fact that external pressure on the vessel may give rise to a less definite murmur in any way invalidates this statement, for the bruit produced by pressure is rare, and far less loud and definite in character.

Progress and Complications.—It may be broadly stated that the typical course of an arterial hæmatoma is one leading to contraction and localization, a definite false aneurysm being the commonest final result. In the most fortunate cases the aneurysm itself may consolidate spontaneously, and a cure by natural processes occur. Among the large arteries, this termination is most commonly met with in the lower few inches of the superficial femoral or in the upper third of the popliteal arteries.

Certain complications, however, occur with a considerable degree of frequency. The most common of these are indications of pressure by the effused blood and clot on neighbouring structures, the development of peripheral gangrene, the occurrence of secondary hæmorrhage, the detachment of emboli from the thrombus, and rarely, the sequence of inflammation from secondary infection. I propose to deal with these complications seriatim; but before proceeding to

their consideration it should be pointed out that they occur for the most part during the stage to which the term arterial hæmatoma is strictly appropriate; that is to say, prior to the definite formation of the smooth secondary rounded sac which has been already described. When this sac has once become complete and of moderate thickness, the condition is far better described by the term false or traumatic aneurysm, and the development of a definite fibrous-tissue wall may be confidently expected. In this stage complications are not to be greatly feared—apart from the obvious fact that the wall may be of insufficient strength to withstand the force of the circulation when active movements are resumed, and the aneurysm may consequently enlarge. For this reason it appears to be both proper and convenient to employ the terms exactly, and in relation to the stage of development which the condition has reached.

Pressure Symptoms.—The most common pressure symptom is peripheral œdema, sometimes increased in consequence of concomitant injury to the vein. Occasionally, thrombosis of the deep veins may give rise to a tense persistent swelling of the limb, but this is not common, and in many instances depends on infection travelling from the wound. Pain from pressure on neighbouring nerves is not an uncommon symptom, but it is rarely persistent, and diminishes *pari passu* with the localization and contraction of the hæmatoma or aneurysm. Pain coming on during the course of the case is usually a sign of extension of the aneurysm. It must be borne in mind also that the pain may depend on concomitant injury to a peripheral nerve.

The most serious effect of pressure is that dependent on obstruction of the blood-stream in the collateral branches of the artery, since this may lead to peripheral gangrene of the limb, not an uncommon occurrence in the lower extremity. This complication is more fully discussed in the sections dealing with special vessels.

Secondary hæmorrhage may occur at two periods, either in the first few days, or after the lapse of a week or ten days. The earlier variety is the less important. It frequently consists in little more than leakage from a small wound during the early progress of contraction of the cavity: a small quantity of blood, really a part of the original effusion, may escape, soil the dressing for two or three days, and then entirely cease. It is important to appreciate that such leakages are not an indication for urgent operative measures, and that they are not to be regarded in the same light as small repeated hæmorrhages from a septic wound.

The later secondary hæmorrhage is vastly more dangerous. It may show itself in two forms, either a rapid extension of the swelling in the limb, or as external hæmorrhage. It is rare for this form of

hæmorrhage to arise from septic infection of the aneurysm itself ; it rather appears to depend on a defective process of localization which allows some part of the limiting boundary of clot to give way, often as a result of infection of the surrounding tissues, or of a rise in the general blood-pressure accompanying increased activity, and perhaps of free movement of the limb on the part of the patient.

In some cases it appears to follow the giving way of the actual line of union of small aneurysmal sacs, such as are depicted in *Fig. 22*, from the original arterial wound, the margins of which have become thinned, smooth, and rounded in the process of repair. It may be repeated that the margins of the sac joining the circumference of the wound of the artery are the most tenuous part of the sac, while the dome opposite the opening, which bears the full force of the blood-stream, is the thickest. In the process of cicatrization of a wound of the intestine we know that the early connecting layer of lymph is strongest at the end of the third day, and that during the next four or five days, while the process of organization of the lymph into connective tissue is taking place, the union is perceptibly weaker and less able to bear strain. A similar weakening of the line of union between the margins of the sac and the arterial opening may be safely assumed to take place while the same process of conversion of lymph into connective tissue is progressing, and the ease with which sacs can be swept off the vessel confirms this assumption. This is the dangerous period, which should be regarded as demanding complete rest to the limb, the more so as it is obvious that the artery, even in its more fixed condition from surrounding infiltration of the vascular cleft, is yet a more freely movable structure than the sac when active muscular contractions occur.

Infection of the boundary of blood-clot itself is infrequent, and even an extensive cellulitis involving the whole limb may only attack the actual wall of the aneurysmal sac at a late date ; yet the track of the missile may be infected and remain unrepaired, and thus may not only weaken the support afforded to the clot by the surrounding tissues at a local spot, but also furnish a ready path for the escape of the blood.

Late secondary hæmorrhages are extremely dangerous to the vitality of the limb, whether they take the form of extensions from the blood cavity or of external bleeding, and may also cause grave risk to the patient's life.

When secondary hæmorrhage is internal and causes extension of a hæmatoma or traumatic aneurysm, its occurrence is usually accompanied by severe pain coming on suddenly and tending to augment, and on local examination the swelling will be found to have increased in size and to have altered in outline and extent. The accident is an indication for prompt surgical intervention.

The question of arterial thrombosis and *embolism* has been already dealt with under the heading of arterial contusion, and will be again referred to in the special sections.

Secondary Inflammation.—The rarity with which secondary inflammation occurs in traumatic aneurysm affords one of the most striking proofs of the enormous capability of the blood, even when extravasated, to withstand and overcome bacterial infection. Among the whole series of cases I met with personally, only two instances of death resulting from acute infection of the blood-clot occurred; in both the infection was anaërobic in nature. In one instance the blood-clot rapidly broke down into a brown fluid offering a strong resemblance to fæces, and the patient died from a sudden profuse secondary hæmorrhage. It occasionally happens also that a false aneurysm already localized becomes hot and reddened over the surface, and this must be regarded as an indication for active surgical treatment. In the only case I operated upon for this reason, the aneurysmal sac itself afforded no signs of inflammatory change, and primary union of the operation wound ensued.

On the other hand, many cases came under observation, especially in the thigh, where widespread infection of the surrounding tissue had led to suppuration requiring free incisions for its relief, in which an existing large aneurysmal sac remained unaffected. In one instance anaërobic infection led to destruction of practically the whole musculature of the thigh, and yet a very large aneurysmal sac failed to give way. It is clear that a strong distinction must be drawn between infection of the aneurysm itself and infection of the surrounding tissues.

The tendency to localization and slow spread of infection in large masses of blood-clot is well exemplified by the phenomena observed in wounds of the chest giving rise to a hæmothorax, particularly when the organisms are anaërobic. In many of these cases repeated exploratory punctures made at intervals, and in different spots, may be necessary before infection can be definitely proved (Elliott and Henry).

The risks of infection are greatest during the arterial hæmatoma stage, when the collection of blood is large and the boundary layer of clot thin. Under these conditions the effusion of blood may increase in amount, or external hæmorrhage may occur. Either of these accidents may necessitate immediate ligation of the artery, and the cases are of a very unsatisfactory nature, since they are not infrequently followed by further secondary hæmorrhage, often not from the point of the ligation placed upon the main trunk, but from wounded collateral branches exposed in the original wound cavity now become septic, which failed to bleed at the time of the operation.

Traumatic Aneurysms Developing in Amputation Stumps.—Although of a totally different nature, aneurysms developing above the site of the ligature placed upon the vessels in an amputation deserve mention in this place, since they are of not infrequent occurrence when the wound is infected. A similarity, moreover, exists between them and some of the aneurysms seen to develop tardily as a result of the secondary giving way of a partial lesion of an artery in a septic wound.

In the early stages of the present war the appearance of a cherry-red pulsating tumour at the site of the ligatured main vessel in an open amputation stump was a not uncommon experience, and afforded an indication for prompt surgical intervention which could not be disregarded. The condition was, in fact, the precursor of a secondary



Fig. 24.—Septic aneurysm of the femoral artery, which formed in the floor of an amputation wound. General dilatation of the softened coats of the artery will be observed above the point of ligature. Intramural extravasation of blood has occurred between the different layers of the arterial wall, and at the under surface complete disintegration and necrosis will be observed. The cavity of the sac has become shut off from the lumen of the artery, and is occupied by recent clot.

hæmorrhage in not a few cases. The type of aneurysm is so well known in civil practice, either in similar circumstances or when arising in connection with the arrest of a septic embolus in the artery, that it is unnecessary to devote further attention to it here. *Fig. 24* illustrates a good example, but in this case the sac was buried in the tissues of the partly-united flaps. The limb from which it was removed was re-amputated by Colonel Gordon Watson, to whom I am indebted for allowing me to have the drawing made.

ARTERIO-VEINUS HÆMATOMA AND ANEURYSM.

In the series of cases upon which this essay is founded, the arterio-venous aneurysms form the majority. In the earlier part of the war, while bullet wounds still formed a large proportion of all the injuries

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met with, the arterial hæmatoma was the more common; this depended on the more sharply defined nature of the wound caused by the bullet when travelling accurately. With the advent of a greater number of injuries caused by fragments of shells, arterio-venous lesions have increased in proportional frequency.

DISTRIBUTION AND NATURE OF 272 TRAUMATIC ANEURYSMS.

Artery	Cases	Arterial	Arterio-venous	Aneurysmal varix
Carotid ¹	57	10	29	18
Subclavian	24	13	11	—
Axillary	41	24	8	9
Brachial	22	17	1	4
Femoral	87	36	34	17
Popliteal	41	20	17	4
Totals ..	272	120	100	52

The aneurysmal sac in the mixed injury is to be regarded as purely arterial in nature, and is always directly connected with the wound in the artery. The vein plays but a secondary part, although, as a result of the local dilatation which always takes place, it furnishes a considerable proportion of the whole bulk of the tumour.

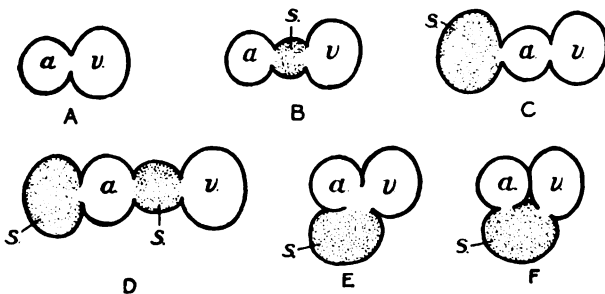


Fig. 25.—A, Simple aneurysmal varix. B, Arterio-venous aneurysm; sac interposed. C, Arterial aneurysm combined with aneurysmal varix. D, Arterial and arterio-venous sac. E, Arterio-venous sac with common opening of communication with artery and vein. F, Arterio-venous sac with separate openings of communication with artery and vein.

The diagrams (*Fig. 25*), representing transverse sections through the aneurysms, illustrate various ways in which the arterial sac may be arranged. A is a pure aneurysmal varix; in B the arterial sac is interposed between the artery and vein—in such cases the missile

has probably passed between the two vessels, and effected a lateral wound in the opposing side of either; in D an arterial sac has been formed in connection with the wound on either side of the artery, and thus a sac springs from the free side of the vessel as well as from that opposed to the vein. This arrangement is the result of the passage of a missile which has traversed both vessels, the wound on the free aspect of the vein having closed spontaneously. In C the sac springs from the free side of the artery, while a direct communication has been established between the artery and vein. This arrangement also results from a traversing injury, and we have the conditions of an arterial aneurysm and an aneurysmal varix combined. In E and F the missile has crossed the vessels either on the superficial or (more often) their deep aspect—in E a common opening of the two vessels communicates with a sac situated in the angle of union, in F the sac has a separate opening for each vessel. This form of sac I have seen both in the case of the carotid and of the femoral vessels lying on their deep aspect.

When the vein has suffered complete severance, the peripheral end may heal and close while the central end remains patent, and in these circumstances the stream of blood from the artery pours directly into the open end of the vein. In one case of carotid arterio-venous aneurysm of this nature upon which I operated, a piece of shell the size of the top of my forefinger was retained within the sac, and probably afforded an explanation of the arrangement. Reference to *Fig. 1*, p. 2, will show how such a condition might readily be established.

In the case of some vessels, e.g., carotid, subclavian, etc., the perforation may not only implicate the corresponding artery and vein, but also such structures as a nerve or muscle situated between them. Examples of the part which may be taken by the vagus will be found in the section devoted to carotid aneurysms, and the classical observation by Matas of a subclavian arterio-venous anastomosis in which the anterior scalene muscle took a part may be again alluded to.

Extended experience has made me doubtful whether an arterio-venous aneurysm ever develops as a result of complete severance of the two vessels. Such aneurysms have been described; but I think this was before common knowledge of the behaviour of a vessel which has suffered division of more than three-quarters of its circumference existed; also of the difficulty which may present itself of recognizing the remaining strand of the wall of the vessel, and of the thorough way in which such strands become incorporated as an integral portion of the wall of the sac of the aneurysm.

I have never seen an aneurysmal sac formed in communication

with an opening on the free side of the vein. In every instance of traversing perforation of the vessels which I have examined, the opening on the free side of the vein had cicatrized. If the mode of development of a traumatic false aneurysm already described be correct, it is very difficult to believe that a sac could be formed as a result of the pressure of a current of blood from the artery crossing the lumen of the vein. Other arguments bearing in the same direction may be cited, such as the constancy with which dilatation of the lumen of the vein is met with, and the well-known ease and regularity with which wounds of the veins undergo spontaneous closure.

I am also inclined to attribute the maintenance of the peripheral pulse after 'complete severance' of the vessels which has been described, to the persistence of a narrow strand of the arterial wall, which in some measure keeps the separated openings in the vessel in line, and aids in directing the current of blood. It appears evident that the very great majority, if not all, of arterio-venous aneurysms result from either lateral wounds, or traversing perforations of the vessels.

Some interesting clinical differences are observed between aneurysms of the arterio-venous and the purely arterial variety.

A striking feature is seen in the delay which often occurs before the true character of the lesion can be correctly determined. It is a remarkable fact that while the aneurysmal varix is usually an immediate development, it is sometimes days or even weeks before an arterio-venous aneurysm can be diagnosed with certainty.

Fig. 26 affords a good example of an instance in which delay occurred in the possibility of making a diagnosis. The conditions for the formation of an arterio-venous aneurysm are present and favourable, but sufficient time had not elapsed for the process to be completed, or even actually commenced. The blood in the primary hæmatoma, as is often the case, had coagulated into a large firm clot in which no cavity existed. The clot exercised pressure, not only on the main trunk, but also on the collateral branches of the wounded vessel, and gangrene of the leg resulted, necessitating an amputation.

A second cause for delay in the development of arterio-venous aneurysms is found in a temporary closure of the openings or opening in the vein by a thrombus. Occluding thrombi are naturally far more common in veins than in arteries, by reason of the lesser force of the venous circulation. It may also happen that the opening into the vein is occluded by a foreign body; thus, in one instance operation on an apparently pure arterial injury disclosed a wounded artery, with the piece of shrapnel case which had caused it filling and controlling the contiguous opening in the vein.

The clinical evidence in support of the comparatively late development of arterio-venous sacs is equally strong. The first indication of the possible formation of an aneurysm may be the presence of the characteristic systolic arterial bruit, a sign which can be detected prior to the appearance of either swelling or pulsation. In many cases the systolic bruit becomes softer as the margins of the opening



Fig. 26.—WOUNDED POPLITEAL ARTERY AND VEIN, FOLLOWED BY GANGRENE OF THE LEG.

The wound in the artery involves nearly half its calibre and gapes widely; the margins of the opening are comparatively smooth. The limb was amputated on the fifth day.

A characteristic traversing perforation of the vein is shown, the shape of the openings being irregularly circular.

The extravasated blood from these wounds had clotted firmly *en masse*; no murmur was audible in the swelling formed by the clot. Gangrene of the leg and foot was definite on the fourth day.

*Under the care of
Capt. West, I.M.S.*

in the arterial wall become smoother in the process of repair, and then is replaced by the characteristic continuous murmur of the arterio-venous communication, and a bubbling thrill becomes palpable. This sequence of events may occupy a few days, or sometimes as much as a couple of weeks, and may often be observed.

In arterio-venous aneurysms the tumour and extent of pulsation which may be present in no way indicate the size and extent of the

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actual sac, since both may be exaggerated by the existing dilatation of the vein. Lastly, the aneurysms do not tend to reach so large a size or acquire so firm a walled sac, neither are they so likely to give rise to trouble from secondary hæmorrhage or extension of the sac. The explanation of these peculiarities of the arterio-venous aneurysm is obvious: the presence of the open vein furnishes a species of safety-valve; hence the pressure exerted on the walls of the sac is less severe than is the case with pure arterial aneurysms. This fact is demonstrated clinically by the fact that a large proportion of the arterial variety need to be operated upon as an urgent measure, while a much larger number of the arterio-venous are able to be temporized with, and transferred safely to base hospitals for treatment in England or elsewhere.

COMPLICATIONS ATTENDING 87 FEMORAL ARTERIAL AND
ARTERIO-VEINUS ANEURYSMS RESPECTIVELY.

	Arterial	Arterio-venous	Aneurysmal varix
Secondary hæmorrhage	4	3	0
Extension	6	1	0
Pre-operative gangrene	3	4	0
Post-operative gangrene	2	2	0
Gas gangrene	2	1	0
Inflammation	2	0	0
Amputation	3	3	0
Death	6	5	0
Sent home without operation ..	8	15	17
Totals	36	34	17

Signs of Arterio-venous Aneurysm.—Special observation of a large number of cases has revealed some points of interest with regard to the character of the murmurs which accompany the condition. The fact that the systolic element of the bruit may be audible first has already been dwelt upon. It remains to say that the characters of this may vary considerably: it may be soft and musical, or harsh in sound. Sometimes it acquires a 'slamming' character, simulating in an exaggerated degree the so-called 'pistol shot' murmur heard in valvular disease over the aortic orifice of the heart. Such murmurs are associated with a highly excitable state of the general circulation and apparent cardiac dilatation, conditions which in some degree accompany every traumatic aneurysm in its earlier stages. The increased rapidity of the pulse tends to settle down, but does not

always subside at once even when the wound in the vessels has been dealt with by operation.

The loud systolic murmur is conducted widely peripherally, and to a much less extent centrally; but in exceptional cases it may be transmitted centrally even from the lower extremity to the heart. The diastolic roar is conducted in either direction, but, as might be expected, more freely in a central direction in the vein. It is always loudly audible in the opposite side of the neck in cervical aneurysms, and when the aneurysm is at the root of the neck, may be audible over the whole cardiac area, quite separately from the normal valvular sounds of the heart itself.

In some instances the murmur may be conducted by the whole mass of the tissues of the limb, and be audible wherever the stethoscope is placed upon the surface; occasionally the sound may be heard even when the ear is in neither direct nor indirect contact with the limb. These phenomena are more common in the lower limb, and in the early or arterial hæmatoma stage when a large collection of effused blood is present.

As a rule, the murmur is only conducted along the actual line of the peripheral vessels; and the presence of the bruit, either at the wrist or the ankle, is a valuable indication of the persistence of a column of blood in the vessels when the amount is of insufficient volume and force to be palpable as a pulse.

The height of pitch of the murmur is a valuable guide to the exact site of the arterio-venous communication. It is highest and loudest immediately over this spot, the tones gradually softening and deepening in either the upward or downward direction as the stethoscope is moved along the lengthening column of blood in the course of the vessels.

Bubbling Thrill.—What has been said regarding the tardy development of the arterio-venous murmur holds equally good for that of the thrill. It may not, as is usually the case with aneurysmal varices, be palpable in the earliest stage, while it tends to become stronger and more readily palpable during the first few days. Thus, while it may be of the feeble 'faradic-current' type when first detected, with the reappearance or strengthening of the peripheral pulse it may become strong and easily felt.

The thrill is often widely diffused, and is not a valuable localizing sign of the exact position of the opening of communication. In this respect the loudness and height of pitch of the murmur is more reliable. In many cases the communication of the thrill consequent on a wound of a branch of the main vein may give rise to a quite erroneous diagnosis if depended upon alone. This is a marked feature in wounds of the circumflex vessels of the thigh—in these the thrill

is often strong and most easily detected in the femoral vein ; and the same feature is not uncommon in connection with wounds of the branches joining the internal jugular vein in the neck.

When the aneurysms are of long standing there is no doubt that the vessels, both artery and vein, tend to enlarge and become thickened on the proximal side of the obstruction, while varicosity of the veins and swelling of the peripheral part of the limb develop. These sequelæ are common in the lower extremity, far less so in the upper. In either situation a previous disposition to enlargement or varicosity of the veins may influence adversely the degree to which these troubles attain. In the earlier stages, and especially while the patient is still confined to his bed, little evidence of venous obstruction is present beyond some general swelling of the limb. The swelling may be more marked if progressing thrombosis occurs, but this accident is uncommon unless it starts in connection with septic infection of the main wound of the soft parts.

There is no essential difference of nature between the sacs and those of purely arterial origin, and they are liable to the same process of gradual contraction and regularization ; but progress to spontaneous consolidation and cure is rarely or never seen. Resumption of active life on the part of the patient is therefore liable to be followed by increase in size of the sac, and the development of venous obstruction, or other pressure symptoms.

The sacs are liable to the same early complications as the arterial variety, but, as has been already explained, these are of less frequent occurrence.

ANEURYSMAL VARIX.

The immediate establishment of a direct lateral anastomosis between a contiguous artery and vein is the most remarkable of any results of gunshot injury to the vessels. Its occurrence is in great part dependent on two points in the anatomical arrangement of the two vessels implicated, viz., contiguity and parallelism of course ; and the most typical examples are seen when the missile passes between the artery and vein, causing a lateral wound in both. *Fig. 27* depicts an aneurysmal varix of this class ; it will be seen that a transverse slit wound has been caused in the artery, and a roughly stellate one in the vein. Examination of the carotid sheath and vascular cleft showed that no gross bleeding had taken place into the tissues, and that direct primary adhesion between the two vessels had resulted. A better anastomosis could not have been established by the most skilful surgical operation. A similar observation was made in a case of femoral varix included in Surgeon-General Stevenson's Report on the surgical cases noted in the South African War, and the

frequency with which such primary adhesion takes place without the occurrence of hæmorrhage is now common knowledge.

Fig. 28, built up from a series of sections of the point of junction of the vessels in a femoral aneurysmal varix of ten days' standing, for which I am indebted to the aid of Captain Bashford, furnishes

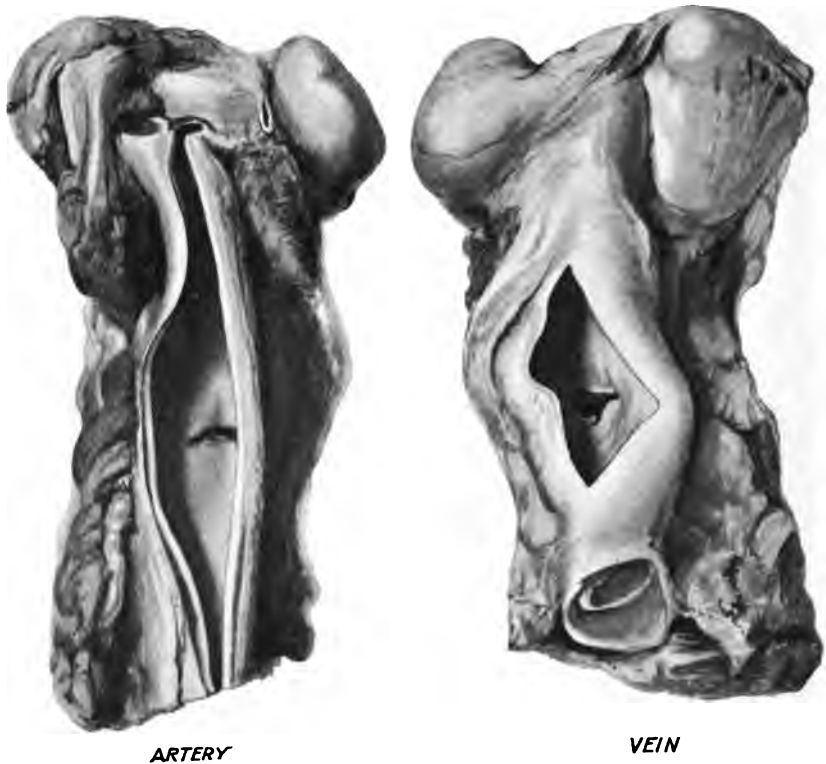


Fig. 27.—ANEURYSMAL VARIX OF THE LEFT COMMON CAROTID ARTERY AND INTERNAL JUGULAR VEIN.

A simple transverse lateral slit is seen from the interior of the artery, and a roughly stellate opening from the interior of the vein. No blood had been extravasated into the vascular cleft, and adhesion between the two vessels was immediate and complete.

The typical signs of a carotid aneurysmal varix were present. The patient died on the seventh day from concurrent injuries to the head. *Under the care of Major Parsons.*

the finer details of the mode of union. The illustration shows that the actual bond of union consists in part of displaced fragments of tissue originating from the various elements of the walls of the vessels, in part of organizing blood-clot. The significance of the small tongue of arterial adventitia projecting into the blood-stream has been alluded

to in connection with the factors involved in determining the character of individual local vascular murmurs. At a later date of cicatrization much of the irregularity of surface depicted would have disappeared.

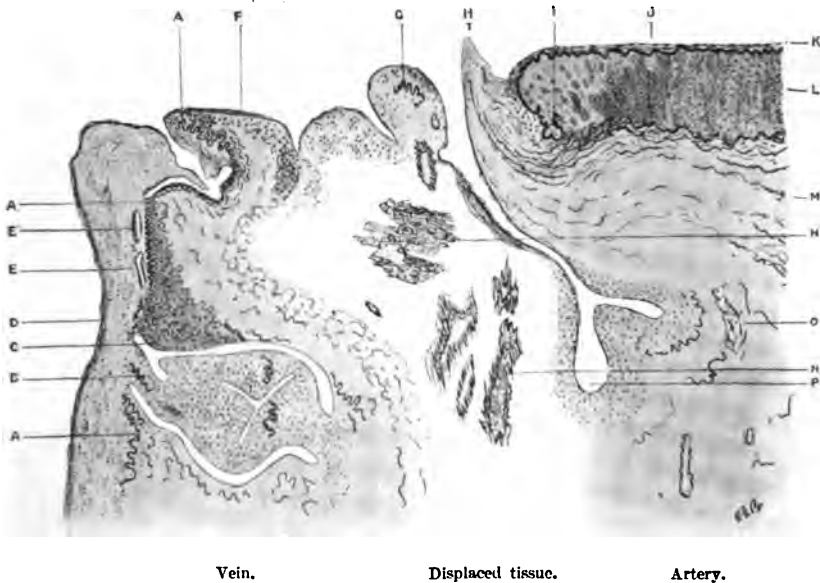


Fig. 28.—ANEURYSMAL VARIX OF FEMORAL ARTERY AND VEIN.

Semi-diagrammatic view of the angle of junction of the artery and vein. Union has been effected by means of an intervening portion of displaced tissue derived from the adventitia and muscular coats of the artery, and it contains also a portion of the internal elastic lamina. The displaced tissue is united to the wall of the artery partly by continuity and partly by blood-clot, but to the wall of the vein by blood-clot only.
Captain Bashford.

A. Internal elastic lamina of vein. B. Deep clot in rent in vein continuous with the wound and containing portions of internal elastic lamina. C. Disorganized muscular coat of vein. D. Endothelium covering organized clot adherent to vein wall. E. Spaces lined by endothelium at original level of endothelium of vein. F. Everted wall of vein, muscular coat and adventitia covered with organized clot and lined with endothelium. G. Displaced internal elastic lamina, probably of the artery. H. Everted external elastic lamina and adventitia of artery; this projecting point is the only surface not covered by endothelium; this fact, and the fibrin clot and leucocytes situated between it and the artery, suggest that it may have vibrated in the bloodstream. I. Retracted internal elastic lamina of artery. J. Proliferated endothelium of artery, the proliferation being slight compared with that of the vein. K. Increased thickness of sub-endothelial tissue. L. Muscular coat, disorganized clot only at site of injury and becoming normal at extreme right. The muscle fibres throughout appear somewhat swollen, and there is everywhere a slight infiltration of red blood-corpuscles. M. Adventitia of artery. N. Displaced portions of muscular coat of artery. O. Displaced portions of small nerve. P. Part of the track of the missile, lined throughout by endothelium lying either on blood-clot, or directly on the walls of the vessel. In the mid-point of the left-hand side of the track, much proliferation of endothelium.

We are well aware, moreover, that the general tendency is for these openings to contract in size, and even to close spontaneously. I have

observed this latter result in its various stages in two instances of carotid arterio-venous aneurysm, in which primary consolidation of the sac was induced by proximal ligation of the common carotid artery. In both these cases the venous roar was reduced or disappeared after the operation, only to return to its original strength in a few days. In both it subsequently gradually decreased in strength, and after intervals of fifteen and twenty months respectively, finally disappeared. One of the patients served actively during the first two years of the present war, fourteen years after the date of his operation. I have also had the opportunity of observing continuously the slow contraction and eventual complete closure of an arterio-venous communication between the innominate artery and vein, the process extending over a period of five years.* A similar result, with pathological details from the specimen obtained after death, has been recorded by Sir W. Osler† in a case of axillary varix (*Fig. 29*).

Experimental arterio-venous anastomoses established in animals have also demonstrated the tendency for spontaneous closure to follow, and this tendency has been further illustrated by the experience gained in the treatment of senile gangrene by establishing communications between the arteries and veins.

The direct nature of the adhesion between the vessels sufficiently explains the fact that the signs of an aneurysmal varix are developed immediately after the reception of the injury in the great majority of instances. The only secondary change which develops in these circumstances is a dilatation of the lumen of the vein, with thickening of its wall. The dilatation may be sufficient to create suspicion as to the presence of an aneurysmal sac, the more so as the arterial pulsation is communicated to the enlarged vein. Aneurysmal varices sometimes follow wounds in which such accurate primary adaptation of the two vessels is impossible; in such instances the development of thrill and murmur may be a later event. In these circumstances it must be supposed either that the union and cicatrization has been effected under a larger mass of blood-clot, such as has been described as present at a certain stage in the development of the traumatic aneurysms, but in which no secondary cavity has been formed; or that a temporary venous thrombosis occurred. A case of injury to the innominate vessels, in which a thrill and double murmur developed at a late period, is quoted on p. 117. Here no evidence of an aneurysmal sac could be detected, but as the lesion was within the chest, one cannot be certain on this point.

* *Journal of the Royal Army Medical Corps*, 1905, vol. iv, June, p. 746.

† *Lancet*, 1913, vol. ii, p. 1248.

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An extended experience of cases of aneurysmal varix has led me to doubt, however, whether this condition often develops primarily except in instances in which the vessels are wounded by a missile which passes between the artery and the vein implicated, or in those instances of perforation of both vessels from side to side in which



Fig. 29.—S.A.M., Scalenus anticus muscle. A.A., Axillary artery. T.A.A., Thoracico-acromial artery. C.V., Cephalic vein. A.V., Axillary vein. I.M.A., Internal mammary artery. B.P., Brachial plexus. *Sir W. Osler.*

the two outer openings cicatrize while those in the contiguous sides of the vessels adhere.

The two examples of the conversion of arterio-venous aneurysms into pure varices as a result of ligature of the artery alluded to above, make it reasonable to suppose that spontaneous consolidation of an aneurysmal sac would also be followed by a like result.

A case such as that depicted in *Fig. 30* offered a considerable field for speculation; here no aneurysmal sac had developed at the end of the eighth day, neither was there any collection of blood



Fig. 30.—WOUNDS OF THE LEFT COMMON CAROTID ARTERY AND INTERNAL JUGULAR VEIN. *Twice the natural size.*

A traversing perforation of the vein is seen, with fairly symmetrical openings, and a lateral transverse wound of the artery. Between the vessels the left vagus is shown, greatly enlarged by the extravasation of blood into its sheath.

The signs were those of a typical carotid aneurysmal varix; no symptoms attributable to the vagal injury were noted beyond hoarseness of voice from abductor paralysis. The patient died from secondary hæmorrhage. *Under the charge of Captain Oliver.*

in connection with the wounds in the vessels except that enclosed in the sheath of the left vagus. The track leading from the arterial wound into the larynx had remained narrow—so narrow, in fact, that

it was only discovered by a very careful search when the specimen was dissected. It is possible that a permanent indirect aneurysmal varix might have been developed here; or an arterio-venous aneurysm, the sac of which occupied the distended sheath of the vagus, might have formed between the vessels; or again, a sac might have developed between the wound of the artery and the larynx. In fact, instances of both the latter possibilities are included in the section devoted to injuries of the carotid arteries. A case has also been recorded by Matas* in which the communication between the subclavian artery and vein was established through the anterior scalene muscle.

The presence of an aneurysmal varix may be accompanied by no further physical signs than the arterio-venous murmur and bubbling thrill. What has been said regarding these signs under the description of arterio-venous aneurysm applies equally well to aneurysmal varix. Besides these phenomena, some swelling usually exists, due to dilatation of the vein in the vicinity of the communication. When this dilatation is considerable, communicated pulsation from the artery may raise the question of the existence of an aneurysmal sac. The dilatation of the vein may persist in cases in which the arterio-venous aperture closes spontaneously. This was so in Sir W. Osler's case illustrated in *Fig. 29*, and the remaining varicose dilatation might be regarded as an illustration of a venous aneurysmal sac.

In the early stages some general swelling of the limb may be met with, due to the disturbance of the normal venous circulation. In the upper extremity this swelling is often temporary, but in the lower limb it often persists, and at a later date the superficial veins may become dilated and thickened, and develop varicosities. A sense of weight in the limb, or more rarely actual pain, may call for operation; but the condition is not usually sufficiently serious to make such a procedure necessary.

Clinical evidence is not wanting of early spontaneous closure of arterio-venous communications. Thus, in a man with a traversing bullet wound of the right thigh, ten days after the injury a local arterio-venous murmur was present in Scarpa's triangle, and a loud similar murmur was audible over the base of the heart. A fortnight later, both the local and the cardiac murmurs had completely disappeared, and no sign suggestive of any vascular injury remained.

* *Transactions of the American Surgical Association*, 1901, xix, 237.

TREATMENT OF TRAUMATIC ANEURYSMS.

The lines which govern the treatment of any of the forms of traumatic aneurysm are influenced, and should be actually determined, by the period which has elapsed since the initial injury was received, and the stage of development which has been reached.

Arterial Hæmatoma.—If immediate treatment has not been undertaken, either as a result of unsatisfactory conditions for operation, or because the hæmatoma has developed gradually, certain definite considerations should govern the attitude of the surgeon.

Speaking generally, if the hæmatoma is of some three days' or more duration, an expectant attitude is advisable, except in the presence of the following conditions :

(1) Increasing extension of the hæmatoma ; (2) Continuing hæmorrhage, or even continuous leakage of blood from the external wound ; (3) Obliteration of the distal pulse as a result of increasing pressure exerted by the collection of fluid blood or firm clot ; (4) Symptoms due to pressure on neighbouring organs or structures ; (5) Signs of extending infection of the structures bounding the collection of blood, in which case prompt ligature and division of the wounded artery to allow of its retraction are highly necessary.

Should none of these conditions exist, an expectant attitude is advisable for several reasons.

1. The most serious contra-indication to intervention at this stage is found in the recent occurrence of free hæmorrhage. This prelude may involve loss of life to the patient as well as increased risk to the local vitality of the parts supplied by the injured vessel. The manner in which death is apt to follow operations undertaken after a severe primary hæmorrhage is very characteristic. The operation may appear to have been borne well, and when the patient is removed from the table the surgeon may see no reason to feel undue anxiety as to the further course of the case. Yet, when the man is placed in bed, he fails to recover from the anæsthetic, and quietly sleeps himself away to death within a few hours. The danger to the local vitality of the parts supplied by the occluded vessel is also great. I believe it is the previous occurrence of excessive hæmorrhage which is in great part responsible for the frequency of cerebral symptoms after primary ligature of the common carotid artery, as also for many cases of gangrene of the toes, foot, or leg, after ligature of the femoral, or the more striking loss of fingers, hand, or even forearm, after primary ligature of the brachial artery, which have all been observed to occur. The total volume of blood in the body has, in fact, been reduced to a degree which renders it impossible for a sufficient collateral circulation to be established to

maintain the vitality of the parts beyond the point of occlusion of the main vessel.

The lessons to be learned from these facts are, to avoid operation if practicable, on patients who have suffered a recent hæmorrhage; to employ local anæsthesia if possible; and to make the most strenuous effort to restrict any hæmorrhage incident to the operation to a minimal amount.

2. The operation may be one of considerable magnitude, involving extensive exposure of the tissues at an unfavourable moment. If a short period be allowed to elapse, the following advantages may be gained: the general condition improves, cardiac excitement dependent on the injury subsides, loss of blood is to some extent made up for, compensatory changes go on in the collateral circulation; and further, better local conditions for the operation are obtained. The cavity and the contained clot contract, and thus the extent of the field of operation is reduced; œdema subsides, not only in the part of the body implicated but also in the vascular cleft and the walls of the vessels themselves, and the tissues generally become more pliable and suited to the necessary manipulation. Thus, the blood-clot has become more or less consolidated into a well-limited mass, and hence is more readily removed; the vessels themselves have become more mobile, so that if suture is undertaken, not only is less tension needed to bring the gap together, but the tendency for the stitches to cut out is also reduced. Loss of time is of course entailed, but this is not as a rule accompanied by any lowering of the general nutrition of the parts concerned. It is indeed remarkable how very little a limb may suffer in the continued presence of the hæmatoma; while occlusion of the main vessel at this stage is often followed by a shrinking of the limb which may reach a very serious degree.

Remote Operations.—When neither primary nor early measures for dealing with the vascular injury have been taken, there is little doubt that the local conditions as a rule steadily improve for ultimate surgical intervention provided the patient be kept at rest. The tissues surrounding the aneurysm regain a more normal condition, the only remaining troublesome sequela of the injury being found in a variable amount of cicatricial tissue in the line of the original track of the missile, and spreading along the vascular cleft to an extent corresponding with that of the blood which infiltrated the perivascular connective tissue in the primary stage.

The cicatrix of the wound track ties down and immobilizes the vessel at the point of original injury, and renders it necessary to free this by dissection with the knife, while the extension along the vascular cleft necessitates a like procedure in order to mobilize the artery sufficiently if suture is contemplated; or to separate and free the

accompanying vein, or nerves which may have acquired an intimate adherence, if either a provisional or permanent ligature needs to be applied.

Unless evidence is present that steady progress towards spontaneous cure is taking place, all arterial or arterio-venous aneurysms should be subjected to operation, and the procedures which are applicable may be shortly summarized as follows.

Arterial False Aneurysm.—

1. Ligature of the artery above and below the sac, and in as close proximity to the latter as practicable. It is not advisable to limit the occlusion of the trunk to the proximal side alone, for although this procedure generally suffices to procure solidification of the sac, a risk of the detachment of emboli from the interior of the sac exists, and I have seen this sequence with unfortunate results. Application of a distal ligature necessitates only a little more free dissection, and should be laid down as the rule, unless exceptional difficulties should render its adoption inadvisable.

2. The sac may be excised after the application of a proximal and distal ligature. In dealing with the false aneurysmal sacs following gunshot injury, precaution is highly necessary in order to ensure that a neighbouring nerve is not a constituent of the actual wall. It is not at all an uncommon thing to find a more or less injured nerve trunk spread out widely on the surface, or even buried in the wall, of the aneurysm.

3. The cavity of the sac may be obliterated by plication of its walls. This method, although simple and easy of application, has some disadvantages. It increases the risk of immediate thrombus formation in the artery, and it may be followed by recurrence as a result of opening out of the folds.

4. The sac may be dissected away from the artery, and the opening in the vessel wall closed by suture. This is the ideal method if the defect in the wall of the vessel is moderate in extent. When the defect is large, if the aneurysm be one of some standing so that no doubt can exist as to the strength of the adhesion between the opening in the artery and the margins of the sac, the method may be modified by removing the main part of the sac but preserving enough of its base to unite and close over the opening in the vessel. This modification has obvious technical advantages, both in facilitating introduction of the stitches and in avoiding narrowing of the lumen of the vessel. As far as my experience goes it is, however, much less satisfactory than union of the actual margins of the artery, and is more liable to be followed by ultimate thrombosis. This probably depends upon the absence of a proper endothelial lining, which renders the line of union a more likely starting-point for clotting. In one case

in which I adopted it, the axillary artery thrombosed and complete local obstruction took place before the main wound was closed.

Arterio-venous Aneurysm.—

1. Ligature of both artery and vein on the proximal and distal sides of the sac. This method may be employed when difficulty is likely to attend removal of the sac. If it be chosen, great care must be exercised to ensure that the excluded sac be not further supplied by a branch of the artery. The existence of such branches is common, and, as we know, may have determined the actual location of the injury or prevented the escape of the vessel from injury by checking possibility of displacement.

Many failures after this operation are to be attributed to the fact that such branches have escaped detection at the time of operation, and although the reduction of the supply has been at first sufficient to abolish any pulsation or murmur, both may reappear and gradually increase at a later period.

2. The addition of excision of the sac to the above procedure adds little to its difficulty or gravity, and is preferable as eliminating all chance of recurrence.

3. Mobilization of the vessels, removal of the sac, and repair of the defect in the walls of the artery and vein by suture. This operation is preceded by the application of four provisional ligatures to control the circulation during the process of suture and removal of the sac. If a direct opening exists between the artery and vein, the latter should be opened up freely; the communication is thus exposed, and may often be stitched up without any further preparation. If the sac be situated between the vessels, it should be opened first, and the communication can be stitched from this aspect. If the aneurysm be on the free aspect of the artery, the sac is removed and the opening in the vessels sewn up.

A word of caution should be added as to the free utilization of flaps obtained from the wall of an established aneurysmal sac, to make up for extensive loss of substance of the arterial wall. Arteries reconstructed in this manner are liable to subsequent dilatation, and it must be remembered that the conversion of an arterio-venous into an arterial aneurysm is not prognostically desirable.

Aneurysmal Varix. — The indications for operation for this condition are less precise than in the case of the aneurysms. There is no doubt that many aneurysmal varices, especially in the upper extremity, do not call for operation, and may be left untouched without risk to the patient. Either pain, increasing local distention of the vein, or signs of increasing and troublesome obstruction to the peripheral venous circulation, may render operation advisable or necessary.

The vessels may then be ligatured above and below the level of the communication, and the varix excised. A far preferable method is to close the communicating opening by suture, as has been already described under the heading of arterio-venous aneurysm. In pure aneurysmal varices the almost invariable route to the anastomotic opening should be through the vein; if this procedure be adopted, the closure of the opening into the artery is easy, and that of the incision made into the vein simple in the extreme.

When a short channel connects the two vessels, this may be occluded by the simple method of applying a ligature around it. Several cases have been reported in which this plan has been successfully adopted.

*CHAPTER V.***THE IMMEDIATE AND REMOTE EFFECTS
OF OCCLUSION OF THE MAIN BLOOD-VESSELS ON THE
VITALITY OF PARTS SUPPLIED.**

COMPLETE occlusion of the arteries may be a result of thrombosis following contusion, with a varying degree of disintegration of the walls of the vessels; of thrombosis secondary to a wound; or of obliteration of the lumen by a ligature applied by the surgeon. Whatever be the actual cause of interruption of the main current, some disturbance of the normal process of nutrition of the parts situated in the area of peripheral distribution of the occluded vessel is inevitable, and to some extent must be permanent in its effects. Great variation in degree is met with in this respect. It will be convenient first to consider the immediate and minor effects, and then trace the gradation of events from temporary and practically negligible phenomena upwards, to the occurrence of actual necrosis of the tissues implicated.

The first obvious effects of obstruction to the normal blood-flow are seen in local pallor, or, if both artery and vein be implicated, cyanosis; a fall in the local temperature; and lessened functional capacity—the latter manifested in lowering of the common sensation, the incidence of subjective sensations, and loss of muscular power progressing to paresis or actual paralysis. These signs may be fugitive, or at most persisting for hours or days; in other instances they may be present for weeks or months, or they may become permanent.

Associated lesions of the peripheral nerves are common in connection with vascular injuries, in which circumstances all the symptoms are more pronounced in character. The frequency with which this association is met has in fact led the pure effects of anæmia to be less fully appreciated than they deserved prior to the work of H. Meige and Athanassio-Bénisty. Cases in which the effects of occlusion of the main vessel of a limb had been compared with the condition termed muscular ischæmia or von Volkmann's contracture, and also those in which gangrene of a limb followed a slight injury after occlusion of the main arterial trunk, had been reported; and the question of the effect of "a nervous element of unknown quantity,

the effect of the form of injury on the vasomotor nerves accompanying the great vessels, had been taken into consideration."* Until this war, however, little opportunity had existed for the observation of a large number of cases.

In published reports of operations for either recent wounds or for traumatic aneurysms by ligature of the vessels, it is common to meet with the broad statement, "The condition of the limb was excellent." These reports are indeed well enough founded; the functional capacity of the limb suffices for all ordinary efforts, the skin and nails are normal in appearance, a peripheral pulse may have re-developed, and when the patient's limb is exposed for inspection it may appear normal in all respects. Even in these instances, however, measurement of the limb will show it to have lost in volume, if an artery in the upper segment has been occluded. Comparison with the uninjured limb will show it to have suffered a permanent decrease in circumference of from half an inch to an inch, this decrease being most marked in the forearm and leg respectively.

It is rare to meet with a re-developed distal pulse which approaches the normal in strength and volume. Palpation usually reveals one of greatly diminished volume. It would be unreasonable to expect that the main vessel can ever regain its normal calibre when the circulation is mainly collateral in character; but in examining a considerable number of cases at an interval of two or three weeks after a vessel has been ligatured, I have been struck with the late period at which an appreciable pulse appears. In the case of the brachial artery, three or four days usually suffice for the reappearance of a palpable radial pulse, but this is then usually weak and very inconstant in strength. In the lower extremity the reappearance of the posterior tibial pulse after ligature of the femoral artery is a much later occurrence, two weeks being a rare and early date; it is often impalpable for weeks or months.

Estimation of the peripheral blood-pressure will also show this to be lower than that of the sound limb in the majority of cases, a decrease of 10 to 20 mm. of mercury being common.

Loss of volume in a limb may certainly be ascribed to the uncomplicated effect of a decreased blood-supply which is permanent. It is the development of these persistent changes that has afforded the strongest argument for attempting to repair the blood-vessels by plastic measures, rather than to effect permanent occlusion.

In cases which progress favourably after ligation of a trunk

* G. H. MAKINS, *Bradshaw Lecture*, 1914, p. 49; *Surgical Experiences in South Africa*, 1st ed., 1901, p. 152.

vessel, the immediate changes noted above are followed by some phenomena of a more lasting character. These consist in an increase in firmness of consistence of the muscles of the area implicated, with a varying degree of limitation of freedom and activity of movement. This change depends in part on the exudation of fluid within the muscle sheath, and in part in a change in the muscle itself which has been described as resembling an early stage of rigor mortis.

Clinically this condition is of interest, in that it tends to convey a false impression of the actual condition when the limb is inspected. The slight swelling, together with accurate retention of the normal outline of the limb, suggest in fact the absence of any morbid change, until comparison with the uninjured limb reveals in the latter the flabby condition which commonly follows disuse for a short period.

Together with these changes in the muscles, a certain degree of loss of freedom of movement of the joints also develops, in part due to peri-articular œdema and infiltration; in part to the joint having been kept at complete rest. Massage, electrical treatment, and careful exercises, however, will overcome any disability in such instances, and the typical 'good result' will be attained.

In less favourable cases, rapid wasting of the limb follows occlusion of its main artery. This event is most striking in the case of the common femoral and axillary trunks, and is seen in its extreme degree in patients who may require to be operated upon while suffering from general systemic infection. In my own experience this rapid wasting is seen only after operations performed at an early date, when the patients are suffering from great decrease in general volume of blood, or from wound infection; I have never seen it occur as a consequence of a remote operation, and it is certainly never induced by the presence of an aneurysm. In estimating the amount of wasting in such cases, it must be remembered that the mere absolute disuse of the limb plays a not unimportant part, and in the case of the lower extremities the uninjured limb will also be found to have lost considerably in volume as a result of confinement in the recumbent position. In many cases the early stages of change in the musculature of the limb may be masked by general œdema similar to that which follows the too tight application of a bandage to a fracture. In a certain proportion of the cases, early wasting of the muscles may be followed by the development of the rigid inelastic condition characteristic of Volkmann's contracture, with deformity of the joints and more or less complete loss of function of the limb.

In the most unfavourable class of case, short of early massive gangrene of the limb, the sudden local anæmia consequent on ligation of the vessel is followed by more rapid destructive changes in the

muscles. An excellent description of these is given by Captains Harold Burrows and A. W. Stott.*

“The limb was amputated on the fourteenth day after ligation of the popliteal artery. No concurrent nerve lesion was present. The limb was swollen and hard, the tips of the toes and a patch of skin upon the dorsum of the foot were gangrenous, otherwise the foot was warm. There was no loss of sensation except in the limited gangrenous area, but there was absolute paralysis of all the muscles below the knee, except for very slight movement which could be made by the gastrocnemius and soleus.

“After amputation, examination showed a striking alteration in the colour of all the muscles; this was pale, and scarcely a tinge of red existed except in the distal portions. The gastrocnemius was affected in its lower two-thirds, the soleus in its lower third only. The upper portions of these muscles were of normal colour and looked healthy. Transition from the healthy tissue above to the altered tissue below was gradual, and in an intermediate zone a streaky appearance was displayed, bundles of red fibres being interspersed amongst the pale ones.” Captain Stott made histological specimens from the muscles, and reported as follows: “Portions of the peronei and the gastrocnemius muscles were cut; each showed gross pathological changes. No normal muscle fibres were seen. In sections stained with hæmalum and eosin, the general impression given was that of an anæmic infarct. The muscle fibres and interstitial tissue stained a uniform pink. The fibres showed various stages of degeneration; some presented almost normal striation but no nuclei, others had completely lost all striation and appeared as granular masses. Fibres exhibiting different degrees of change were often found next each other. The majority of the fibres appeared swollen, some were broken up into irregular masses, others were split into longitudinal fibrillæ or transverse discs. There was no hyaline degeneration, and no gross fatty change was seen. The interstitial tissue appeared œdematous, stained a faint pink with van Gieson, and was almost cell-less. There were few capillaries. Throughout the sections there was little trace of inflammatory reaction. The large vessels, arteries and veins, contained blood and no blood-clot, and appeared normal.”

In rare instances this process of muscular degeneration and disintegration may be equally complete but much slower in progress. Thus, in a patient whose superficial femoral artery had been ligatured, extreme wasting of the thigh and leg ensued. After a lapse of some three weeks, the area corresponding with the compartment of the leg containing the anterior tibial group of muscles became soft and

* *British Medical Journal*, 1918, vol. i, Feb., p. 199.

fluctuating. An incision gave vent to a flow of grumous fluid corresponding in volume to the whole mass of the muscles, which latter had suffered a species of molecular disintegration quite irrespective of infection from without. The overlying skin, though dry and scaly, retained its vitality, and the wasted musculatures of the peroneal region and calf also retained their structural continuity.

The development of a condition identical with that described by von Volkmann as muscular ischæmia is easily comprehensible in view of its familiarity as a consequence of obstruction to the circulation by tight bandaging or the too tight or prolonged application of a tourniquet. Although even in this condition the association of nervous influence in the ultimate results has been debated, I think it must be conceded that local anæmia is competent to explain the occurrence of the changes met with, and that it plays the all-important part in them all. It is significant that the muscles, the most highly organized element of the limbs, suffer first and the most severely of all the tissues. Reference has been already made to the immediate signs of nerve disturbance which may follow an arterial injury, and also to the attempt made by Captain Burrows to establish a definite line of separation in the signs of those cases in which the arterial injury is complete or partial. He suggests that in those in which the obstruction is complete, the signs of nervous disturbance are a direct result of ischæmia, while those accompanying lesions only partially obstructing the circulation are of 'reflex' nervous nature. Such a distinction, if reliable, would be of some clinical and prognostic value; but it is not easy of acceptance, even putting upon one side the difficulty in absolutely excluding concomitant nerve injury of minor degree. It appears equally reasonable to ascribe the differences in the signs to varying degrees of local anæmia, as also the fact that the 'reflex' symptoms clear up with the greater rapidity.

H. Meige and Athanassio-Bénisty,* in the course of investigation of a number of cases in which vasomotor, trophic, and secretory disturbances were present and considered to be consecutive to division of or serious damage to the peripheral nerves of the limb, observed that these changes only appeared in instances in which an associated arterial lesion was present. They therefore laid down the rule that a co-existing arterial lesion is suggested in any case in which the skin of the hands or feet has assumed a purplish-red tint or a blue cyanotic hue, a tense glossy appearance with tumid succulent character, together with signs of trophic degeneration of the nails or terminal ulceration of the digits. Athanassio-Bénisty draws a comparison between the condition of a hand the subject of an uncomplicated

* *Formes Cliniques des Lésions des Nerfs*, 1918, p. 214.

lesion of the median nerve, and one in which the main vascular supply has been interrupted, as follows :—

The 'median hand' is trembling, and more or less emaciated, hot, red, and painful; it reacts promptly to external influences, and is in a state of what may be called perpetual combustion.

The 'vascular hand' is cold, purplish or dusky in hue, with a shiny scaling skin; it is insensitive objectively and subjectively. If the vascular lesion be of minor gravity, there may be neuralgia of the articulations, or of the margins of a digit or the member, or—as in arteritis obliterans—the neuralgia may follow the course of a nerve. Causalgia, if present, is less intense and persistent than in the case of the median hand.

These authors have approached the subject from a neurological standpoint, and in the majority of the cases investigated it is clear that associated arterial and nervous lesions were present, since it is pointed out that exploratory operations for the mobilization of nerve trunks were always followed by improvement in the trophic conditions. The investigations none the less shed an important light on the effects produced by interference with the local blood-supply.

The question of the relation of the vascular and nervous elements respectively, in the production of trophic changes, has been investigated from another aspect by Leriche and Heitz.* They point out that the researches of Babinsky, Froment, and Heitz on the circulatory disturbances which accompany paralyzes and reflex contractures, have shown a vasomotor contraction to be a constant element, and that this contraction of the vessels can be temporarily overcome by the application of heat, with consequent disparition of most of the objective signs of a muscular nature which accompany motor disorders. Leriche and Heitz regard an obliterated main vessel as a 'nerve,' the fibrous cord representing a segment of the vasomotor chain, since it contains the remains of the perivascular sympathetic. Further, that the 'nerve' is an abnormal one, of which the functions are distorted.

On this theory Leriche has based his operation of perivascular sympathectomy, i.e., either the dissection away of the perivascular sheath to the extent of an inch or more, or the resection of a corresponding length of the injured vessel together with its sheath. The stripping away of the cellular sheath immediately enveloping the vessel is followed at once by an intense contraction of the artery in the whole extent involved by the operation, while a secondary vasomotor dilatation succeeds the initial contraction. This secondary reaction persists for two or three weeks, the first results being a considerable increase

* *Lyon Chirurgicale*, xiv, No. 4, p. 754.

in the local temperature of the part of the body involved, increase in metabolic and katabolic changes, and a manifest effect upon the power of contraction of the voluntary muscles. Leriche considers this operation justifiable on the grounds that the vasomotor dilatation obtained is more constant and persistent than that induced by the employment of heat, baths, etc., and on the amelioration of the symptoms which he has observed to follow the procedure in six recorded instances.

Some significant observations on the relative parts played by the vascular and nervous elements respectively, in the causation of trophic lesions, have been made by J. B. Stopford.* These tend to elucidate the serious effect of association of the two elements in influencing or even aggravating the disturbance of the normal process of nutrition, and causing its persistence. It is pointed out as a common experience that vasomotor and trophic changes are an outstanding feature of many cases of incomplete division of nerves which, when consequent on gunshot injury, are almost invariably accompanied by evidence of nerve irritation. Stopford considers that confusion has been caused by attributing the origin of these disturbances to concomitant vascular lesions, and that the view that uncomplicated nerve injury is responsible for profound vasomotor symptoms is very strongly supported by experience of the modification which is immediately effected in the vasomotor manifestations by neurolysis or resection and secondary suture of nerves, in the absence of any possible disturbance of the arterial trunks. Thus, as to the remote changes in a limb in which a vascular and nerve lesion are associated, he considers there is strong reason to believe that irritative nerve lesions can produce changes in the walls of the arteries supplied by the implicated nerve, and agrees with T. W. Todd that the trophic lesions are preceded by vascular changes. It is suggested that the muscular contractures which follow uncomplicated lesions of the peripheral nerves are due to an ischæmia secondary to vascular changes caused by the injury to the nerve. In support of this opinion a report is furnished of the histological changes found in the arteries of a limb in which the popliteal nerves had suffered injury but the popliteal vessels had escaped all implication. An endarteritis localized to peripheral branches of the vessel was demonstrated, and illustrations are given of the changes in the wall of the *dorsalis pedis* artery.

The views expressed by Stopford are not in agreement with those of Meige and Athanassio-Bénisty; yet the practical conclusion drawn from them, that early relief from irritation should be striven for in order to prevent the occurrence of secondary vascular changes in the

* *Lancet*, 1918, i, Mar. 30, p. 665.

distal part of the circulation, is of great practical importance, and is in strict consonance with their observation that improvement invariably follows measures undertaken for the mobilization of injured nerve trunks, and hence early intervention is justified.

The question has been dealt with at some length, because in arteries such as the axillary, where the nerves can scarcely escape concurrent injury, the results of the combined injury are especially bad; while the frequency with which the arterial lesion heals spontaneously, as a result of thrombosis, removes the vascular injury itself from the category in which operation is necessary.

THE OCCURRENCE OF ANÆMIC GANGRENE.

The development of gangrene is a common sequence of gunshot injuries to the arteries, whether the vessel be operated upon or not. Old collected statistics show the incidence of gangrene following ligation of the main arteries from all causes to vary from 6 to 12 per cent. A consideration of the cases upon which this essay is founded appears to show that this estimate is too low in the case of gunshot injuries; but it must be remembered that a consulting surgeon with the army has most of the unsatisfactory cases brought to his notice, while those which progress uneventfully will escape attention amongst the very large number of wounded men nominally coming into his purview. It is obvious, however, that series of collected statistics from published records contain many sources of fallacy also.

It may be of interest therefore to offer three small tabular statements to illustrate the variations which may occur in the experience of one individual, the circumstances to which these variations are attributable, and how they may influence the apparent results.

Table I includes 86 operations performed at the casualty clearing stations by different surgeons, but the cases may be regarded as a consecutive series, and the patients to have been subject to the same conditions. The large majority of these patients would only have remained under the personal observation of the operator for a period of less than ten days. The incidence of anæmic gangrene amounts to 10·5 per cent, and that of gas gangrene to 7·8 per cent.

Table II includes 42 operations performed at casualty clearing stations for the most part, but in which progress was sufficiently favourable to allow the patients to be evacuated to a base hospital in London. As the primary failures have been weeded out, by amputation or otherwise, the apparent incidence of anæmic gangrene falls to 7·1 per cent, and gas gangrene has disappeared from the table.

Table III shows the variation in incidence of gangrene after operations on the femoral and popliteal arteries alone, at the three various positions in the line. With regard to the series collated on

TABLE I.

Artery	Cases	Gangrene	Gas Gangrene	Injury to Nerves	Deaths	
Axillary	27	2	1	5	1	2
Brachial	11	—	—	3	1	—
Femoral	27	4	5	1	4	5
Popliteal	13	2	—	2	—	4
Posterior tibial	8	—	—	—	—	—
Totals	86	8 10·5 per cent	6 7·8 per cent	11 14·4 per cent	6 7·8%	11 14·4 %

TABLE II.

Artery	Cases	Gangrene	Gas Gangrene	Injury to Nerves	Deaths
Axillary	3	—	—	2	—
Brachial	7	1	—	1	—
Femoral	18	1	—	2	—
Popliteal	6	1	—	3	—
Posterior tibial	8	—	—	1	—
Totals	42	3 7·1 per cent	—	9 21·4 per cent	—

TABLE III.

Artery	Table I.—C.C.S.		Table II.—Base		Table III.—L. of Com.	
	Cases	Gangrene	Cases	Gangrene	Cases	Gangrene
Femoral	27	4 = 14·8%	18	1 = 5·5%	93	19 = 20·4%
Popliteal	13	2 = 15·3%	6	1 = 16·6%	48	19 = 39·5%

the lines of communication, I am inclined to believe it most nearly represents the result likely to be attained in any war of movement, when the men are subjected to the inconvenience of early transport, and are unable to be dealt with effectively at special operating centres quite near the front.

Further details regarding the incidence of gangrene will be found in the sections dealing with the special vessels. It may be convenient, however, to summarize shortly the conditions which favour the occurrence of gangrene after wounds of arteries received on military service. These conditions amply account for the unsatisfactory nature of the results obtained, in comparison with those following

remote operations, in which the supervention of gangrene is sufficiently rare to merit but slight consideration.

1. Decrease in the total amount of circulating blood, due to loss by primary hæmorrhage, and consequent fall in the blood-pressure.

2. Exposure to cold, and exhaustion; in several cases gangrene after an arterial injury has been accompanied by a condition of trench foot or hand in the uninjured limb.

3. The prolonged application of the tourniquet, especially dangerous in the case of the popliteal artery.

4. Infection of the wound, independently of gas gangrene.

5. General systemic infection, and secondary hæmorrhage.

6. Associated injury to nerves, especially noticeable in the upper extremity in connection with injury to the median nerve.

7. The extent and severity of the injury to the soft parts and to the bones which may be associated with the arterial lesion.

In connection with the above conditions, it is noteworthy that among 175 injuries to the femoral artery, in 11, or 6·29 per cent, gangrene developed prior to the performance of any operation. The occurrence of gangrene as a result of local spontaneous thrombosis is also suggestive, in so far as it illustrates the danger of sudden abrogation of the main blood-supply, and it forms one of the grounds upon which an expectant attitude is based, in what may be called the intermediate stage in the course of vascular injuries.

The cases included in the series afford little evidence of embolism being a frequent factor in the production of gangrene; only four instances occurred among the injuries to the limb arteries; and experience has shown that in injuries to the carotid arteries, progressive thrombosis is quite as frequent a cause of cerebral complications as embolism.

Lastly, it may be added that the area involved by purely anæmic gangrene is as a rule limited in extent, and except in the case of the popliteal vessels it seldom renders the sacrifice of a large part of a limb necessary. Speaking generally, the ultimate result of arterial injuries may be said to be better in the lower than in the upper extremity, mainly in consequence of the large proportion of uncomplicated injuries to the superficial femoral vessels. The ill effect of associated injuries to the nerves is most striking in the axillary vessels, and the worst results of purely vascular injuries are seen in the case of the popliteal vessels.

The influence exerted on the incidence of gangrene by simultaneous occlusion of the satellite vein when an artery is tied, is dealt with in the next chapter. No doubt can exist that the introduction of this practice has effected a material decrease in the proportion of limbs lost.

CHAPTER VI.

THE GENERAL LINES OF OPERATIVE TREATMENT APPLICABLE TO GUNSHOT INJURIES TO THE BLOOD-VESSELS.

It will be convenient in this place to introduce some general remarks upon the forms of operation, and their technique, which are suitable to the treatment of gunshot injuries of the blood-vessels, and their consequences, since these remarks will be applicable to any of the special uses of the procedures to be mentioned later.

The first question to be considered is the form of provisional control of the local circulation during the course of the exploration necessary for the location of the actual wound of the vessel. The wounded man may come under observation with a tourniquet already applied; but if this has been properly placed it probably encroaches too nearly on the field of operation, and will need to be reapplied if it be decided to make use of this form of aid.

The objection raised to the rubber-tube tourniquet, that it encourages parenchymatous bleeding after its removal from the limb, cannot be gainsaid. Yet the subsequent application of a bandage to the limb meets this difficulty in great measure; and if the Esmarch's bandage be not employed, and the arterioles and capillaries have not been completely emptied, the objection becomes of little importance. A justifiable practical objection which may be raised to its use lies in the experience that it is often desirable to release the control in order to obtain an indication of the exact source of the bleeding, and whether it emanates from one point alone. In this respect the tourniquet is inconvenient. With full appreciation of the disadvantages which accompany its use, I still think that the india-rubber tourniquet furnishes the readiest and most generally serviceable form of provisional control of the circulation when applicable, as is the case in a large proportion of the injuries to the large blood-vessels of the limbs.

When a tourniquet is impossible, as in the case of wounds of the neck or of the limbs close to the trunk, a provisional ligature may be placed on the main vessel on the proximal side of the injury. As a rule, the incision for the main operation should be sufficiently extensive to give access to the point or points at which it is desired to establish the provisional control. The subclavian artery at the root of the neck,

and the external iliac arteries, form perhaps the only exceptions to observance of this rule; in both these instances a separate incision possesses manifest advantages.

Mention of the occasional troubles attendant on adoption of the procedure of provisional ligature is necessary, since in my opinion they provide sufficient grounds for not considering it a measure suitable for routine application. Putting on one side the minor objection that it may be necessary to make an additional wound (although under some circumstances this drawback may be a very real one), other objections may be raised. The chief of these lies in the danger of creating a local weakening of the vitality of the arterial wall as a direct result of the constriction of the vessel; this may amount to actual tissue damage if the loop be drawn too tightly or be maintained too long in position. Under these circumstances thrombosis may develop at the weakened spot, or if the wound should become accidentally infected, secondary hæmorrhage may be favoured. Both these unfortunate results have come under my observation.

It must always be borne in mind, therefore, that delicacy is of the greatest importance in the application of the method, and various plans of avoiding the dangers of unnecessary tightening of the ligature may be mentioned. The simplest is not to knot the ligature, but to use the thread merely as a loop to raise the vessel from its bed, which act generally suffices to control the circulation through the vessel. The weak point in this method lies in the fact that the surgeon then becomes dependent on his assistant for the delicacy and efficiency of the traction maintained, and if the assistance be limited to one person, a part of whose thoughts are claimed by other details of the operation, it may be difficult for him to devote constant attention to this point. A second plan is to apply an arterial clamp; this instrument is available in several patterns, and is often useful; it requires sometimes, however, to be applied in situations where it cannot be readily kept in position without constant attention, and this trouble is aggravated by the fact that it can only be applied loosely, and is apt to slip out of position unless continuously held.

I have found a method first introduced to my notice by Colonel Gordon Watson the most satisfactory. This consists in passing a piece of narrow tape, or, if this is not forthcoming, a thick, smooth ligature, beneath the vessel, and knotting it by a single surgical turn over a piece of drainage tube of about the same calibre as the artery, placed upon its surface. By this method a soft elastic form of compression is obtained. Hence the walls of the vessel run less risk of injury, from the facts that the ligature is wide, and the knot (always the most dangerous point) is made over the rubber tube and not on the vessel itself.

We may now turn to the incisions, and it must be pointed out that these need to be planned upon a much wider scale than is the case with the classical operations so well known to the student of operative surgery. The latter have been so devised as to allow the artery to be secured at the 'seat of election' with the least amount of damage to the body. The military surgeon is able to concern himself little with such operations and the theory upon which they have been planned, except in so far as their study and application has familiarized him with the anatomical details which still form his chief guide.

Exploratory incisions need to be free for more than one reason. The operations as a rule need to be completed in the shortest time compatible with efficiency, and the surgeon has to work under very special conditions. The wounded man may be already suffering from considerable loss of blood; the exact location of the wound in the course of the artery may be doubtful—indeed, it may happen that when the surgeon sets out to deal with an injury of the main trunk, exploration may show that the actual source of hæmorrhage is in a branch only; or, again, there may be more than one lesion in the main trunk, or more than one branch may need to be dealt with. In other cases the course taken by the missile may have so nearly corresponded with that of the artery that extensive loss of substance has been effected, and the two extremities of the vessel may be widely separated. Added to these difficulties, the vessel, if a mobile one, may have become greatly displaced from its normal course, extravasated blood having pushed it over in the direction of least resistance. Normal landmarks, such as nerves, may have been divided; portions of them may have been shot away, or they may have been considerably displaced from their normal position. Injury to the satellite veins, or others, may greatly aggravate the difficulty of stilling hæmorrhage and pursuing the search for the wounded artery under comfortable conditions. The infiltration of the tissues generally with extravasated blood often renders structures difficult of recognition and troublesome to deal with, in every part of the field of operation. Lastly, the lesion may be so situated anatomically as to be in the most inconvenient and inaccessible segment of the course of the artery as far as the surgeon is concerned. This list of difficulties, if not exhaustive—and it takes no account of paucity of assistance, and possible deficiencies in the conditions suitable for a troublesome operation—offers at any rate sufficient explanation of the necessity for a wide exploratory incision.

All these difficulties, moreover, tend to be exaggerated if the case comes under treatment more than twenty-four to thirty-six hours after the injury. The tissues are then already stiffened and œdematous generally; the same condition is met with in the wall of the artery itself, and the vessel has become fixed and immobile in its sheath.

When the field of operation has been freely laid open, the first step consists in clearing it of extravasated blood and blood-clot. Whether a tourniquet or a provisional ligature has been applied, it may now become necessary to apply ligatures to bleeding veins. It is sometimes useful to have a second tourniquet placed in position on the distal side of the wound, which can then be tightened up when required, should venous hæmorrhage from the distal direction be free.

A portion of the blood will be fluid, but that in contact with the walls of the cavity will have already coagulated and formed more or less firm connections, as a result of infiltration of the surrounding connective tissue. When the blood and clot have been removed, it will be found necessary in some cases to cleanse the wound mechanically by removing badly damaged and possibly infected tissue in the line traversed by the missile. If this be considered needful, it should be carried out at this stage, so as to obviate diffusion of infection to the large exposed surface of the tissues.

The search for the wounded spot in the vessel is now commenced, bearing in mind the possible displacement of the artery from its normal course in the direction of least resistance ; that this displacement will probably be away from the bone, and that the vessel is more likely to be in the side of the wound, or more superficial than normal rather than pressed backwards. If the lesion be a lateral wound of some size, it will often be seen readily, the white inner lining of the artery showing up strongly through the gap in the wall. If the lesion is in a deep, not readily inspected position, the gap may often be easily felt, the tip of the finger detecting the firm ring formed by the margins of the defect and the resistant smooth floor afforded by the opposite wall of the vessel. If no lesion of the main trunk be detected, a search should be made in the line of the course of the principal branches, and if difficulty arises even yet in locating the wounded spot, the tourniquet or provisional ligature must be cautiously loosened, and the point or points observed from which blood commences to flow.

The wounded vessel may now be ligatured on either side of the opening and completely divided. Careful search should now be made to be certain that no branch is taking origin from the excluded segment of the vessel, as this may be a source of recurrent or secondary hæmorrhage if not occluded. The origin of branches in such a position is not uncommon, and as we have already seen, fixation by one of its own branches often accounts for the involvement of the walls of the vessel. Division of the narrow strand connecting the two open ends of the vessel in extensive lateral wounds is particularly important, in order to allow of full retraction.

A word should be added as to the inadvisability of hastily placing a proximal ligature on the artery before the bleeding point has been

located exactly. In certain positions where a number of small branches arise (e.g., common femoral artery), the free flow of blood may apparently indicate a lateral wound of the trunk ; but after the main trunk has been tied and all is clear, it may prove that the injury was after all of one of the small branches in close proximity to its origin, and the main vessel has been needlessly sacrificed.

SHOULD BOTH ARTERY AND VEIN BE OCCLUDED ?

In preparing a former contribution to the surgery of wounded arteries,* I was much struck by the observation that proximal ligation of the femoral artery in cases of arterio-venous aneurysm was followed in a large proportion of instances by gangrene of the limb, while excision of the implicated segments of both artery and vein gave consistently good results. An explanation of this apparent inconsistency will be found below, as also further considerations which led me to conclude that when an artery needs to be tied, the satellite vein should be occluded also.

It is to be regretted that John Hunter himself did not write the paper describing his operation of proximal ligation and the grounds upon which he was led to undertake it. In at least one of the cases described in the paper by Sir Everard Home,† possibly in the first three, both the femoral artery and vein were included in the ligation ; in the fourth we are definitely told that the artery only was included. From that period onwards surgical opinion has been definitely to the effect that the greatest care should be taken, when occluding a main artery, to avoid all injury to the vein. In fact, every operation for the ligation of an artery has been so devised that the aneurysm needle is passed in a direction away from the vein in order to minimize the risk of injury to that vessel, not alone to avoid the technical inconvenience of immediate hæmorrhage, but also with the definite object of preserving the venous circulation intact.

Observation of a large number of coincident wounds of large arteries and veins has in no way endorsed the view that simultaneous occlusion of both artery and vein exercises any deleterious influence on the subsequent collateral arterial circulation and the vitality of the limb. In support of this statement a few examples illustrating the innocuous nature of operations for the occlusion of veins in general may be first given. Operations for the cure of varicose veins have demonstrated the ease with which a compensatory balance is attained when the blood is diverted from the larger channels. Occlusion of the internal

* *Bradshaw Lecture, 1913.*

† JOHN HUNTER'S *Works*. Palmer's edition, vol. iii, p. 604.

jugular and other large venous trunks effected in order to prevent the diffusion of septic emboli has not given rise to obvious permanent trouble. As is well known also, occlusion even of the vena cava by surgical methods has been survived, and the capacity of the venous circulation to maintain itself by compensatory changes, which is seen when this vessel undergoes obstruction by thrombosis, is a familiar experience.

In a very considerable proportion of gunshot injuries to large arterial trunks the neighbouring vein is contused and becomes thrombosed, and this has not been shown to give rise to increased risk of gangrene of the limbs. Ligature of the common carotid artery together with the internal jugular vein *en masse* has been performed in cases of emergency without increased risk of the development of the cerebral anæmia and softening so often a consequence of ligature of the artery alone. Further, where simultaneous ligature of both artery and vein in other parts of the body has been obligatory on account of wounds of both vessels, untoward events have not been observed.

Evidence exists, moreover, that under certain conditions simultaneous occlusion of both artery and vein is a preferable procedure. The first example, not an unmixed or simple one, may be sought in the results observed to follow the application of a single proximal ligature to the artery in cases of arterio-venous aneurysm or aneurysmal varices of the femoral vessels. In patients so treated during the South African War,* gangrene of the limb followed in more than 50 per cent of the cases. The frequency of this accident finds a simple explanation if we consider what actually results from the operation. The main vessel being occluded and the direct arterial pressure from behind being abolished, blood which has been carried by the arterial collaterals to the distal portion of the injured trunk, instead of passing to the peripheral circulation, takes the course of least resistance backwards into the vein through the arterio-venous communication, and thus the limb practically bleeds to death much in the same way as if the distal end of the wounded artery opened on the surface of the limb. Hence the comparative safety of removal of the communication *en masse* and occlusion of all four openings by ligature which has been confirmed by numerous operations during the present war.

A more striking example is offered by the result of ligaturing the popliteal vein alone for the treatment of senile gangrene of the foot. W. A. Oppel,† ascribing the good results occasionally observed to follow arterio-venous anastomosis for the cure of this condition to control of

* SURGEON-GENERAL W. F. STEVENSON, *Report on the Surgical Cases noted in the South African War, 1899-1902.*

† *Zentralblatt für Chirurgie*, 1913, No. 31, p. 1241.

the venous circulation and consequent rise in the blood-pressure of the limb, was led to substitute simple occlusion of the popliteal vein to produce the same effects. In six cases thus treated the extremities were seen to recover not only their warmth and colour without the development of œdema, but also a certain degree of hyperæmia of the feet and toes.

On these and other grounds it must be admitted that the balance of the collateral circulation is likely to be more efficiently maintained if the vessels which carry it on more nearly correspond in size and consequent equality in the blood-pressure and rate of flow. The elimination, in fact, of the capacious main vein is a real advantage, since this for the time affords a too ready channel of exit for the diminished arterial supply, as well as an undesirable reservoir for stagnation.

These considerations have led me not only to regard obligatory simultaneous occlusion of a main artery and vein as a negligible factor in the risk of gangrene of a limb; but to hold further, that the procedure is preferable whether the vein be wounded or not; the result of the combined procedure being to maintain within the limb for a longer period the smaller amount of blood supplied by the collateral arterial circulation, and hence to improve the conditions necessary for the preservation of the vitality of the limb.*

M. van Kend tested the accuracy of the above conclusions as to the rise of blood-pressure at the laboratory of the Ocean Ambulance at La Panne by some experiments on animals, and made the following remarks in his observations at the Inter-allied Conference of Surgeons held in Paris in May, 1917:—

“In carrying out a series of experiments made with the object of determining the indications and the physiological basis for transfusion of blood, I have had the opportunity of measuring the blood-pressure in limbs of which the main artery had been ligatured. The blood-pressure was taken successively after the artery alone had been tied, and again when ligature of the vein had been superadded. My observations confirm the view that has been expressed by Sir George Makins; in fact, plethysmographic tracings demonstrate clearly that a slight rise in the blood-pressure in the limb follows the application of a ligature to a main vein, after previous ligature of the artery.

“It appears, then, from the standpoint of the physiologist, that to leave the main vein viable after occlusion of the main artery of a limb, diminishes what may be called the *residuary blood-pressure* maintained by the collateral circulation. If the contribution of the collateral circulation is allowed to remain with the main vein intact, it

* *Hunterian Oration, Lancet, Vol. i, 1917, Feb. 17, p. 249.*

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is natural that the *residuary blood-pressure* should fall. If this view be adopted, ligature of the vein as well as the artery should be recommended in order to retain the blood supplied in longer contact with the tissues. Thus the most satisfactory conditions for the maintenance of the nutrition of the organs are provided, because the obstacle to the return circulation provided by ligature of the vein retains the blood for a longer period in the member."

After discussion of the question at the meeting, the following conclusion was adopted: "Contrary to what has until now been believed, simultaneous ligature of both artery and vein when both vessels have been wounded does not give rise to increased risks of gangrene; in fact it diminishes them. Facts tend to prove, even when the wound is limited to the artery, that simultaneous occlusion of the unwounded vein is to be recommended." *

The numbers given below were submitted to the same meeting; these were collected on observations of my own, which included every case of the kind operated upon during a period of two years in the district in which I worked. It is obvious that the incidence is abnormally high, but this was certainly the case during the years 1915-16.

COMPARATIVE RESULT OF LIGATURING ARTERY ALONE, AND SIMULTANEOUS LIGATURE OF ARTERY AND VEIN.

Artery	No. of cases	ARTERY ALONE		No. of cases	ARTERY AND VEIN	
		Good result	Gangrene		Good result	Gangrene
Subclavian	4	3	1	1	1	—
Axillary	6	5	1	4	4	—
Brachial	13	10	3	1	1	—
Femoral	32	24	8	32	25	7
Popliteal	24	14	10	23	22	6
Tibial	4	4	—	1	1	—
Carotid	18	12	6	4	3	1
Totals	101	72	29 28 per cent	71	57	14 19·7 per cent

Every effort was made to exclude any instances in which the gangrene was due to anaërobic infection, and it must be understood that the table does not generally imply gangrene *en masse* of the limbs, but in many cases a very limited amount confined to digits or patches of skin.

* *Comptes Rendus, Conf. Chir. Interall., Paris, 1917, p. 348.*

Further statistics on this subject will be found in the sections devoted to the special vessels; but they are of less value because, since the middle of 1917, the practice in France has been generally in favour of simultaneous ligation of both vessels.

Major Hamilton Drummond has kindly furnished me with a note regarding some investigations which he made on this subject in the case of the visceral vessels. Loops of the small intestine of the cat, and of the colon of the Belgian hare, were made use of. After a careful study made by means of barium injections and *x*-ray photographs

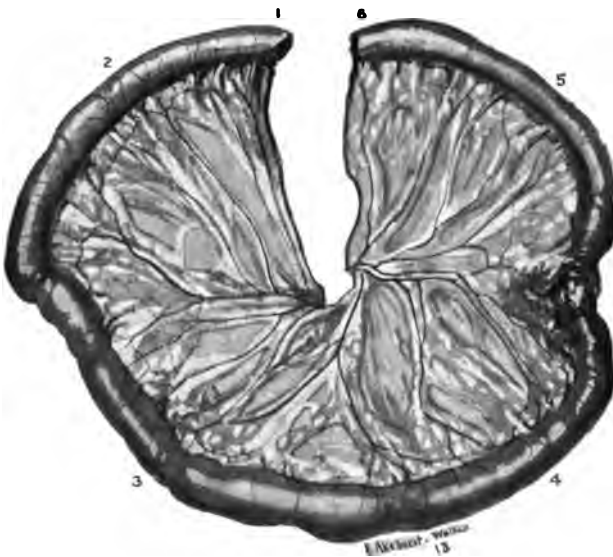


Fig. 31.—Portion of small intestine of a cat. The segment between 2 and 3 has been treated by ligation of arteries and veins in the mesentery. The gut on examination 48 hours later showed some blue discoloration, but contracted normally and was quite free from gangrene. The bowel between 3 and 4 is normal. The portion between 4 and 5 has been treated by ligation of the arteries only, the venous supply being left intact; it shows a patch of gangrene 1 in. in length. Each devascularized group is $4\frac{1}{2}$ in. in length. *Major Hamilton Drummond.*

to determine the number of vessels which should be ligatured in order to avoid error from leaving too free an anastomotic supply, the following experiment was made six times on cats' intestine (*Fig. 31*).

“A loop of ileum towards the cæcal end was drawn out of the abdomen, and the arteries and veins supplying about five inches of the gut were ligatured, cutting off the total macroscopical blood-supply to that portion. The loop was returned into the abdomen, and a second loop about six inches higher was delivered and devascularized by ligation of the artery alone.

“Of six experiments performed upon the cat, in three a definite ring of gangrene developed in the middle of the segment of bowel which had been deprived of its arterial supply alone, while the segment treated by simultaneous ligature of artery and vein showed little or no change. In one case where the animal was killed while still looking in good health, twenty-four hours after ligature of the vessels, the segment treated by ligature of the arteries only, showed more serious changes than the segment treated by simultaneous ligature of artery and vein. Of the remaining two cases, one showed no change at all, consequent upon the fact that too short a segment of the bowel had been deprived of its blood-supply, while the result in the sixth case was complicated by the development of an acute volvulus.”

ANGEIORRHAPHY.

Suture of wounded vessels, the ideal method of dealing with the injuries, has been widely advocated, and a large number of these operations have been performed. The largest numerical series are those recorded by Soubbotitch and Bier; the latter reported upon no less than 100 cases as early as Easter, 1915. As far as my own experience goes, so many operations have not been performed by any individual surgeon in the British service. Wound conditions in the early part of the campaign were not favourable to the performance of arteriorrhaphy, and only a few tentative operations were performed, after the experience of which, most British surgeons returned to the simpler procedure of ligature. Such operations as were still performed, moreover, were usually undertaken after the lapse of some days from the receipt of the original injury, when general infiltration and consequent stiffening of the walls of the vessels made the technique particularly difficult. The technical difficulties were further increased by the use of extremely fine needles and thin silk, such as had been used by Dr. Carrel for his experimental work on animals, or by the opposite conditions in which silk or catgut of too coarse a calibre was employed.

During the past two years—1917–18—considerable change has taken place in these conditions. Earlier operations have been undertaken; and it has been realized that fine silk, such as Japanese 0000, and needles of a corresponding size, are fine enough for the purpose required, that they meet the difficulty of dealing with stiffened vessels, and are far more readily and easily manipulated.

Beyond this, experience has been gained as to the particular vessels, and to the nature of the wounds, most suited to this form of treatment. The indications for primary suture of the vessels may be shortly summarized as follows:—

1. An accompanying wound of the soft parts which there is a reasonable probability of maintaining in an aseptic condition.

(Suture of vessels in connection with arterial hæmatomata or aneurysms is dealt with on p. 85.)

2. Wounds of moderate dimensions, exhibiting as far as possible an incised or mildly lacerated character. The most favourable are those produced by sharp fragments of metal, and of these the most suitable to suture are the longitudinal, traversing perforations with not too great a loss of substance; and lateral wounds, generally not involving more than half the circumference of the vessel.

Many bullet injuries also form favourable subjects for treatment by suture, but in the early stages it is often difficult to estimate the degree of contusion which accompanies the actual wound.

3. More extensive injuries can only be treated by excision of the damaged ends of the vessel, followed by a complete circular union. With a highly developed technique, reunion of the ends of the severed vessel offers no immediate difficulties, and the opportunity afforded of ensuring tissue which has not suffered contusion is an important element in final success. On the other hand, the line of union is necessarily exposed to considerable tension, and the limb needs to be placed in a forced position to overcome this obstacle to union as far as possible. This question of position renders transport more difficult, and prolonged assumption of a flexed position may also be followed by great difficulty in straightening the limb eventually. Again, mobilization of the vessel needs to be very free, and this necessitates an amount of dissection of the limb which is often undesirable. All these conditions need to be taken into consideration in deciding upon establishing a circular union. The most promising arteries for this procedure are the carotid, the brachial, and the superficial femoral, in which three vessels not only long stretches are assured, but also stretches which may be free from any fixation by branches.

4. With regard to the arteries suture of which is most strongly called for—as far as the question of ultimate maintenance of the vitality of the limb at a high level is concerned—two or three vessels stand out prominently.

The common carotid, the external iliac, and its continuation the common femoral, may be first considered. Fortunately, in the case of both these trunks, the importance of their peripheral distribution, and their comparative accessibility and capacity for the necessary mobilization, are in consonance. To a lesser degree the same may be said about the main trunk of the upper limb; but it cannot be said that the axillary is a really satisfactory vessel to deal with, on account of its depth of position, the important muscles which require division

to gain the needful exposure, and the difficulties often arising in dealing with the veins.

5. Suture of the veins is an easier matter in almost any position, and as far as the control of hæmorrhage is concerned, it may be said to be generally successful.

With regard to the surgical technique of these operations, I do not think any material modification of the method of Carrel, beyond the use of somewhat larger silk and needles, can be called for. In effecting circular unions, it has been shown that two fixation threads are sufficient; otherwise I consider that the main aim of those practising arterial surgery should be to strive to approach the excellence attained by the master of this method.

A remark has already been made as to the unsatisfactory results which may follow plication as a means of obliterating the cavity of small aneurysmal sacs, and of the employment of flaps fashioned from the wall of the sac for the purpose of reconstructing an artery. It would, after all, appear to be obvious that a flap containing neither muscular nor elastic tissue can hardly be regarded as satisfactory material for repairing an arterial defect. Such flaps, moreover, not only lack the power of active contraction and elasticity, but also, as consisting of cicatricial tissue, are liable to subsequent contraction or they may prove of insufficient resisting capacity to withstand the force of the circulation. These criticisms also apply to the employment of fascial flaps for strengthening weak unions; in most instances the subsequent fate of a vessel repaired by this method will probably be contraction and occlusion.

As to the general results attained by the method of suture in the series of cases under consideration, reference may be made to the sections devoted to the individual arteries. I think these results may be regarded as demonstrating that the method of suture is not so difficult of practical application as has been sometimes assumed; further, that the ultimate results may be claimed to be superior to those to be obtained by simple ligature of the vessels.

It cannot, however, be said that ideal results are common, since experience has shown that either early thrombosis, or later cicatricial contraction, may after all lead to occlusion of the artery. Early thrombosis may reasonably be ascribed in most cases either to defective surgical technique or to the choice of unsuitable cases. Ultimate occlusion taking place at a later date is probably beyond the power of the surgeon to avoid. It is disappointing as vitiating his principal aim, yet the great advantage of a gradual cutting off of the main blood-stream has been gained.

A word may be added as to the course which should be taken by the surgeon should immediate thrombosis follow the closure of

the wound in the wall of the artery. Under these circumstances, perhaps little is to be hoped for, but I believe it is probably wiser not to re-open the vessel and evacuate the clot, which will probably be rapidly re-formed. It is a local obstruction, and consists of a soft thrombus, probably attached firmly only along the actual line of suture, and capable of contraction and absorption. Hence it is wiser to trust to these possibilities.

As to the objection concerning the length of time needed for these operations, it is obvious that a decision on their advisability must be determined by the state of the patient and the judgement of the individual surgeon.

Suture of the open end of a divided vessel is often preferable to ligature, as it avoids any stripping up of the vascular cleft.

THE PROVISION OF A TEMPORARY CONDUIT IN PLACE OF IMMEDIATE OCCLUSION OF THE VESSEL.

No doubt can exist that the most serious of the effects following abrupt and complete obstruction of a main artery depend on the sudden anæmia produced in the area of the peripheral distribution. The most striking example of immediate effects is seen when the most highly organized tissues, as those of the central nervous system, are included in the area rendered anæmic. Thus, in the case of the carotid artery, a sudden hemiplegia may follow obstruction of the main blood-supply, and this may even be followed by a fatal issue in as short a period as thirty-six hours; or permanent or a merely temporary paralysis may result.

In the case of the less delicate tissues of the limbs, the onset of the signs is not so dramatically demonstrated, but the limb may at once become cold and functionless, and gangrene, more or less extensive, may follow in a couple or more days.

There is no doubt that a number of elements combine to influence the grade of local vital depression, or actual death of the parts, induced by abrupt suppression of the blood-supply. Such are irregularities in the arrangement of the normal anastomoses peculiar to the individual; the common interference with some of the normal channels so characteristic of gunshot wounds; and, more rarely, arterial degeneration, although this last is not often present in the young and healthy adults who form so large a proportion of the military class. Then, certain more general causes may be contributory, such as psychical depression, exhaustion from exposure, and prolonged exposure to cold; and lastly and above all, the recently induced severe general anæmia and fall of blood-pressure attendant upon a large hæmorrhage.

Any or all of these influences may be brought to bear on individuals in whom no preparatory changes in the circulation have taken place, as may have been the case in the subjects of spontaneous aneurysms, or of tumours which have exercised a slowly increasing influence on the calibre of the main vessel of supply. As a result, we find gangrene a far more frequent sequela to the operation of ligature than we should have primarily expected it to be.

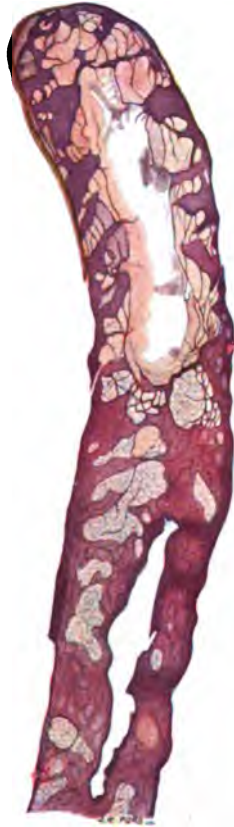
Again, it cannot be too strongly emphasized, that the immense majority of the cases of gangrene which have been observed in this war followed primary or intermediate operations of urgency; while the incidence after operations performed at a later date, when the dangers dependent on primary hæmorrhage, shock, and the risks of infection have passed by, has been almost negligible.

Dr. Carrel has shown many years ago the possibility of maintaining the circulation in animals, even for very prolonged periods, by the insertion of a glass junction tube into the ends of a divided artery. Professor Tuffier has utilized this experience by introducing a similar procedure in the treatment of wounded arteries in man. A silver tube is made use of, and allowed to lie in position until it has evidently undergone obstruction, when it is removed and the ends of the vessel are secured if necessary. The silver tube is previously coated with paraffin, and may serve to maintain a gradually decreasing stream in the artery for from a few hours to as much as ten days; during this period the interior becomes gradually filled with laminated blood-clot. *Plate IV* is drawn from a section of such a clot removed from the interior of a tube which had lain in position for four days. During this interval time is afforded for progressive enlargement of the collateral branches of the main trunk, and thus a gradually increasing strain is imposed upon the compensatory mechanism, rather than an abrupt and complete demand.

These tubes have been widely employed, with a considerable measure of success. In two cases of injury to the popliteal artery in which I employed the tube, in neither did gangrene supervene; and I have seen the same result several times when the tube has been used by others. A striking case was reported to me in which the completely divided femoral artery had been at once ligatured, and shortly afterwards signs of incipient gangrene were noted. Captain Cowell removed the ligatures and introduced a tube, with the result that gangrene was avoided. In one instance in the service of Professor Tuffier, the circulation was maintained through the femoral artery for a period of ten days; but I think this must be regarded as a very exceptional occurrence, and as a rule the tube should be removed at the end of four days, and at this date I have always found it occluded.

The main element in procuring success in using these tubes lies

PLATE IV.



Clot removed from a Tuffier's tube, on the fourth day. Occlusion has resulted from the union of irregular processes of clot, which have united at the centre, and either end, enclosing spaces. The green strip is a remnant of the paraffin lining of the tube, still adherent to the clot.



in observing care that the coating of paraffin be not disturbed in the process of introduction. The free margins of the apertures are the parts most likely to suffer. Introduction of the tube into the proximal extremity of the divided vessel is easy, but that into the distal end often gives trouble from the fact that it is already contracted and difficult to dilate mechanically. No more striking exemplification of the force exerted by the normal blood-pressure can be afforded than by witnessing the difficulty with which the surgeon can stretch the open end of a divided vessel, and the rapid dilatation which at once follows entrance of the blood-stream when the junction is effected.

The following formula recommended by Captain Bazett for a paraffin mixture to coat the tubes used in direct transfusion of blood is very useful for coating the Tuffier tubes, and their introduction is much facilitated by the employment of a pair of forceps made upon the same pattern as one of Professor Tuffier's: About equal parts of paraffin wax and vaseline are mixed, the proportion of each being slightly modified so as to obtain a mass which will set at from 43° to 48° C. The mixture is then strained through cotton-wool. The tubes are coated by immersing them in the mixture heated to about 130° C., taking care to avoid the presence of air-bubbles.

Wounds of Individual Vessels.

CHAPTER VII.

THE GREAT VESSELS OF THE TRUNK.

THE fatality attendant upon wounds of the great vessels of the trunk cannot be better illustrated than by reference to the Table (p. 7) which shows the regional distribution of the cases dealt with in this essay.

In all communications concerning gunshot injuries to the chest and the abdomen, hæmorrhage is generally acknowledged to be the main cause of early death; and in considering the effects of gunshot wounds of the lungs, hæmorrhage into the pleural cavity and its consequences obtain a dominant position.

VESSELS OF THE CHEST.

Aorta.—That a wound of the thoracic aorta need not prove immediately fatal is not a novel observation. *Fig. 32* depicts a specimen of



FIG. 32.—Spherical ball wound of the ascending aorta. Plug of soft tissues, and bullet retained in the lumen of the vessel.

Mr. Guthrie's preserved in the Museum of the Royal College of Surgeons (No. 3051). In this instance the patient died on the third day, and

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temporary hæmostasis appears to have been effected by a plug of the skin and soft tissues carried by the spherical bullet into the aperture in the wall of the artery. This mode of spontaneous closure of a defect in the arterial wall is not, I think, common, although mention is made of it in the case of a wound of the brachial artery recorded by Sir W. Stokes quoted on p. 27. When Guthrie's specimen was



FIG. 33.—Bullet wound of thoracic aorta, fifth day. Infiltration of mediastinal connective tissue with blood, but no aneurysmal sac. *Capt. Adrian Stokes.*

first removed from the body, the bullet was retained in its position against the wall of the artery by a covering of fibrinous clot and possibly shreds of the fibrous tissue it had carried with it into the lumen of the aorta.

A beautiful specimen obtained by Captain Adrian Stokes, from a post-mortem examination performed in a fatal case of injury to the

chest in which a large hæmothorax was the prominent feature, is preserved in the War Collection at the Royal College of Surgeons (*Fig. 33*). The patient sustained a perforating wound of the chest, and during the next twenty-four hours was operated upon, and four pints of blood were evacuated from the right pleural cavity. The wound underwent a severe streptococcal infection, and as a result the patient died on the fifth day after reception of the injury. At the autopsy the areolar tissue of the posterior mediastinum was found to be densely infiltrated with blood-clot, but no aneurysmal cavity was present. A slit aperture of entry was found in the descending aorta, and the bullet which had caused this wound was discovered in the right common iliac artery with the base directed downwards. There is no reason to assume, from the conditions discovered after death, that this patient might not have recovered so far as the aortic injury was concerned.

The instances of spontaneous closure of the abdominal aorta referred to on p. 26 and p. 119 would also seem to support the view that wounds to the thoracic aorta inflicted by bullets of small calibre or minute fragments of shell may in like manner heal spontaneously and escape observation. This possibility helps to make the exact localization of arterio-venous communications situated within the confines of the thorax a matter of some difficulty; the following case forms an illustrative example.

Case 1.—Thoracic arterio-venous communication, transverse arch of the aorta or left subclavian artery.

Pte. W. A bullet entered at the centre of the left suprascapular fossa, and was retained beneath the centre of the manubrium sterni.

Some hæmoptysis followed the reception of the wound, and a left hæmothorax developed. The man was kept at rest at the casualty clearing station for a week, and then transferred to a hospital on the lines of communication. On admission, there was some cellular emphysema at the root of the neck on the left side, and a large hæmothorax with considerable displacement of the heart to the right, but the man's general condition was good. Respiration was easy, the pulse-rate 90, and the heart's action was not excited. The left radial pulse was present and unaltered.

A loud arterio-venous bruit was audible over the entire præcordial area, louder still over the manubrium sterni, and attaining its greatest intensity over the sternal end of the left clavicle. It was audible in both posterior triangles of the neck, but stronger in the left. I was inclined to localize the communication to the left subclavian artery.

During the next fourteen days the patient remained in much the same condition, but he then had a sudden attack of dyspnœa and became excited and depressed by turns. The character of the bruit at this time underwent considerable alteration; the systolic element took on a sharp whistling character, and the venous roar became lower in pitch and softer in tone. The normal cardiac sounds could be very readily distinguished from the adventitious vascular murmur, and the latter had become more strongly conducted towards the right side of the chest. Little change had taken place in the condition of the hæmothorax.

The patient was kept at rest in bed during the succeeding four weeks, and steadily improved. The whistling character of the systolic element of the bruit was maintained, the venous roar becoming still less prominent. The radial pulses were equal in strength and volume. The hæmothorax steadily decreased in extent, and dyspnœa and distress disappeared completely. An x-ray plate revealed a shadow in the upper part of the chest, extending beyond the right border of the sternum, but neither pulsation nor thrill could be detected in the upper intercostal spaces.

At the end of seven weeks the man was transferred to Folkestone, where he stayed three months, and was then sent back to Canada to be discharged from the service.

While at Folkestone a second skiagram was taken, and the skiagrapher was of opinion that the lesion was one of the transverse portion of the arch of the aorta. The man was complaining of occasional attacks of breathlessness at night, but was otherwise comfortable.

Innominate Vessels.—Aneurysmal varices of the innominate vessels are occasionally met with, but I have only once had the opportunity of observing an arterio-venous aneurysm, and never a pure arterial hæmatoma.

Quotation of the three cases which have come under my own observation will probably be more useful than any attempt to give a detailed description of innominate lesions. The first case is of special interest as illustrating one of the anomalous types of hæmatoma which may be met with in aneurysms due to gunshot injury, while the third, an old experience, is quoted as an example of the occurrence of spontaneous closure of an arterio-venous communication.

Case 2.—**Innominate arterio-venous aneurysm. Death from secondary hæmorrhage on the tenth day.**

Pte. A., age 19. The man was wounded by a small fragment of shell which entered over the centre of the right supraspinous fossa, and was retained in the chest. He was kept at rest at the casualty clearing station for some days, and then transferred to a hospital on the lines of communication. He was brought to my notice on the seventh day after reception of the wound, as a youth suffering with congenital heart mischief, the diagnosis having been made as a result of the roaring murmur audible in the præcordium and at the back of the chest. The boy was then somewhat cyanosed and dyspnœic, but not in great distress. He had expectorated a good deal of blood for the first two days after the injury, but none since; the temperature was normal, the pulse-rate 120.

On palpation, some pulsation and a purring thrill were detected above the right clavicle. The right apex was dull on percussion, and the breath sounds were diminished and tubular at the right base.

On the evening of the same day the patient died, as a result of a profuse hæmoptysis.

At the autopsy, a wound the size of the little finger-nail was found on the anterior surface of the root of the innominate artery; the wound of the vein could not be localized. The apical area of the pleural sac was obliterated by old adhesions; hence the absence of a hæmothorax. The sac was formed by an old tuberculous cavity in the apex of the right lung, and within its confines a small sharp fragment of shell was found.

Case 3.—Pte. X. was admitted with a small slit entry-wound situated over the left sternoclavicular joint. The missile was retained and its position was never discovered. The patient was suffering from an extensive right hæmothorax and was very ill. During the next ten days he improved, and meanwhile the whole chest was examined almost daily, and was also aspirated.

On the eleventh day a double machinery murmur was heard for the first time by Lt.-Col. T. R. Elliott, under whose observation the man had been since his admission. The systolic element was of the 'slamming' or 'pistol-shot' character, the roar was conducted loudly to both sides of the neck and to the base of the heart. A bubbling thrill was palpable in the line of the right axillary vein. A week later there was little change, except that the thrill was now felt only in the line of the jugular vein in the neck, and that the murmur was louder and more definitely localized over the line of the innominate vessels. No local dullness was to be detected beneath the first piece of the sternum or in the upper right intercostal spaces. The patient was shortly afterwards transferred to England.

In contrast with the above two cases, one observed during the South African Campaign may be shortly narrated.* I had the opportunity of keeping in touch with this patient for some years.

Case 4.—The wound was caused by a Mauser bullet, which, entering at the posterior border of the sternomastoid on the left side of the neck, crossed the chest to emerge at a point in the right anterior axillary line one inch below the fold.

Some hæmoptysis followed the injury; and later, some pulsation, a thrill, and an arterio-venous bruit were detected over a circular prominent area the centre of which corresponded with the right sternoclavicular joint. Little change occurred in the signs, except that some gravitation ecchymosis became apparent at the lower costal margin on the right side and in the epigastrium.

The patient suffered little inconvenience, but was discharged from the service, and at the end of seven months returned to his occupation as a lamp trimmer.

Four and a half years later the arterio-venous bruit was the only persisting sign; at the end of five and a half years the bruit had disappeared, and, except for a somewhat distended external jugular vein, no evidence of the original vascular injury remained.

Other Vessels.—I have seen no instance in which the intrathoracic portion of the left carotid artery was suspected as the seat of a lesion, but a case of injury to the left subclavian artery within the thorax is recorded in my book *Surgical Experiences in South Africa*, and one is reported here on p. 188. The following case is quoted as illustrating the difficulty in correctly localizing an intrathoracic lesion.

Case 5.—**Intrathoracic arterio-venous communication of uncertain position.**

Pte. L. A small aperture of entry was present at the left margin of the manubrium sterni in the first intercostal space, and a skiagram showed

* *Surgical Experiences in South Africa*, p. 140.

a small fragment of shell apparently lying one inch anterior to the root of the transverse process of the fourth dorsal vertebra of the right side. The signs present shortly after the injury suggested a small hæmothorax.

At the end of a month, when the case came under my observation, the patient was in no distress, the pulse-rate varied from 70 to 100, the radial pulse was present and equal on the two sides, and there was paralysis of the sympathetic of the left side.

A loud arterio-venous bruit was audible over the front of the chest, loudest at the situation of the wound of entry; this was conveyed to the left posterior triangle, but not to the left arm. The apex of the heart was just within the nipple line, cardiac pulsation was heaving and visible, the sounds were clear. A cardiographic examination made by Dr. Cassidy revealed no abnormality.

The patient was kept at rest in bed for two months, during which time he did not complain of any discomfort; he was then allowed to get up and about, and at the end of four months was discharged from the service, suffering no inconvenience when taking life easily.

Wounds of the parietal vessels of the chest have proved to be a much less frequent source of the blood in cases of hæmothorax than was believed to be the case before the present war, and Elliott and Henry* have proved conclusively by post-mortem observations that the pulmonary vessels form the most common source of supply. In the section dealing with the subclavian vessels generally, some cases will be found bearing on this question beyond that just recited above.

Mediastinal hæmorrhage does not occupy such a prominent position in relation to injuries of the thoracic vessels as does retro-peritoneal to those of the abdomen, because the extravasated blood is not so liable to secondary infection from the viscera; but gravitation ecchymosis at the lower margin of the thorax sometimes affords a useful diagnostic indication.

I have met with one case of arterial aneurysm in connection with a wound of a branch of the internal mammary artery. The chief interest in this observation depended on the fact that although the local systolic bruit was loud and in near proximity to the heart, yet it was not conducted, as may be the case in more distant arterial lesions.

VESSELS OF THE ABDOMEN.

Wounds of the visceral arteries account for a very large proportion of the deaths which follow gunshot wounds of the abdomen, and in many instances wounds of the visceral arteries are dealt with during the performance of abdominal explorations. Injuries of the latter character are commonly complicated by coexistent ones of the viscera,

* *Journal of the Royal Army Medical Corps*, vol. xxvii, Nov. 1916, p. 552.

and need no further mention here. It may be remarked, however, that it is not common to meet with cases of secondary hæmorrhage from the intestinal vessels in the hospitals on the lines of communication or at the base; while, on the other hand, deaths following wounds of the solid abdominal viscera are attributable to secondary hæmorrhage in from forty to fifty per cent of all fatal cases.* These deaths are mostly consequent on secondary infection, and as a rule the bleeding is not from vessels of the first magnitude, the latter having already exacted their toll in the primary stages of the injuries.

In arterial surgery the interest rather centres upon retroperitoneal injuries, and on wounds of the parietal series of vessels. There can be little doubt in the great majority of instances in which a missile crosses the peritoneal cavity and implicates the aorta or the iliac vessels, or even the great veins, that the patients die rapidly from intraperitoneal hæmorrhage. Again, when the hæmorrhage is retroperitoneal, although death may be deferred, not a few of the patients succumb as a result of secondary infection of the masses of clot which infiltrate the extraperitoneal tissue. This opinion is supported by the fact that, in the series of cases upon which this essay is founded, only one injury to the abdominal aorta and five to the iliac vessels are met with.

Abdominal Aorta.—In the general section (p. 26), reference has been made to a classical case of spontaneous closure of a bullet wound of the abdominal aorta, and by the kindness of Captains Morgan and Young I am able to quote a case observed during the present war, in which the patient survived a bilateral perforation of the aorta by a fragment of shell for more than three weeks, and eventually died from other causes. The preparation from which *Fig. 34* has been drawn is preserved in the War Collection at the Royal College of Surgeons (No. 664).

Case 6.—Cpl. R., age 32, was admitted into Millicent Duchess of Sutherland's Hospital five days after receiving two wounds, one in the left axilla, the second just within the vertebral border of the left scapula. The wounds were almost healed at the time of admission, and were at first thought not to have penetrated the thorax. The injury had been followed by moderate hæmoptysis and some dyspnœa, but by no abdominal pain.

When admitted to hospital on the fifth day, the patient was slightly dyspnœic, but there were no abdominal signs; the temperature was 101.6° F., and the pulse-rate 116. The signs discovered in the chest were slight, and considered to indicate either a small hæmothorax or a traumatic pneumonia. An *x*-ray examination showed slight opacity at the left base, and the outline of the diaphragm was obscured. An exploring needle entered at the

* *British Journal of Surgery*, 1916, vol. iii, No. 12, p. 650.

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left base gave a negative result. The abdomen was supple and not tender ; there was slight jaundice of the conjunctivæ.

During the next few days the patient's general condition improved, the evening temperature rose to 101° to 102°, but the pulse-rate averaged only 88.

On the seventeenth day after the injury the man began to vomit freely, and complained of pain all over the abdomen ; the latter remained supple, but was tender throughout, and distended. A rectal examination afforded no information. The signs in the chest had cleared up, except for evidence of slight bronchitis in both lungs.

All food by mouth was forbidden, pituitrin was administered subcutaneously, and dextrose was given by enema. These measures relieved the vomiting and distention, but the abdominal pain persisted, and on the twentieth day became localized to the right half of the abdomen. Some resistance to palpation now developed, especially in the right iliac fossa. A repeated rectal examination proved negative. The temperature was 101°, and the pulse-rate had risen to 100.

A diagnosis of appendicitis was made, and a laparotomy performed. The operation disclosed little beyond the existence of generalized distention, and some old adhesions in the region of the appendix ; there was no excess of peritoneal fluid.

The pain and vomiting continued, the temperature remained high, the pulse became progressively more rapid and weaker, and on the twenty-third day the patient died : there was never any hæmaturia, and the coloration of the conjunctivæ had not appreciably increased.

Autopsy, by Captain R. J. Bethune.—On incising the scar an inch below the left axillary folds and just posterior to the mid-axillary line, a track leading to the left pleural cavity could be distinguished. No track could be detected leading from the scar at the vertebral border of the scapula. Half a pint of bloody fluid was found in the left pleural cavity, and tenacious adhesions were present in both pleuræ between the lung and chest wall. The upper and the inner surfaces of the sixth rib were grooved and denuded of periosteum.

An aperture half an inch in diameter was found in the diaphragm near the mid-line and towards the back of that portion of the muscle in contact with the inferior surface of the lower lobe of the left lung. The opening was partially closed by a tag of omentum, which adhered to its margin. (The specimen can be seen at the Royal College of Surgeons, No. 665.)

The myocardium was paler than normal, and broke down with moderate digital pressure. The pericardium, endocardium, and valves were normal.

A moderate quantity of clear brownish fluid was found in the peritoneal cavity, no blood or pus, and no evidence indicative of recent peritonitis. The spleen was enlarged, soft, and of an opaque pink colour. The liver was enlarged, soft, and yellow in colour. On section, a fatty area was seen at the upper aspect of the left lobe, corresponding in position with the overlying aperture in the diaphragm. The connective tissue of the capsule was infiltrated with blood. The fundus of the gall-bladder was adherent to the transverse colon, the organ was not distended, and its contents were normal in character. The kidneys were somewhat swollen, soft, and pale. They presented no sign of injury. The pancreas was embedded in blood-clot, but no sign of interstitial hæmorrhage was seen on section.

The entire retroperitoneal tissue was infiltrated with soft blood-clot, the mass being greatest in the right renal region, and around the right crus of the diaphragm and the pancreas. When the right kidney had been



FIG. 34.—Bilateral perforation of abdominal aorta by shell fragment.

removed by division of the vessels entering the hilus, a small, more or less cylindrical fragment of metal, measuring one-half by one-quarter of an inch, was found in the clot near the pedicle. Two apertures were found in the

aorta just above the level of origin of the renal arteries. One opening was triangular in shape, with a small flap, the other was oval with ragged margins. The openings permitted the passage of the fragment of metal introduced lengthwise (Fig 34).

The lumen of the vena cava could not be clearly distinguished on account of the firm clot.

Captain Bethune makes the following remarks: "The post-mortem evidence points to septicæmia as the cause of death. It is remarkable that neither blood nor blood-clot was seen in the peritoneal cavity either at the operation performed on the seventeenth day or at the post-mortem examination made upon the twenty-fourth. Had there been a hole in the posterior peritoneal layer, death would surely have occurred rapidly from hæmorrhage into the peritoneal cavity. The conditions found on both occasions suggest that the projectile passed through the lesser sac of the peritoneum, subsequently travelling in the subperitoneal tissue of the aorta. If one may assume that the man was lying on his face when he received the wound in the axilla, the escape of the stomach and liver from injury may be accounted for by the falling forward of these viscera towards the anterior abdominal wall. One other point is deserving of notice, namely, that no suppuration or abscess was found in the clot or elsewhere which might have acted as a focus for the septicæmia."

Iliac Vessels.—Only five cases of injury to the iliac vessels are included in the series, yet these afford several points of interest, and they are therefore all quoted briefly below. Injuries to these vessels may be readily overlooked, as they are commonly complicated by visceral lesions; while, if retroperitoneal, the primary blood extravasation tends to be ill-marginated, widespread, and obscured by the presence of abdominal distention. For these reasons auscultation may be the chief or the sole aid at the disposal of the surgeon in making a diagnosis.

It is noteworthy that of the five cases here dealt with, the injury was to the lower part of the external iliac artery in three, and I think it may be assumed that the lower the wound is situated in the course of this vessel, the greater is the chance of the hæmorrhage being restrained. A difficulty may arise, when the wounds are in this position, in discriminating between a wound of the external or the common femoral artery, because the blood extravasation may sometimes track downwards into the thigh, or in some cases track upwards from the thigh into the iliac fossa. Observation of the possible course taken by the bullet, and careful auscultation, may be the only means of correctly localizing the point of injury. I have seen mistakes made in this particular, and they are the more intelligible since the iliac swelling is sometimes the more prominent feature in femoral lesions. In an interesting operation in which I assisted Colonel J. Gunn, C.A.M.C., an arterio-venous aneurysm ostensibly of the left external iliac artery and vein proved to be due to a wound of the deep circumflex iliac vessels, in close proximity to the parent trunk.

Again, the fact that the blood in the retroperitoneal injuries rapidly clots in the meshes of the loose connective tissue, may account for absence of expansile pulsation in the early stages of the cases.

Case 7.—Abdominal wound. Wounds of the intestine. Arterial hæmātoma of the external iliac vessels. ? Spontaneous cure.

Pte. E. A piece of shell entered the abdomen at the outer margin of the left rectus muscle, one inch above Poupart's ligament.

The abdomen was explored by Captain Meyer twenty-four hours later, and five perforations of the small intestine situated at the lower end of the jejunum and the commencement of the ileum were found. Two of the perforations were sutured, and the piece of intestine containing the remaining perforations was excised *en masse*.

Blood-clot was removed from Douglas's pouch and from the anterior abdominal wall, and it was noted at the time that the femoral vessels were pulsating normally.

The after-progress was uneventful, and at the end of fourteen days the patient was transferred to a hospital on the lines of communication. His general condition was good, but two days later he complained of pain in the left groin, and on examination a small diffuse swelling was discovered beneath Poupart's ligament. Pulsation and a blowing systolic murmur were present, but no thrill. The condition of the limb was normal, and a good posterior tibial pulse was present.

The patient was kept at rest, and three weeks later the swelling had practically disappeared, the pulsation was localized to the line of the artery, and the systolic murmur had become very faint. A few days later the man was transferred to England, and no further details are to hand.

Case 8.—Arterio-venous aneurysm of the external iliac artery.

L.-Cpl. M. The man was wounded by a revolver bullet, which entered above the centre of Poupart's ligament on the left side and was retained, lying about at the same level on the posterior abdominal wall. The tibial pulses were maintained, and good. There was a well-marked thrill over the situation of the wound, and a loud machinery murmur extending down to the foot and upwards as far as the lower margin of the thoracic wall. The venous roar alone was audible in the cardiac area. The patient was transferred to England for treatment.

Case 9.—Wound of external iliac artery. Primary ligature of artery and vein.

Lieut. B. Both artery and vein were lacerated by a fragment of shell, and were ligatured. Twelve days later the primary wound had healed, and the lower limb was in good condition.

Case 10.—Complete severance of common iliac artery. Hæmothorax. Death on thirteenth day.

Pte. E. The patient was wounded by a fragment of a trench mortar shell, which entered to the left side of the lower dorsal vertebræ. A hæmothorax developed promptly, and eight to ten hours after reception of the wound the man began to complain of pain in the left lower limb, which became swollen.

After a stay of nine days at the casualty clearing station, the patient was transferred to a hospital on the lines of communication. When

admitted he looked pale and ill ; he was restless, with a good deal of cough, and a small amount of blood-stained mucus was still being expectorated. A hæmothorax extending up to the angle of the scapula was present, and on examination of the abdomen, resistance to pressure was detected in the left flank and iliac fossa.

The right lower limb was thin and wasted ; the left swollen, but with no subcutaneous œdema, and the calf muscles were firm and resistant on palpation. Sensation was present throughout the limb, and there was no loss of motor power.



FIG. 35.—Arterial hæmatoma developing in connection with a complete severance of the common iliac artery. The cavity laid open, and a portion of the clot still in position.

The man was very restless, and complained much of pain in the lower limb. On the thirteenth day the limb became still more tense, and pulsation in the femoral vessels was ablated. Sensation became impaired in the thigh, and although the limb remained warm, the foot commenced to be discoloured and mottled. On the fifteenth day the man died suddenly from no obvious cause.

At the autopsy, a pint and a half of blood was found in the left pleural cavity, and the track of the missile was traced through the base of the left lung, diaphragm, and psoas muscle. After emerging from the

latter, the missile had completely severed the common iliac vessels near their commencement (*Fig. 35*), and then dropped into Douglas's pouch. The femoral vein was thrombosed as low down as the popliteal space. A pint of bloody fluid was present in the peritoneal cavity, there was extensive retroperitoneal extravasation, and a large thick-walled arterial hæmatoma in connection with the severed ends of the artery.

Case 11.—Wound of right internal iliac artery. Arterial hæmatoma.

L.-Cpl.—An abdominal exploration resulted in the discovery of a large quantity of evil-smelling clot in the peritoneal cavity, but no visceral injury was detected, neither was the source of the hæmorrhage localized.

Three days later a secondary hæmorrhage occurred, but again the source of the bleeding was not localized. The man, however, improved in condition, and ten days later he was sent down the lines. At this time he was still very anæmic, and on examination a systolic apical murmur was detected. There was a marked diastolic shock both in the cardiac sounds and in the arteries, and diffuse præcordial pulsation.

Continuous improvement took place in the general condition, and on the thirteenth day the systolic bruit was no longer audible over the heart, but a blowing systolic murmur was localized over the right iliac fossa, which could be traced upwards to the aorta. The patient was shortly afterwards transferred to England.

Prognosis and Treatment.—The above material affords little scope for dogmatism regarding the treatment of injuries to the iliac vessels; its scantiness, however, supports the view of the serious results which attend wounds in this region, and also, I think, the opinion that wounds of the distal quarter of the external iliac artery are the most likely to be met with by the surgeon. The cases also illustrate the possibility of spontaneous healing in this region, the fact that these lesions may be readily overlooked primarily, and that the development of a pulsating hæmatoma may be deferred. Case 10 is an interesting example of a temporary maintenance of the circulation in spite of practically complete severance of continuity of the vessel.

With regard to the treatment of aneurysms of the iliac arteries, it is clear that the operation may need to be of the transperitoneal type, since this method gives the surgeon the opportunity of establishing control of the circulation by placing a provisional ligature around the common iliac or the commencement of either of its branches, as may be dictated by the position of the actual lesion. It may be added that placing the patient in the so-called Trendelenburg position much facilitates any procedure undertaken; otherwise the ordinary rules guiding the treatment of arterial or arterio-venous lesions need no modification.

The few cases recorded furnish no reason to depart from the opinion that ligature of the iliac vessels is a successful procedure, and that unsatisfactory ulterior consequences are not to be apprehended.

This is perhaps the most convenient place to add a few words as

to the results of ligature of the iliac arteries for the treatment of either common femoral injuries or wounds of the vessels of the buttock. When a common femoral aneurysmal sac extends up to or above Poupart's ligament, the transperitoneal route may be the more convenient, as it allows the conformation and extent of the sac to be made out, without any dissection. I have seen this operation done twice with good results, and with small disturbance of the ultimate nutrition of the limb.

When it is required merely to expose the vessel for the application of a provisional ligature, or to deal with a small aneurysm of the lower part of the vessel, the operation should be of the extraperitoneal type, and the most satisfactory incision, as far as the future strength of the abdominal wall is concerned, is that in which the rectus sheath is opened and the rectus itself displaced, as in operations for appendicectomy or for exploration of the pelvic portion of the ureter.

Ligature of the internal iliac, or its posterior division, has been most frequently needed for the treatment of hæmorrhage from the vessels of the buttock or for the treatment of gluteal aneurysms. In my own experience this is the only form of proximal ligature at a distance for secondary hæmorrhage which has afforded good results, and which is to be regarded as a normal procedure. I have seen it employed with success in at least ten instances. Sloughing of the tissues of the buttock has, however, been known to follow it when the buttock wound was infected; and it is scarcely necessary to add that, if there is any reason to suspect anaërobic infection of the tissues, the wound in the buttock must be maintained very widely open.

WOUNDS OF THE GREAT VEINS.

A number of specimens illustrative of wounds of the great veins are contained in the War Collection at the Royal College of Surgeons. These were obtained mostly from the bodies of patients who had other visceral injuries, but it is noteworthy that in the majority of instances death occurred during the first twenty-four hours. On p. 22 a short account of a wound of the portal vein, successfully treated, is recorded.

*CHAPTER VIII.***VESSELS OF THE NECK.****CAROTID ARTERIES.**

THE injuries to the carotid arteries that come into the hands of the surgeon are usually of a limited character, being either of the nature of contusions, lateral wounds, or traversing perforations. In only one of the whole series of cases on which this chapter is founded was a complete severance of the vessel met with. Amongst 85 injuries treated upon the lines of communication or at the base, no complete severance was diagnosed, and in all the cases operated upon the lesion was of a limited nature. It may also be noted that the accompanying wounds of the soft parts were of a similar type; thus, amongst 66 cases, in 20 the wound was a simple through-and-through track of small or minimal calibre, in 45 the missile was retained, and in only 1 was the external wound extensive.

Among 60 injuries, 22 were produced by bullets, and 38 by fragments of shells or bombs, often of very small size.

As to the position of the injuries in the course of the vessels: Of 85 cases, 44 were on the right side, 39 on the left; in 2 cases the vessels of both sides were implicated. Amongst 76 cases, the external carotid was wounded in 9, the internal in 9, and the common trunk in 58. The 49 injuries to the common carotid were located as follows: upper third 25, middle third 19, lower third 5.

It may be inferred from these facts that if the wound of the soft parts of the neck be extensive, or if the vessel be completely severed, a fatal result usually ensues. The small proportion of injuries to the lower third of the vessel suggests that wounds in this part of its course are particularly dangerous. Lastly, the large proportion of the cases in which the missile was retained, and was a fragment of a shell, illustrates well the favourable prognostic significance of low velocity on the part of the missile in decreasing the severity of the injury.

Amongst a total of 85 injuries, in 19 the lesion was of the nature of a contusion, or of a wound of such limited extent as to occasion no gross leakage of blood. The interest of this small series of cases is twofold. It throws light on the possibility of spontaneous closure of wounds of great vessels, and it is remarkable that, in all, the lesion was discovered, not by the presence of local signs, but as a result of the

remote consequences it was responsible for. The second feature seems to indicate also that thrombosis leading to spontaneous healing of arterial lesions cannot be uncommon, since the occurrence of cerebral signs was alone responsible for the detection of the vascular injury in these instances. It cannot be assumed that obliteration of the lumen of the carotid artery as a sequence of contusion is more likely to be followed by complications in its area of distribution than may be the case with any of the other large arteries of the body; and, in addition, we have positive evidence that extensive obliterating thrombosis of the carotid itself may be evidenced by no remote consequences whatever. Hence we are justified in concluding that many cases of contusion or minimal wound of the carotid vessels may pass unnoticed and never be discovered.

DIAGNOSIS OF INJURIES TO THE CAROTID ARTERIES.

Observance of the rules guiding the investigation of a suspected arterial injury in any region suffices to determine the question with comparative ease in the neck. The chief difficulty consists in the small amount of aid which can be obtained in this region by investigation of the peripheral pulse. It is true that in many cases of obstruction of the main trunk seen at an early date, the pulsation in the external carotid may be absent or feeble, but after a very short period the free cross-anastomosis between the arteries of the two sides may abolish the difference. Although, therefore, we may obtain evidence by palpating the temporal pulse, it cannot be regarded as giving an absolute indication; and, as will be pointed out later, examination of the fundus oculi is useless in furnishing an estimate of the freedom of circulation through the internal carotid.

Determination of the important question as to whether an injury involves the carotid immediately above or immediately below the bifurcation of the common trunk, can usually only be made by operative exploration. It may be noted, in this particular, that when the internal carotid is the vessel injured, the hæmatoma is generally palpable beneath the tonsil, and tends to spread backwards; while the extravasation from wounds of the trunk tends rather to follow the more superficial course of the external carotid. The existence of an intracranial injury to the internal carotid may usually be determined by auscultation of the skull, when the characteristic systolic bruit, or an arterio-venous murmur, will be audible. *Fig. 36* furnishes an interesting example of the value of auscultation under such circumstances. In this instance a fragment of shrapnel case had entered the skull, and the injury was followed by the development of a pulsating exophthalmos, which was at first thought to indicate an injury to

the internal carotid artery or its ophthalmic branch. The absence of any vascular murmur, however, negated this view, and on the man's death a few days later, the pulsation was found to have depended upon the protrusion of a hernia cerebri into the deep part of the orbit.



Fig. 36.—Pulsating exophthalmos, due to a hernia cerebri at the apex of the orbit.

At the root of the neck it is often difficult to make certain whether the injury has been to the carotid, the first part of the subclavian, the inferior thyroid, or the vertebral artery. I have seen the difficulty

in the case of all these vessels only cleared up by operative exploration. When the injury is purely arterial, the softness of a systolic murmur may suggest the vertebral as the injured vessel; but little faith can be put in such a diagnosis. When the lesion is arterio-venous, the difficulties are far greater, not only on account of the widespread area over which the murmur may be audible, but still more by reason of the transmission of the characteristic thrill from a minor branch to the current in the main vein.

The following case illustrates well the difficulties which may attend the establishment of a correct diagnosis when multiple wounds are present.

Case 12.—Multiple wounds from a bomb explosion. Arterio-venous injuries to vessels of neck and axilla.

An officer was admitted to a hospital on the lines of communication on the seventh day after being wounded by a number of fragments of a bomb. He was still suffering from the effects of severe shock. Two small wounds were situated over the course of the right common carotid artery, and one over the anterior axillary fold.

A pulsating hæmatoma was present in the lower part of the neck, and over this a purring thrill was marked, and a loud arterio-venous bruit was audible. The machinery murmur was conducted over the entire area of the chest, but not to the head. The murmur over the axilla was somewhat different in character, and the systolic element was widely conducted along the course of the brachial artery. The heart's apex was in the nipple line, the sounds were audible distinct from the adventitious bruit. The man's right hand was shattered.

The patient was kept at rest, but he picked up slowly, and three weeks later a probe was passed into a small opening at the posterior margin of the sternomastoid, on account of the persistence of a high temperature. This procedure was followed by hæmorrhage of a leaking character, and on the evening of the same day it was considered advisable to deal with the supposed wound of the carotid. An exploration made by Major Copeland, however, showed the aneurysmal sac to lie behind the great vessels, and that the wound was really one of the inferior thyroid artery and vein. I think it was quite impossible to have made a correct diagnosis in this instance except by operative exploration.

The bruits characteristic of vascular wounds are well marked in the neck, and discovery of these may lead to the detection of a lesion which otherwise would have passed unnoticed. Conduction of the systolic murmur to the cardiac apex is not common; but I have noticed it in a few cases, and the presence of such a bruit would suggest that examination of any minute or multiple wounds of the neck should be made.

Amongst injuries of the carotid arteries followed by the development of traumatic aneurysms, severe primary hæmorrhage was noted in only twelve. The nature of the wounds of the soft parts which accompanied these cases, and which has been already referred to,

sufficiently explains this observation, as also the experience that, when hæmorrhage did occur, it was readily controlled by a pad and bandage, or ceased spontaneously. When the track of the missile has crossed the larynx or trachea, or the pharynx or œsophagus, the bleeding may



Fig. 37.—Arterial aneurysm of external carotid artery.

be from the mouth, or blood may pass down into the air-passages or the stomach.

Extravasation into the tissues of the neck takes place mainly along the line of the vascular cleft, but its direction may be influenced

by that of the track of the missile, and considerable subcutaneous ecchymosis is not rare; the ecchymosis tends to spread by gravitation downwards over the front of the chest, or over the shoulder.

COMPLICATIONS.

Secondary Hæmorrhage.—This complication is met with in some degree of frequency. Thus, among 66 instances of perforating lesions, secondary bleeding occurred in 15. It formed the indication for operative intervention in 14 cases, and in 8 it proved the actual cause of death.

As in other situations, the occurrence of this complication is usually to be traced to infection of the wound; but, as has been pointed out already, the wounds in the patients who survive are of a type which frequently escapes infection. In two of the fatal cases a streptococcus and an anaërobic infection respectively were responsible for the accident, but in two others there was no reason to refer the bleeding to infection. Three of these cases are of sufficient interest to merit brief relation.

Case 13.—*Arterio-venous hæmatoma. Anaërobic infection. Secondary hæmorrhage. Death.*

The patient was wounded two days prior to admission; there was no information as to the occurrence of primary hæmorrhage, but the patient was ill and very anæmic. Temperature 101°; pulse 104.

A circular wound two and a half inches in diameter existed at the posterior border of the sternomastoid, two inches above the clavicular origin of the muscle. A small entrance wound at the back of the neck was closed. From the wound a dark brown discharge with a strong fæcal odour was escaping; the nurse indeed said that 'fæces' were coming out of the neck. *B. aërogenes capsulatus* was cultivated from the fluid.

Four days after the reception of the wound a sudden severe secondary hæmorrhage took place. This was arrested by plugging the wound with gauze soaked in adrenalin. On removal of the plug the next day some pulsation was noticed, and auscultation revealed the presence of an arterio-venous bruit. Shortly afterwards the patient became hemiplegic, and he died on the sixth day.

The right side of the neck is shown in *Fig. 38*. The opening, still occupied by blood-clot, is exposed, and leads down to an aperture in the internal jugular vein; the wound in the artery was not exposed. No laminated cavity had been formed; hence the condition was still that of an arterio-venous hæmatoma, in which the rare accident of acute infection had occurred. The hemiplegia was either thrombotic or embolic in origin, but unfortunately no examination of the brain was made.

Fig. 39 is of much interest as illustrating the size which collections of gas may reach in suitable situations in *B. aërogenes capsulatus* infections. The large space behind the pharynx and œsophagus contained gas only.

Case 14.—*Carotid-jugular arterio-venous wound. Secondary hæmorrhage in the absence of obvious infection.*

A man was admitted three days after the reception of a transverse

bullet wound of the neck. The aperture of entry half an inch below the upper margin of the left ala of the thyroid cartilage, and the aperture of exit at the margin of the right trapezius muscle, two and a half inches above the clavicle, were both minimal in size, and closed.

The skin of the left side of the neck was of an orange tint from fading ecchymosis, and there was some general swelling of the neck, but no localized tumour or expansile pulsation. The man was breathing quietly, but the



Fig. 38.—A dissection of the neck, showing the aperture of exit of a bullet track crossing the course of the right carotid artery and internal jugular vein, and establishing a communication between them.

A glass rod projects from the track, and the blood-clot seen in the opening is in direct continuity with the wound in the vein. The arterial wound has not been exposed.

The wound underwent anaërobic infection, and the patient died from secondary hæmorrhage, associated with left hemiplegia, on the sixth day. *Lieut.-Colonel Butler.*

voice was hoarse and low, the latter fact being ascribed to recurrent laryngeal paralysis. The pulse was 120, of fair strength, and regular. On auscultation a loud arterio-venous murmur was heard, most marked at the posterior border of the left sternomastoid muscle, in which position a bubbling thrill was also palpable and strong.

The man showed little distress, and for the next four days lay quietly in bed, the swelling of the neck steadily decreasing. He took food easily,

breathing was practically normal, and no suspicion arose that the vascular injury was not settling down as is usually the case.

At 8 p.m. on the tenth day after the injury, without any warning, about half a pint of bright blood was coughed up. I saw him at 9 p.m., when, except that he was rather excited, he seemed little changed. In view of the amount of blood coughed up, it appeared advisable to ligature the root of the carotid artery, or possibly deal directly with the wound in the vessels.



Fig. 39.—A mesial section of the same neck. A glass rod in the retropharyngeal space indicates the central portion of the track of the bullet. The retropharyngeal space itself is highly distended by gas emanating from the action of anaerobic bacilli, but no pus was present in the space. The condition illustrates well the fact that the extension of the gas precedes that of actual invasion of the tissues by the anaerobes, and renders the latter process more easy and rapid. *Lieut.-Colonel Butler.*

Open ether narcosis was chosen as the anæsthetic; nothing special was noted in the breathing except that the inspirations were shallow and the patient went slowly under the influence of the anæsthetic. As the first incision was made, the man ceased to breathe, and since there was evidently mechanical respiratory obstruction, I opened the trachea. Much fluid blood and clot escaped, but no relief was afforded, and the man died.

At the autopsy, the trachea and all the bronchial tubes were found full of blood and clot, there was massive collapse of the lower lobe of the right

lung, and localized patches of collapse in both right and left lungs. An enlarged thymus was present, and some post-operative ecchymosis of the mediastinal tissues. Beyond the presence of some enlarged mesenteric glands, no further visceral disease was discovered.

The condition of the vessels is shown in *Fig. 30*, p. 80. A double perforation of the vein and a lateral wound of the carotid are present, while the two vessels are separated by the left vagus nerve. The latter has been perforated, and beyond the blood which had collected within the confines of its sheath, no hæmorrhage of any moment has taken place into the vascular cleft.

Case 15.—Wound of superior thyroid vessels. Secondary hæmorrhage. Death.

A man was admitted two days after receiving a bullet wound. The bullet struck the tip of his nose, passed through the upper lip, wounded the tongue, and then entering the sinus pyriformis, travelled vertically down the neck. Its final resting-place was never localized.

There was considerable swelling of the right side of the neck, and some ecchymosis, but no evidence of the existence of an injury to the carotid vessels.

On the third day after admission two severe attacks of dyspnœa and some hæmoptysis occurred. In the second of these the man died.

At the autopsy, the trachea, bronchi, and lungs were swamped with blood, and there was septic pneumonic consolidation of both bases. Extravasated blood was present in the neck and in the anterior and middle mediastina. A large amount of blood had also trickled down the gullet, and the stomach was loaded with clot. No injury to the main carotid trunks had occurred, but the thyroid gland was much lacerated, and its capsule bounded a large hæmatoma.

Subsequent examination of the specimen for preservation in the Museum proved the injury to be limited to the branches of the superior thyroid artery. The hæmatoma was bounded by the capsule of the thyroid gland.

In this instance again, the uneventful development of the hæmorrhage was very striking. Until the first attack of dyspnœa the man appeared to be progressing well, and the moderate hæmoptysis excited little suspicion. There is no doubt that commencing infection influenced the occurrence of the secondary bleeding, and was perhaps mainly responsible for it.

The gradual unnoticed filling up of the lungs and stomach by blood welling up from the wound in the fossa pyriformis, I believe again to be explained by the presence of anæsthesia in the area of distribution of the superior laryngeal nerve consequent on the wound of the pyriform fossa and larynx.

Concurrent Injury to Nerves.—The two trunks obviously liable to injury are the vagus and sympathetic.

Vagus.—*Figs. 30* and *44* illustrate well a class of injury to which the pneumogastric is liable, in common with other nerves; in each the nerve has been perforated and hæmorrhage has occurred within its sheath. In both the nerve takes part in the formation of the channel of communication between the artery and vein. It might be thought that a lesion of this character and extent would give rise to symptoms

such as great disturbance of the pulse-rate, or variation in the rate and ease of respiration; but although both cases ended fatally, one from secondary hæmorrhage, the other from septic infection, in neither was the injury suspected during life. This being the case—and the observation is in consonance with the results of physiological experiment—it must be assumed that many minor injuries to the pneumogastric nerve, and perhaps many cases of complete severance, pass unrecognized. In a number of operations which I have performed, and others of which I have been a witness, I have never met with any totally destructive lesion, although in many cases the nerve has been tied up and immobilized by the scar tissue of the wound track, or in others had acquired a solid adhesion to the carotid artery which required dissection with the knife to separate it. The average pulse-rate in a large number of injuries to the carotid vessels which I have examined amounted to 88, with extremes of 62 and 120. In two cases in which grave infection was present, the rate reached 120, but the vagus could not be held responsible for these.

With regard to any general respiratory difficulties, again, I have never detected any indication of disturbance of vagal function; but local laryngeal symptoms are not uncommon, especially if the missile has penetrated or traversed the larynx. The most common sign is weakness or hoarseness of the voice; this is usually temporary, and may be referred in most instances to laryngeal concussion, or the local influence of the injury. In other instances definite unilateral abductor paralysis is observed, and this both in injuries to the upper and lower segments of the artery. This latter observation shows that abductor paralysis may follow injury to the trunk as well as local injury to the recurrent laryngeal branch, so that the sign is of little use in localizing the site of the arterial lesion.

The insidious manner in which blood may trickle through the larynx and flood the air-passages has already been referred to, and there seems reason to believe that this may depend on anæsthesia of the area supplied by the superior laryngeal nerve, and abolition of the cough reflex.

Cervical Sympathetic.—Evidence of injury to the sympathetic chain is often present, and in contrast to what occurs in the case of the vagus, it can scarcely escape recognition. General flattening of the face, sunken eyeball, slight ptosis and narrowing of the palpebral fissure, contracted pupil, and absence of sweating on the affected side of the head, are met with in varying degree in more than 12 per cent of all the cases of carotid aneurysm. In many instances the signs persist for months, and in some they are no doubt permanent. They are met with whichever part of the carotid is wounded. In some instances the signs are rather those of irritation than of ablation of

function ; in such the paralytic signs may be less marked, the eyeball may be prominent rather than sunken, and hyperidrosis may be present. In this relation it is of interest to note that the same susceptibility on the part of the sympathetic is sometimes exhibited in the form of unilateral flushing and sweating of the stimulated side after operations on the carotid vessels. The frequency with which signs of injury to the sympathetic are discovered is due to their obvious character, but a further factor of a mechanical nature of considerable importance enters into the question of the frequency of these injuries. The *vagus* lies in the comparatively loose and roomy vascular cleft, and is capable of very considerable displacement either laterally or in a forward direction ; while the sympathetic chain lies in intimate contact with the prevertebral layer of the cervical fascia, and in addition is more or less immobilized by the branches which pass laterally from its ganglia. Hence it is a comparatively fixed and immobile structure, more liable to suffer the full force of any missile which may traverse its course.

The remaining nerve lesions are of less interest ; but injuries to the hypoglossal and spinal accessory nerves are met with, especially in connection with lesions of the external or internal carotid arteries. Any of the branches of the cervical plexus may be damaged, and to low injuries of the carotid may be added signs of contusion or division of one or more of the cords of the brachial plexus. Instances of all these lesions are not uncommon.

CEREBRAL COMPLICATIONS.

It will be convenient to deal here with the whole question of cerebral complications, whatever be the nature of the lesion of the carotid vessels they follow, since there is no essential difference in the consequences observed.

The development of cerebral symptoms may be a sequence of uncomplicated wound of the common or internal carotid artery ; of contusion ; of local occlusion of the vessel by thrombosis ; of thrombosis extending widely into the cerebral vessels ; of embolism ; or of surgical occlusion of the trunks. Examples of all these conditions and sequences of events are given below, but we are practically ignorant of the factors which may determine the occurrence, or influence the gravity of the symptoms, in any individual case.

Certain conditions which certainly influence the incidence of cerebral symptoms may be first mentioned ; these are a considerable reduction in the total volume of blood in the general circulation following hæmorrhage, and the co-existence of a general toxæmia or septi-

cæmia. Of other possible factors, such as personal idiosyncrasy, variations in the mode of formation of the circle of Willis, the scheme of anastomosis of the cerebral vessels, the size and shape of the bony foramina by which the vessels enter the skull, or the manner in which the nerves supplying the arterial wall in any individual case may be implicated, we know little or nothing; while in the class of patients likely to suffer from gunshot injuries, the question of arterial degeneration seldom comes into consideration.

No doubt can exist as to the unfavourable influence exerted by the previous occurrence of a primary or secondary hæmorrhage, for this accident is seen not only to be of import in the case of the susceptible tissue of the brain, but also in determining the degree of muscular degeneration, or even gangrene, of a limb. The same may be said with regard to the ill effects of a condition of general toxæmia. The cerebral complications which follow interruption of the carotid circulation are, however, far more dramatic in onset and in gravity than those due to obstruction to the arterial supply of a limb, and in view of the special arrangements of the intracranial circulation which are calculated to reduce to a minimum the danger of interruption of any one source of blood-supply, they are still more striking. It is most disconcerting that one patient may develop signs of hemiplegia while still upon the operating table, or detected as soon as he recovers from the anæsthetic, while in others no sign of any disturbance whatever of the intracranial circulation can be discovered. Putting upon one side, moreover, actual cerebral symptoms, the opportunities for gauging the freedom of circulation in the carotid arteries is remarkably limited. Decrease in volume of the pulse in the branches of the external carotid, such as the temporal or the facial, may be of some aid; yet the cross-anastomosis between these vessels is so free that little weight can be placed upon a diminution of strength of pulse, for such diminution may be observed in patients in whom no cerebral signs develop, inequality of the two sides may not be marked when evidence of cerebral disturbance is certain, and it may be observed in the subjects of arterial or arterio-venous aneurysm in whom the vascular obstruction is not more than very partial in its nature. With regard to examination of the circulation in the branches of the internal carotid artery, Mr. Fisher has been kind enough to investigate for me the fundus oculi in a number of men whose common carotid has been tied fourteen to twenty-one days previously; in none could evidence of vascular disturbance be detected.

These observations raise the further question as to whether the extreme cerebral anæmia depends solely on the local obstruction of one of the sources of blood-supply, or whether to the local obstruction there is superadded a condition of vasoconstriction or vascular spasm

which augments and renders more persistent and harmful the anæmia induced by the occlusion of the carotid.

In the absence of evidence of vaso-contraction as an actual response to the stimulus afforded by a local injury to the vessel, it must be assumed that the lowered blood-pressure—a prominent feature if primary hæmorrhage has been abundant—combined with a deficient total volume of blood in the circulation, are the actual factors. The cerebral arteries, being more or less completely emptied by the sudden interruption of their main blood-supply, contract even to the degree of obliteration of their lumen, and the remaining blood-pressure proves insufficient to overcome the muscular resistance offered to their dilatation. This explanation obviously obtains, even if in lesser degree, when the lowered blood-pressure depends upon shock alone.

Some observations on the condition which has been described and designated as 'vascular stupor' (see p. 14), occurring as a result of contusion of the vessels of the extremities, has also a bearing on this question, since in that condition the bloodlessness of the peripheral circulation must be secondary to the local obstruction, which depends upon extreme and persistent local contraction of the artery at the site of the injury.

The observations of Leriche and Heitz,* although apparently based upon an incomplete appreciation of the actual anatomical arrangement and distribution of the nerve-supply to the blood-vessels, yet furnish experimental evidence of the vaso-constrictor effect produced by interruption of the continuity of the nervous chain in the case of the limbs, as seen after the performance of Leriche's operation of perivascular sympathectomy (see p. 56). Unfortunately, however, these phenomena cannot be considered applicable in the case of the cerebral circulation.

If the theory of lowered blood-pressure and an insufficient total volume of blood be the correct explanation, it is obvious that the correct method of treatment is the transfusion of blood, as the most efficient means of both heightening the pressure and supplying a proper supplement to the blood content of the body. As far as I know, this procedure has not until now been adopted.

Nature of the Cerebral Symptoms observed.—Little special description needs to be given of these. They may vary greatly in severity and distribution. In the most severe cases the patient may become at once unconscious, and later comatose, the onset sometimes being accompanied by restlessness or struggling. In other instances the loss of consciousness may be short, or mere drowsiness and mental

* *Lyon Chirurgicale*, xiv, No. 4, p. 754.

slowness may take its place. The local paralytic signs may vary in a similar manner: thus there may be temporary or permanent aphasia, paresis or paralysis of the limbs, temporary or permanent loss of power over the sphincters. In some cases aphasia, or loss of motor power in one limb only, may develop. In monoplegias, the upper extremity is the more frequently affected; the paralysis may be complete, or disturbances of sensation or loss of muscular sense may be the main feature. Great variations are seen in the distribution and severity of the sensory disturbances, and all these symptoms may be evanescent, temporary, or permanent in different instances.

The varying circumstances under which cerebral complications may follow injuries to the carotid arteries will be most satisfactorily set forth by a brief recital of some illustrative cases.

Case 16.—**Injury to the left common carotid artery. Thrombosis extending into the internal carotid trunk. Right hemiplegia.** (Under the charge of CAPTAIN ALAN CURRY, to whom I am indebted for the notes and specimen.)

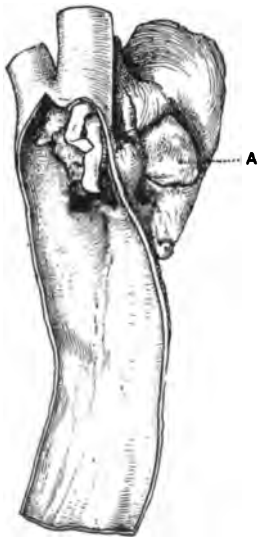


Fig. 40.—Wound of left common carotid artery. Local thrombosis of internal carotid and partial obstruction of external carotid. Localized external clot, and fragment of shell (A) projecting into wound.

Pte. R. was admitted into a casualty clearing station suffering with severe shell wounds of both legs, and a compound fracture of the left tibia and fibula. A small wound of entry was present over the thyroid cartilage in the mid-line of the neck. The man was drowsy and could not speak, there was right hemiplegia, increase of the right knee-jerk, no ankle-clonus, and an extensor response to stimulation of the sole. Temperature 99°. Pulse 110. No swelling or bruit could be detected in the neck, and the temporal pulses were equal.

The wounds were cleansed and dressed, and for the next two days the patient appeared to be progressing satisfactorily, but on the third day the left leg became gangrenous as a result of a wound of the posterior tibial artery, and was amputated.

Death occurred on the fourth day. At the autopsy a wound of the left common carotid half an inch below the bifurcation was discovered. The fragment of shell which had occasioned the wound projected into the opening in the wall of the vessel, while it was surrounded externally by a small incipient aneurysmal sac. On laying the artery open it was found that a thrombus completely obliterated the lumen of the

internal carotid branch, and partially obstructed the external carotid (*Fig. 40*). The internal jugular vein was uninjured.

There was well-marked softening of the basal ganglia of the left side of brain, but neither intracranial thrombosis nor embolism was present.

Case 17.—Complete severance of continuity of the right internal carotid artery. Local thrombosis. Left hemiplegia. (Under the charge of CAPTAIN G. L. KEYNES, to whom I am indebted for the notes.)

Pte. L. was admitted into a casualty clearing station with a wound of the neck. The bullet had entered over the left angle of the mandible, and emerged an inch and a half below the tip of the right mastoid process. The ramus of the jaw was fractured. There was some respiratory distress, inability to swallow, and the pulse was rapid and feeble. No external hæmorrhage was occurring.

On the evening of the second day the respiratory distress increased and the pulse became more feeble. It was considered advisable to perform tracheotomy, and the operation afforded the patient considerable relief. On the night of the third day he became hemiplegic, the temperature rose to 105°, and death occurred on the evening of the fourth.

At the autopsy, the right internal carotid artery was found to have been completely divided at the level of the aperture of exit. An ante-mortem clot occluded the lumen, extending downward for two inches and upward into the sigmoid bend in the cavernous sinus. No thrombus or embolus was discovered in the cerebral vessels; and beyond pallor, no naked-eye change was detected in the brain.

Case 18.—Minimal contused wound of the common carotid artery. Spreading thrombosis. (Under the charge of CAPTAIN H. B. WALKER, to whom I am indebted for the notes and the specimen—*Fig. 41*).

Pte. D. was brought to a casualty clearing station shortly after receiving several wounds. A wound of entry the size of a halfpenny was present in the right cheek, also a small perforating wound of the right pinna, and a superficial wound over the right mastoid process.

When taken to the theatre to have the wounds cleaned up, the man was drowsy, but no actual paralysis was noted. Pulse 72. Temperature 98°. Some blood-clot was present around the nostrils. A fragment of shell the size of a walnut was removed from the right pterygoid fossa, also some fragments of bone from the fractured mandible. No serious hæmorrhage occurred.

The patient remained in a drowsy condition, with a pulse of 60 and temperature of 97°, but his condition did not at first give rise to any special anxiety. During the night he became restless and tore off his dressings, and on the morning of the second day he had become comatose. The pulse was irregular, without periodicity, at times full and slow, at others rapid and feeble. The breathing was slow and stertorous. The right pupil was



FIG. 41. — Contusion and minimal wound of common carotid. Thrombosis of internal carotid, extending into cerebral vessels. The minute perforations are indicated by the two dark spots at the upper part of the carotid trunk.

dilated and fixed, the left narrowly contracted; there was extensor spasm of the limbs, with pronation of the arms. The abdominal reflexes were absent; spasticity of the limbs prevented elicitation of the tendon reflexes. The right plantar reflex was extensor, the left flexor.

A provisional diagnosis of fracture of the base of the skull, with possible middle meningeal hæmorrhage, was arrived at, but the condition of the patient was such that a projected exploration was abandoned and lumbar puncture substituted. Three drachms of clear fluid under no great pressure were withdrawn. Improvement followed this procedure, the pulse became slow and full, and the breathing less stertorous. As a last hope the middle meningeal area was then explored with the aid of local anæsthesia. The result was negative; as the dura showed no pulsation, it was opened, but no sign of congestion or of pressure was discovered.

Death followed shortly after the operation. No trace of injury to either brain or skull was found on post-mortem examination. The right internal carotid was noticed to have already become much larger than the left, and the latter was distended with ante-mortem clot. The left middle cerebral artery was also filled with clot, and downwards the thrombus extended to about $\frac{1}{2}$ in. below the lateral mass of the atlas. Opposite this process two small perforations, apparently the result of the vessel having been nipped between the fragment of shell and the bone, indicated the initial cause of the thrombosis.

† *Case 19.*—Wound of the right external carotid artery. Contusion and extending thrombosis of left internal carotid artery. (Under the care of CAPTAIN H. LAWSON WHALE, to whom I am indebted for the notes.)

Pte. S. was admitted into a stationary hospital with a wound at the junction of the right ala nasi with the cheek, the further direction of the track being apparently toward the left mastoid process. Immediately after admission, and before there was time to remove his clothes, a copious and persistent hæmorrhage occurred from the patient's mouth. It was doubtful from which internal maxillary artery the blood came, but as bleeding was checked by pressure over the right common carotid, the external carotid of that side was promptly ligatured. Within three hours from the time of operation, right hemiplegia was noted, and the man became comatose. The patient was seen by Colonels Gordon Holmes and Percy Sargent, who agreed that the slow pulse and accompanying signs suggested pressure from intracranial hæmorrhage, but considered that the patient's condition negated surgical intervention.

Death occurred a few hours later. At the autopsy, the right external carotid artery was found thrombosed for an inch beyond the point ligatured. On the left side of the neck a shrapnel ball was discovered lying in the fork of bifurcation of the common carotid; from this spot a continuous thrombus extended into the circle of Willis and into the branches of the middle cerebral artery as far as they could be traced into the fissure of Sylvius.

The above four cases afford post-mortem evidence of the nature of the primary lesion to the vessels, and of its ultimate consequences. It will be observed that in the first two, local thrombi developed at the site of the arterial wound; hence the obstruction corresponds in nature with that which might have followed the application of a ligature. In the second case, the occurrence of septic infection

cannot be disregarded as an influencing factor, and in a less degree this remark applies to the first case also. The fact that symptoms are accompanied by a high temperature must not, however, be estimated too highly as a sign of septic infection, since such rises commonly attend the development of arterial thrombosis.

The third and fourth cases, in which continuous thrombi extended to the middle cerebral artery, obtain special diagnostic interest. Both exhibited cerebral symptoms indistinguishable from those of severe intracranial pressure such as may accompany the occurrence of a hæmorrhage; hence in one an exploration was performed, and in the other taken into consideration. I have seen the same course taken in another case.

In a paper published in 1916,* a series of instances of injury to the carotid arteries accompanied by cerebral complications is discussed, and the cerebral symptoms are ascribed to embolism. In all of these the diagnosis was made on clinical grounds alone, and it appears clear in many of them that the nature of the symptoms and their localized character warranted the conclusion then arrived at. The post-mortem findings that we now have at our disposal, however, suggest that, in some of the more severe and complete, extending thrombosis was an equally probable explanation of the symptoms.

Some of these cases are again quoted; they are especially valuable, as Colonel Gordon Holmes kindly made the neurological examinations and notes, and in some of them the further progress can now be recorded. In those cases in which a non-perforating lesion was assumed, the distinction was made on the absence of bruit, purring thrill, pulsating tumour, or the occurrence of secondary hæmorrhage. Increased experience, however, shows that the presence or absence of these signs does not furnish sufficient grounds for establishing the distinction, and that in any of the cases minimal wounds, or even more extensive lesions, may have existed.

Case 20.—Non-penetrating lesion of the left common carotid artery.

The patient was admitted into No. 1 Canadian General Hospital under the care of LIEUT.-COLONEL FINLEY on Dec. 12, 1915, having probably been wounded a day or two earlier. He thinks the bullet entered by his mouth, and this statement is supported by the presence of scarring of the lip and fractures of the left premolar and incisor teeth. The wound of exit is situated two inches to the left of the fifth and sixth cervical spinous processes. Consciousness was not lost at the time of the accident, and the man walked a mile to a first-aid post with full power over his limbs. Twelve hours later, during the night, he suddenly lost power in the right upper and lower extremities, and his speech became affected. No fit occurred.

When admitted to hospital, there was complete flaccid palsy of the

* *Lancet*, 1916, ii, Sept. 23, p. 543.

right upper extremity, the left lower extremity could only be moved slightly, and aphasia was complete. During the succeeding fortnight some improvement took place, and the condition on Dec. 21 was as follows:—

“The wound of exit is healed; there is slight fullness over the left carotid artery, but no abnormal pulsation, thrill, or murmur. Pulsation in the temporal vessels is equal. There is some difficulty of speech, but the patient answers questions rationally. Pupils, both circular, and react to light; but the left is much smaller and ? no dilatation to shade and no skin sympathetic reflex. The left eye is sunken and the palpebral fissure narrowed. Both sides of the face are equally dry. There is considerable weakness of the right facial muscles, and the tongue is protruded to the right. *Motor system*: Right upper extremity somewhat wasted, especially distally; all movements are possible but much weaker than on the left side, distally proportionately more so. Slight rigidity of shoulder and elbow. No ataxia. Right lower extremity, all movements possible but weaker than left. No rigidity. *Reflexes*:—Arm-jerks: R. ++; L. normal. Knee-jerks: R. ++; L. normal. Ankle-jerks: R. ++; L. normal. Right ankle-clonus. Abdominal reflex: R. -; L. +. Plantar reflex: R. extensor; L. flexor. *Sensation*:—Touch unaffected. Pain unaffected. Position: R. diminished. Form lost. *Diagnosis*:—Cortical embolism.”

Seven months later the following note was made on the occasion of the man's discharge from the army as permanently unfit: “Aphasic; dysarthria. R. facial paralysis. R. arm useless. Paresis of left leg, but this is steadily improving.”

Case 21.—Non-penetrating injury of the right common carotid artery.

The patient was admitted into No. 1 Canadian General Hospital under the care of LIEUT.-COLONEL FINLEY. He had been wounded probably on Dec. 18. A superficial glancing wound of the scalp was present in the left occipital region, with no apparent injury to the bone (*x* rays); also a small irregular wound at the middle of the posterior border of the right sternomastoid muscle. Temporal pulses equal. Nothing abnormal palpable in course of carotid. Three days after infliction of the injuries left hemiplegia suddenly occurred. No fit. On Dec. 20 the man became incontinent and the left limbs spastic; also some rigidity of the right arm was noted. On Jan. 21, 1916, the condition was as follows:—

“The patient is dull and stupid, also incontinent. He complains of sharp pains in the left leg. Pupils: R. smaller than L.; the right eye is not sunken, but the palpebral fissure is smaller than the left. The right side of the face is less greasy than the left. Much weakness of left facial muscles. Tongue protruded slightly to the left. *Motor system*:—Left upper extremity powerless and somewhat rigid. Joint changes have developed. Left lower extremity rigid; the only movement that can be made is slight extension of the limb as a whole. Right lower extremity normal. *Reflexes*:—Arm-jerk: L. ++. Knee-jerk: R. normal; L. ++. Ankle-jerk: R. normal; L. ++. Abdominal: R. +; L. absent. Plantar: R. flexor; L. extensor. *Sensation*:—Touch: Definite loss on whole left side. Pinch: Sharper and sorer on left side. Position: General loss on left side. The application of cold, pinching, and scraping causes more pain and a greater reaction on the left than the right side. *Diagnosis*:—Embolism deep in the right hemisphere involving the internal capsule and the lateral aspect of the optic thalamus (thalamic syndrome).”

No improvement occurred before transference to England two weeks later.

Case 22.—Penetrating wound of the left common carotid artery.

Patient was admitted into No. 1 Canadian General Hospital under the care of LIEUT.-COLONEL GUNN about June 8. He had been wounded on May 21, 1916, and had been subsequently trephined, with a negative result. A gutter wound was present in the scalp just above the left pinna, also an irregular entry wound in the left side of the neck in the superior carotid triangle at the level of the upper margin of the thyroid cartilage, and an exit wound at the posterior border of the left sternomastoid muscle at about the same level. Both wounds were caused by fragments of a bomb. On June 9 the patient was still completely hemiplegic and aphasic. He emitted some articulate sounds, but could answer no questions, and no previous history was obtainable. The wounds in the neck were still unhealed; forcible pulsation was noted over the carotid, but no palpable tumour. The temporal pulses were equal. On auscultation, a soft systolic bruit was audible over the carotid in the line of the wounds. The heart was of normal size and no murmur was audible. On June 15 a severe secondary hæmorrhage occurred, and the common carotid artery was ligated by Lieut.-Colonel Hutchinson. An extensive laceration of the vessel was discovered in the upper third of its course. The operation was followed by an immediate slight improvement in the paralytic symptoms, the next day some words could be spoken, and eight days later some movements of the leg could be made. The patient was shortly afterwards transferred to England still improving.

Three months later, "the man was beginning to walk, and could move his arm and hand. His mental condition remained very depressed, and he could remember little of his past history." At the end of twelve months he was discharged from the army as permanently unfit.

Case 23.—Non-perforating injury to left common carotid artery.

Patient was admitted into the St. John's Ambulance Brigade Hospital under the care of MAJOR MAYNARD SMITH in January, 1916. He was wounded on Jan. 4 by a rifle bullet which entered the left side of the neck opposite the centre of the anterior border of the sternomastoid muscle, and passing obliquely transversely, emerged just in front of the right angle of the mandible. The man was not rendered unconscious, and one hour later he lost power in his right arm, and experienced for two days much difficulty in speaking: "Couldn't say what he wanted to." His lower extremities were never affected. Steady improvement took place, and a week later (June 11) speech was almost normal, the wounds were practically healed, no abnormal pulsation was palpable over the carotid, no bruit was audible, and the temporal pulses were equal. The following note was made:—

"*Motor system*:—Right upper extremity: No rigidity; all movements of the shoulder and elbow are possible, but weaker than those of the other limb. Extension of the wrist can be made occasionally, but the effort often fails; flexion of the wrist is not obtainable; no movements of the fingers can be made. The lower extremities are normal. *Reflexes*:—Arm-jerk: R. +; L. -. Knee- and ankle-jerks normal. Abdominal: Right less than left. Plantar: Flexor. *Sensation*:—Touch and pin-prick unaffected. Position and form lowered as to right hand. *Diagnosis*:—Small cortical embolism."

Case 24.—Non-perforating injury to right internal carotid artery.

Patient was admitted into No. 20 General Hospital under the care of CAPTAIN BURROWS in 1916. He was wounded on July 27 by a small

piece of shell-casing from a shell that burst close beside him. He fell at once, and has no definite memory of what immediately followed, but he was probably rendered unconscious. He says he was able to get up in about ten minutes' time, but was unable to walk in consequence of weakness of his left lower extremity; the left upper he only discovered to be weak after he reached the hospital on a stretcher. The wound consisted in a gaping slit about an inch long just anterior to the right tragus. X-ray examination showed the piece of shell behind the pharynx on the front of the body of the second cervical vertebra, where it was also palpable. The condition on Aug. 4 was as follows:—

“The man is quite intelligent, but has slight difficulty in articulation due to facial paresis. The right temporal artery cannot be felt to pulsate. The pupils are equal, and react normally. There is incomplete right peripheral facial palsy, and slight but definite paresis of the upper neurone type upon the left side. The tongue is protruded to the left, and the left side lies higher in the mouth. *Motor system*:—The right upper extremity is normal, the left flaccid and toneless. There is slight power of flexion in the fingers, but no power of extension, nor of adduction or abduction. Flexion and extension of the wrist are very feeble, and limited in range. The shoulder and elbow movements are stronger. In forced inspiration the right side of the chest moves better than the left. The right lower extremity is normal; the tone of the muscles of the left is fair, and all movements are possible, especially the more distal, but they are weaker than those of the right limb. *Reflexes*:—Arm-jerks: R. normal; L. feeble. Knee-jerks: Equal and brisk. Ankle-jerks: Equal and brisk. Abdominal: R. brisk; L. almost absent. Plantar: R. flexor; L. extensor. *Sensation*:—Considerable alteration in the sense of touch, but no complete loss, is present in the left side of the head and trunk and the left upper extremity. Contact produces tingling. Localization, sense of form, and position are all very defective in the left upper extremity.”

Of the above five cases four are of the class in which no perforating injury was considered to be present, but they offered no differences in history or character of the symptoms from those in which either an arterial bruit, an aneurysmal sac, or the occurrence of secondary hæmorrhage indicated the presence of an opening in the wall of the vessel—that is, conditions still more favourable for the formation of a thrombus.

This series of cases may be supplemented by the recital of two in which cerebral symptoms developed after operations, an embolism being responsible in one case, and a progressive thrombosis in the other.

Case 25.—*Arterial aneurysm of right common carotid. Ligature below the omohyoid. Cerebral embolism.*

A man was admitted on the fourth day after receiving a wound at the level of the upper margin of the right ala of the thyroid cartilage. The missile was retained. The blood spurted ‘as from a tap’ at first, and the patient fainted, but a pad was applied and hæmorrhage ceased permanently.

On admission, a pulsating tumour $2\frac{1}{2}$ in. by 3 in. was present at about the level of the top of the thyroid cartilage; there was a little

general œdema of the side of the neck, and ecchymosis along the line of the vascular cleft, extending down over the front of the first piece of the sternum. A loud simple systolic bruit was audible on auscultation. The patient improved when kept at rest, the pulse averaging 88, and the œdema of the neck decreased.

On the ninth day, some evidence of extension along the line of the vascular cleft suggested the wisdom of ligaturing the artery, and this was done by Captain Kelly. The ligature was placed below the omohyoid, and pulsation in the aneurysm ceased. The patient progressed well for four days, the aneurysm solidified, and feeble pulsation could be detected in the distal portion of the carotid.

On the fifth day after the operation, the patient, who had been bright and well all the afternoon, suddenly became drowsy and hemiplegic. On the twentieth day he was transferred to England, in fair bodily and mental condition, but still completely hemiplegic.

Little subsequent improvement took place.

Case 26.—Arterio-venous aneurysm. Suture of vessels. Progressive thrombosis.

The patient was suffering with an arterio-venous aneurysm of two years' standing. The sac was large, more than an inch and a half in diameter, and projected forwards in the anterior triangle of the neck. It was showing signs of enlargement, and caused some inconvenience from the buzzing sound at night.

Exploration disclosed a thick-walled sac springing from the right common carotid artery just below the bifurcation. The defect in the vessel wall was three-quarters of an inch long, and involved about half the circumference of the lumen. The artery was reconstructed by utilizing a flap cut from the wall of the sac, and the opening in the vein closed by a vertical line of suture.

The operation occupied two hours, and upon the same evening the temperature rose to 103°. The next morning the temperature had fallen to normal, and the pulse-rate was 96. Twenty-four hours after the operation the patient had hardly recovered consciousness; he was drowsy, and although he appeared to recognize persons, he did not speak. (G. H. M.)

The patient had been very restless during the night, and two injections of $\frac{1}{4}$ gr. of morphia had been administered. During the day improvement took place, and all four limbs could be moved. Urine was once passed involuntarily into the bed.

On the third day the patient was still very drowsy; he answered questions sensibly, but appeared rapidly to tire mentally. The aspect was decidedly cerebral, the face thin, pinched, and slightly cyanotic. He complained of headache on the right side, and of some difficulty in swallowing. The pupils were equal and reacted normally, and no weakness of the limbs was detected. No pulsation could be detected at the site of the suture.

On the fourth day there was left facial weakness, and numbness and some loss of power in the left hand, with loss of sense of position, and inability to discover the nature of an object placed in the hand. The lower limb was normal. The difficulty in swallowing had lessened. The patient was very slow in emptying his bladder, although he felt the desire to micturate. Cerebration remained slow, and efforts to talk rapidly tired him.

From this date steady improvement took place, and at the end of ten days the facial weakness was slight and the power of the arm had been practically regained. The carotids were pulsating freely at this date, suggesting that the primary thrombus had now been absorbed.

Table I.—TRAUMATIC ANEURYSMS ACCOMPANIED

No.	DATE OF WOUND	POSITION OF WOUND AND NATURE OF MISSILE	LOCAL PULSATION, THRILL, OR MURMUR	TEMPORAL PULSES INDICATING THROMBOSIS OR EMBOLISM
1	19.5.15	Small incised wound over left sternomastoid at level of angle of jaw. Fragment of shell	Arterio-venous aneurysm of internal carotid	Equal. ? Embolism
2	18.1.6	Large wound posterior border of sternomastoid. Shell	Arterio-venous hæmatoma, common carotid	—
3	6.7.16	Entry 3 in. directly below left external auditory meatus. Shell	Arterial hæmatoma, common carotid	Left temporal pulse absent. ? Thrombosis
4	10.5.16	Oval slit 1 in. behind anterior margin of right sternomastoid, at level of thyroid cartilage	Arterial aneurysm of common carotid	Right temporal pulse absent. ? Thrombosis
5	—	—	Arterio-venous aneurysm of common carotid	Equal. ? Embolism

BY CEREBRAL COMPLICATIONS.

DATE OF ONSET	SIGNS OF INJURY TO SYMPATHETIC	SIGNS OF CEREBRAL DISTURBANCE	PROGRESS AND COMPLICATIONS
Early	Right pupil dilated, left palpebral fissure narrow	Slight weakness right face, and tongue to right side. Motor system:—Upper extremity: L. normal; R. no power of movement. Lower extremity: L. normal; R. some tone, won't move on order, withdrawal on prickingsole. Sensory system:—Position: Much loss right hand and arm. No further tests possible. Reflexes:—Arm-jerk: +. Knee-jerk: + +; R. > L. Ankle-jerk: +. Abd.: R. 0; L. +. Plantar: R. extensor; L. flexor	No improvement
6th day	None	Complete left hemiplegia	Anaërobic infection. Secondary hæmorrhage. Death
—	Left pupil contracted	Difficulty in articulation and swallowing	Improved after ligation of the carotid
—	None	—	The common carotid was tied proximally. Improvement followed in condition of arm, but none in face and tongue
—	None	Tongue protruded to right. Right facial paresis. Right upper extremity powerless. Some tone in right lower extremity, but could not move it to order	—

Table II.—POST-OPERATIVE CASES

No.	DATE OF WOUND	POSITION AND NATURE OF WOUND	LOCAL PULSATION, THRILL, OR MURMUR	NATURE OF OPERATION
1	1.2.16	Wound at upper border of thyroid cartilage; missile retained left side 4th intervertebral disc	Arterio-venous aneurysm, common carotid	Ligature of carotid in 4th week
2	12.1.16	Through-and-through track from anterior border right sternomastoid to left sternoclavicular joint	Arterio-venous aneurysm on one side, arterial on other side, of neck, common carotid	Insertion of Tuffier tube on 37th day
3	23.7.16	—	Arterio-venous hæmatoma, common carotid	Ligature of artery on 4th day, for extension
4	16.8.16	Wound in posterior triangle; retained missile	Arterio-venous aneurysm, common carotid	Ligature on 16th day for secondary hæmorrhage
5	16.9.16	Missile entered through mouth and was retained	Arterial hæmatoma, common carotid	Ligature on 4th day for secondary hæmorrhage
6	1.9.16	Fractured jaw	—	Ligature of external carotid 8th day. Ligature common carotid 9th day for secondary hæmorrhage
7	—	Fractured jaw	—	Ligature of internal carotid for secondary hæmorrhage
8	15.5.16	Small through-and-through track at level of upper border of thyroid cartilage	Arterial hæmatoma	Ligature of common carotid on 11th day

ACCOMPANIED BY CEREBRAL COMPLICATIONS.

DATE OF ONSET AFTER OPERATION	SIGNS OF INJURY TO SYMPATHETIC	SIGNS OF CEREBRAL DISTURBANCE	PROGRESS AND COMPLICATIONS
1st day	—	Right hemiplegia and aphasia	? Embolic. Death
2nd day	—	Temporary loss of power in left arm. Headache. Vomiting	Died from general toxæmia a few days later. ? Embolic
3rd day	—	Complete hemiplegia	Died the night of operation. No naked-eye changes in brain
4th day	None; but sympathetic irritation (sweating) on same side after operation	Complete hemiplegia. Dull mentally. Limbs flaccid	Much improved at end of three weeks. Some movement of leg
5th day	None	Complete hemiplegia with aphasia	At end of 10th day aphasia gone and limb improving
6th day	None	Complete hemiplegia	No improvement in three months
7th day	None	Aphasia. Laryngeal paralysis	Death. Clot in middle cerebral artery, softening, and hæmorrhage into internal capsule
8th day	None	Complete left hemiplegia	Little improvement

Table III.—CASES OF MINOR INJURY

No.	DATE OF INJURY	POSITION OF WOUND AND NATURE OF MISSILE	LOCAL PULSATION, THRILL, OR MURMUR	TEMPORAL PULSES: INDICATING THROMBOSIS OR EMBOLISM
1	16.5.15	Small slit near anterior border of sternomastoid 1 in. below angle of jaw. No exit wound. Shell	Small circular area of induration. No abnormal pulsation. No murmur. Pulse 120 at first, fell to 84	? Left > right
2	--	Entry wound middle of right sternomastoid on level with thyroid. Exit wound in anterior margin left trapezius 1 in. lower level	No carotid pulsation. No murmur. Pulse 142	Absent on left side
3	12.12.15	Wound back of side of neck over trapezius opposite sixth cervical vertebra. Missile retained, or escaped by mouth	No swelling or pulsation. No murmur	? Diminished on left side
4	18.12.15	Entry right side of neck middle of anterior border of sternomastoid. Retained fragment of shell. (Left scalp wound.)	No pulsation or thrill. No murmur	Equal on the two sides
5	--	Entry anterior border of sternomastoid right side 1 in. above sternum. Retained over spines of 6th and 7th dorsal vertebrae. Bullet	No pulsation or thrill. No murmur	Equal on the two sides
6	21.5.16	Entry and exit small, over left carotid. Left scalp wound; trephined; nil found. Bomb	Soft systolic bruit. No conduction	Equal on the two sides
7	4.1.16	Entry centre of anterior border of left sternomastoid. Exit just in front of angle of jaw, right side. Bullet	No pulsation or thrill. No murmur	Left temporal pulse absent
8	3.1.16	Entry wound just in posterior margin of middle of left sternomastoid. Shell	No pulsation or thrill. No murmur	Equal on the two sides

ACCOMPANIED BY CEREBRAL COMPLICATIONS.

DATE OF ONSET	SIGNS OF INJURY TO SYMPATHETIC	SIGNS OF CEREBRAL DISTURBANCE	PROGRESS AND COMPLICATIONS
---	No evidence	Unconscious at first. Mental condition improved. Speech not bad. Difficulty in reading and writing. Motor system :—Right hemiplegia	Died
---	Pupils, right > left. ? Sweating more left side of face	Right face very weak. Motor system :—Upper and lower extremities : L. normal ; R. no power of movement ; slight rigidity of right limbs. Sensory system :—Reacts to pin-prick on both sides. Reflexes :—Arm-jerk : L. + ; R. 0. Knee-jerk : R. > L. Ankle-jerk : R. > L. Abd. : L. + ; R. 0. Plantar : L. flexor ; R. extensor	—
—	Pupils, right > left. Slight ptosis	Motor aphasia. Weakness of right face. Tongue deviates to left. Motor system :—Weakness right upper extremity. Some rigidity at elbow	Aphasia and paralysis improved
---	Left pupil > right	No mental change. Motor system :—Upper and lower extremities : L. no power of movement ; R. normal.	Rigidity in left arm after three days' interval, which increased, with a great deal of pain
---	No evidence	Dull and stupid. Motor system :—Upper extremity : L. no power of movement ; R. brachial monoplegia. Paraplegia paralysis of bladder and rectum	No improvement took place. Transferred to England
---	No evidence	Aphasic. Quite conscious. Motor system :—Upper and lower extremities : L. normal ; R. no power of movement	Improved after ligation of carotid for secondary hæmorrhage
---	Pupils, left > right	Mental condition normal. Motor system :—Upper extremity : L. normal ; R. forearm paralyzed, and biceps and triceps slightly. Lower extremity : L. and R. normal	Went home nearly well
---	Pupils, right > left. Left palpebral fissure narrow. Left side of face more flushed	Dull and drowsy. Motor aphasia. Right side of face weak. Motor system :—Upper extremity : L. normal ; R. flaccid, distal movement very weak. Lower extremity : L. and R. normal	Went home considerably improved. Right arm better. Speech better

Continued on next page.

Table III.—CASES OF MINOR INJURY

No.	DATE OF INJURY	POSITION OF WOUND AND NATURE OF MISSILE	LOCAL PULSATION, THRILL, OR MURMUR	TEMPORAL PULSES: INDICATING THROMBOSIS OR EMBOLISM
9	24.1.16	Entry $\frac{3}{4}$ in. to right of 4th cervical spine. Exit 1 in. outside right angle of mouth. Bullet	No pulsation, thrill, or murmur	Equal on the two sides
10	27.7.16	Irregular gaping wound about 1 in. long immediately in front of tragus. Shell (retained)	No pulsation, thrill, or murmur	Right temporal pulse absent
11	25.9.16	Entry left side of chin. Exit posterior triangle	Swelling left side of neck. No pulsation or murmur	Equal on the two sides
12	6.4.17	Small entry wound over thyroid cartilage in mid-line	No tumour, pulsation, or bruit	Equal on the two sides
13	20.2.17	Small entry wound at left angle of mandible. Exit below right mastoid process	No tumour or pulsation	—
14	30.1.17	Centre of right cheek. Right pinna. Right mastoid process	No tumour or pulsation	—
15	18.7.16	Entry at junction of right alar nasi with cheek	No tumour or pulsation	—

COMPANIED BY CEREBRAL COMPLICATIONS—continued.

DATE OF ONSET	SIGNS OF INJURY TO SYMPATHETIC	SIGNS OF CEREBRAL DISTURBANCE	PROGRESS AND COMPLICATIONS]
---	Left pupil > right. Right face more flushed	Left face paralyzed (supranuclear). Motor system:—Upper extremity: L. rigid and completely paralyzed; R. normal. Lower extremity: L. rigid, slight voluntary movement at hip only; R. normal. Sensory system:—Entire loss left side. Reflexes:—All increased left side. Plantar reflex extensor on left side	---
---	No evidence	Incomplete peripheral facial palsy right, and slight upper neurone paresis left side. Motor system:—Upper extremity: L. flaccid and toneless, some power; R. normal. Lower extremity: L. movements weaker than right side; R. normal. Sensation diminished on left side. Reflexes diminished. Plantar reflex extensor on left side	---
9.16. Drowsy.	Pupils equal and contracted	Right hemiplegia. Aphasia. Facial paralysis. Incontinence of urine and feces	Slight improvement on transfer. Not continued.
9.16. Excited, hemiplegic, and aphasic			17.10.16. Slight right facial paralysis. Right hemiplegia. Very slight movement of right leg. Knee-jerks ++. Ankle-clonus. Thick speech. Lingual paralysis. Muddles words. Incontinence improved. Right arm total paralysis.
			1.10.17. Facial paralysis slight. Can flex right arm; no extensor power. Fingers contracted, but can be straightened. Can flex thigh, knee, and ankle. Foot stiff and inverted. Knee- and ankle-clonus.
mediate (?)	Pupils equal and reacted	Right hemiplegia	Died 5th day (Case 16).
1 day	---	Complete left hemiplegia	Died 4th day (Case 17).
rowsy nmediately	---	Coma. Signs of compression	Died 2nd day (Case 18).
d or 3rd day	---	Right hemiplegia. Coma	Died 3rd day (Case 19).

Mode of Onset, Variations in Degree of Severity, and Prognosis in Cases attended by Cerebral Complications.—The mode of onset after ligature of the common carotid artery is fairly constant. As a rule the cerebral symptoms are either immediate, or noticed in the course of a few hours. When, after the application of a proximal ligature, the distal segment of the vessel is left in communication with the sac of an aneurysm, the detachment of an embolus may take place after a few days, or even at a more remote period. Two such cases are recorded in *Table II* (Nos. 7 and 8).

When the cerebral symptoms follow thrombosis of the artery, it is far more difficult to say when they are likely to develop. In some of the cases recorded above they were immediate, and the course of events is identical with that seen after occlusion of the vessel by ligature. In other instances the symptoms were delayed, and then it is reasonable to assume that the thrombosis was of the extending variety. This conclusion, however, is open to much doubt, since an extensive thrombus may form without any apparent ill result; thus, the internal carotid artery in the neck has been seen to be blocked throughout during the course of an operation for ligature of the common carotid, and yet no signs existed at the time or developed afterwards. When the symptoms first become apparent at a later date, it seems reasonable to assume the lodgement of an embolus; but here again the mere question of date helps us little, and a certain diagnosis is more likely to be made when the paralysis is incomplete, by a careful consideration of the focal signs present as a means of locating the position of the embolus.

The general lines upon which a diagnosis is to be based have already been mentioned; it remains to impress the experience that it is easy to mistake signs due to a purely vascular disturbance for those of compression resulting from injury to the brain, or intracranial hæmorrhage. Two of the cases related above illustrate this point. I saw a third in which a trephine opening had been made; and in a fourth (No. 4, *Table III*), bilateral symptoms, in conjunction with the presence of a scalp wound on the opposite side of the head, suggested a combination of contusion of brain and possibly hæmorrhage on one side with vascular disturbance on the other. The existence of an optic disc in the early stage of papillitis, so commonly seen in conjunction with the œdema of the brain occurring in the early stage of cerebral injuries, might prove a useful diagnostic point.

PROGNOSIS.—Reference to the tables gives some idea of the gravity of cerebral complications in vascular disturbance, but it must be remembered that the series of cases here recorded are all of a severe type. All except the first four (which terminated fatally) were observed in general hospitals on the lines of communication—that is,

some days after the reception of the injury. This fact tends to show that, while on the one hand fatalities may be even more numerous than was the case here, yet time enough had elapsed for patients with evanescent symptoms to have got over their troubles without the real nature of the signs having been discovered. We are well aware that the pareses and even paralyses which may follow ligation of the common carotid artery are sometimes very transient, sometimes persistent, sometimes followed by a fatal issue; and there can be little doubt that the similar conditions due to vascular disturbance from thrombosis or embolism may follow the same course. We also know that thrombosis of the carotids may give rise to no symptoms whatever; further, that when paralysis does occur, the patients are either unconscious of it, or unwilling to recognize it. Hence we are justified in the assumption that the proportion of patients in whom the symptoms are transient or slight is far greater than the series under consideration would suggest.

The material furnished above may be shortly summarized as follows:—

Amongst 14 cases in which the common carotid artery was ligated for the treatment of secondary hæmorrhage, hemiplegia developed in 3 (21·4 per cent); in one of these death occurred within twenty-four hours, in a second the hemiplegia and aphasia improved, and in a third it was persistent.

In 13 cases in which the operation was undertaken for the early treatment of either arterial or arterio-venous hæmatomata, hemiplegia developed in 5 instances (38·4 per cent). In one patient the paresis was transient; in one partial recovery ensued; in one the paralysis persisted with little improvement; and in two death resulted. One death took place within twenty-four hours; the second was not directly the result of the arterial injury or of its treatment, the patient dying of general infection from multiple wounds, and the paralysis was transient and of the upper extremity only.

If these two short series be combined, we have a total of 27 cases of ligation of the common carotid, in 8 of which (29·6 per cent) cerebral complications ensued, and 3 of the patients succumbed, two as a direct consequence of the operation; only one of the eight patients recovered his normal state.

The prognosis in the 15 cases of cerebral complications consequent on minor injuries to the vessels, followed either by thrombosis, or thrombosis and embolism, is still more grave; but in this instance the fact already mentioned must receive full recognition, i.e., that we are in complete ignorance of the number of such injuries in which traumatic thrombosis has led to no evil effect whatever, and perhaps of the still larger number in which transient

phenomena have been present, the real significance of which was not appreciated.

Amongst the 15 cases, death occurred in 5 (33·3 per cent) during the first four days. Only one instance of transient paresis and complete recovery was observed. In the remaining 9 patients, although improvement occurred in 5, all were discharged from the army as permanently unfit, and probably none are ever likely to be able to follow any active work.

One remarkable observation was made in two of the cases under consideration—ligature of the common carotid artery being apparently followed by a distinct improvement in the symptoms. It is difficult to explain this sequence except upon the theory that complete obstruction of the partially occluded artery led to a greater degree of compensatory dilatation in the remaining vessels.

DEVELOPMENT OF TRAUMATIC ANEURYSM.

Arterial Hæmatoma and False Traumatic Aneurysm.—Amongst 58 cases of aneurysm, 10 were purely arterial in origin and nature, the remaining 48 being of the arterio-venous variety. This disparity in the case of the carotid vessels is to be explained in more than one way. First, the cases from which the above numbers were drawn were all observed in hospitals either upon the lines of communication or at the base at home. Thus, all cases in which hæmorrhage, early increase in size of the hæmatoma, or the attendant wounds of the soft parts, were extensive, are eliminated. Secondly, the long and intimate relation of the carotids and the internal jugular vein affords particularly favourable conditions for contemporaneous injury to the two vessels. Thirdly, pure arterial hæmatomata are more liable to continuous increase in size, or secondary extension, than those of the arterio-venous variety, because the safety-valve afforded by the open vein is absent. The powerful suction action exercised by the induction of negative intrathoracic pressure during inspiration renders this latter point of special importance in carotid arterio-venous aneurysms.

The same reasons explain the fact that the sacs of arterial aneurysms commonly reach a larger definite size than those of the arterio-venous variety. In the early stages those in the upper part of the course of the vessel tend to be the larger and more irregular in outline, as the firm support afforded to the lower part by the depressor muscles of the hyoid bone and the sternomastoid is wanting.

The artery itself tends to be displaced in the direction of least resistance, that is, towards the mid-line or forwards, but in some cases the aspect on which the vessel is wounded may determine both the

position of the sac and the direction in which the vessel is displaced. In others, the position of the sac is determined by that of the track made by the missile, and it may be situated in the actual substance of a muscle such as the sternomastoid or those of the prevertebral region.

A fully-developed sac assumes a more or less rounded outline as a rule. Spontaneous consolidation is possible: I have seen it occur in the stage of wounded artery with a minimal hæmatoma, but never

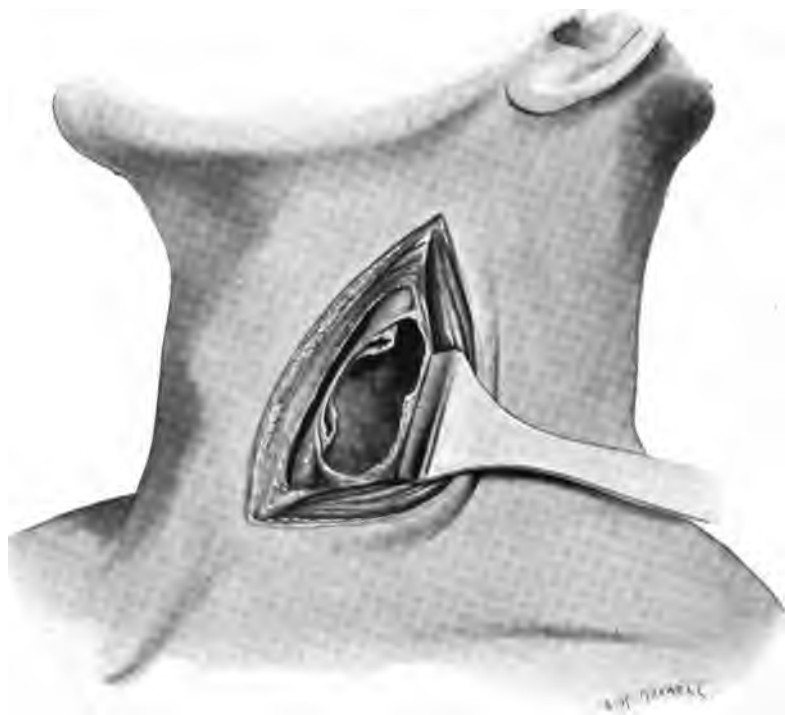


Fig. 42.—Carotid arterial aneurysm. The sac has been opened. The drawing illustrates the part taken by the remaining strand of the wall of the vessel in the formation of the sac, also the anterior displacement of the artery.

when a sac of any extent had formed. The general tendency, however, is towards decrease in size during the early months. I have known one arterial aneurysm to rupture as the result of violent exertion after four years of quiescence; and in another case the sac persisted without any great increase in size for six or seven years, the patient eventually dying when under an anæsthetic for an operation. The latter was determined upon in consequence of the patient developing occasional

fits, which were increasing in frequency, and which it was suspected might be due to the passage of small emboli from the sac to the brain.

The systolic bruit accompanying an arterial aneurysm is occasionally conducted to the cardiac apex or the base of the left ventricle. I have seen three examples of this.

Arterio-venous Aneurysm. — As has been already mentioned, this variety is comparatively common in the neck. The sacs are not as a rule of large size, and this again may be referred to the safety-valve provided to the hæmatoma by the open vein. They may be situated between the artery and vein, in connection with one of the arterial wounds alone, or in both situations. If the sac is interposed between the vessels, it is, in my operative experience, of small size. In one instance in which I operated, the sac was situated behind the vessels, extending into the substance of the prevertebral muscles, and artery and vein communicated with it by separate openings on their posterior aspect. In another, the blood streaming from a lateral wound of the common carotid passed by means of the sac into the open lower end of the internal jugular vein. The upper end of the vein was closed, and the fragment of shell which had caused the injury was enclosed within the aneurysmal sac.

Great dilatation of the vein is a constant feature; it pulsates freely, and in many instances forms the major portion of any tumour which may exist. The wall of the vein becomes at an early stage considerably thickened (see *Fig. 43*). I have never seen a true venous sac. The wall of an arterial sac is firmer than the thickened vein, but the sac may be tucked away laterally or behind the vessels, where it is difficult to feel.

Visible pulsation of the veins in the posterior triangle is not uncommon, and the purring thrill is usually well marked and extensive in distribution. It is well to bear in mind that thrill palpable in the jugular vein by no means always indicates a wound of the main vein itself; it is often strongly conducted even when a branch of moderate size is the vessel implicated.

Signs of venous obstruction in the peripheral veins are uncommon. I have never seen them.

The local murmurs in the neck are loud and widespread, often so strong on the opposite side as to suggest a bilateral lesion. The conducted murmur on the sound side may be of a somewhat different character, the systolic element being softer and more 'blowing' in type. The sounds can usually be heard over the upper part of the chest and the whole precordial area, but the heart sounds are distinct from the adventitious bruit. In a small proportion of all cases, however, the systolic element transforms the first sound into a bruit at the base, or even at the cardiac apex.

Many of the patients complain of the 'buzzing' sound in the head and ears; it may be especially troublesome in the opposite ear. If this be an early symptom it tends to wear off, but when it recurs upon resumption of active life after a period of rest, it may be persistent. The noise is increased on stooping, and in patients of a nervous temperament it may be a serious trouble, particularly when the sufferers are at rest in the recumbent position in bed.

I have never seen a case of carotid arterio-venous aneurysm get well spontaneously if left untouched.

Aneurysmal Varix.—The anatomical conditions are particularly favourable to the development of pure arterio-venous communications without the intervention of a sac. *Fig. 27* illustrates a direct varix of immediate formation. *Figs. 30, 44*, depict two instances in which an intermediate structure, the vagus, is traversed by the channel of communication between the vessels. It is difficult to forecast what would have been the ultimate condition in either of these two lesions, but it may be assumed with a certain degree of confidence that the injury depicted in *Fig. 44* would have ended in the formation of an intermediate sac, the remaining fibres of the vagus being incorporated in the wall.

The signs and symptoms of aneurysmal varices in the neck so nearly simulate those of arterio-venous aneurysms, that, in the absence of a large sac, it is difficult to distinguish the two conditions clinically. A diagnosis really depends upon size, and definite evidence of the presence of a sac, and, as we have seen, the latter may be small.

The tendency is for these communications to contract, and in some cases there is no doubt they close spontaneously. I have twice seen the latter result, but in each instance the volume of blood flowing through the carotid had previously been reduced by proximal ligation of the artery in order to obtain consolidation of an aneurysmal sac.

GENERAL PROGNOSIS IN CASES OF CAROTID INJURIES.

From a consideration of this series of cases it must be assumed that wounds of the carotid arteries are attended by a very large primary mortality. This is shown by the following facts. I never saw a successful case of actual primary ligation of the vessel in the hospitals on the lines of communication or at the base during a period of four years; and although four cases of early ligation are included, in three of these the wound of the vessel was only discovered during operations for the removal of retained foreign bodies, and in the fourth the operation was undertaken on account of steady increase in the size of the hæmatoma. In only one of the whole series here dealt with did a large wound of the soft parts accompany the injury to the artery, and

no case is included in which the vessel was found thrombosed and lying in the floor of a wound of the neck. It only remains to repeat that the infrequency of wounds of the lower third of the common carotid, and the fact that operative procedures have not disclosed complete severances of continuity of the trunk, also point to the fatality of injuries of these classes.

The mortality in this whole series of 85 injuries observed on the lines of communication or at the base, amounts to 13 (15·2 per cent). Three deaths were to be ascribed to concurrent injuries of other parts, three resulted from secondary hæmorrhage, one occurred during chloroform anæsthesia, and six were consequent on cerebral complications.

The question of the occurrence of cerebral complications in injuries to the carotid vessels, and the results of operative treatment, have been dealt with in other sections.

The surgeon is chiefly concerned with the complications that follow upon operation, and in this respect it is clear that the danger is only great when the operation has to be undertaken as an urgent measure immediately, or during the first days that follow the reception of the injury. In remote operations the danger is not great; and although the numbers supporting the opinion are small, yet it may be confidently stated that the dangers in any case are diminished by simultaneous occlusion of the jugular vein.

Arterial Aneurysm.—Of the 10 arterial aneurysms contained in the series, none died. In 3, nerve complications were present, the injury being to the seventh nerve in 1, to the recurrent laryngeal or vagus in 1, and to the brachial plexus in 1. Five patients were sent home without operation, and in 1 of these spontaneous cure took place. Five cases were operated upon, the indications being secondary hæmorrhage in 1 (internal carotid), extension of the aneurysm during the hæmatoma stage in 3, and expediency in 1. In 2 cases cerebral complications followed upon operation: in one, a transient hemiplegia probably due to anæmia; in the second, permanent hemiplegia due to embolism. The operations were in 1 case proximal ligation, followed by embolism, the clot probably originating in the sac; in 1 case (internal carotid) proximal ligation and plugging of the sac; in 2 cases proximal and distal ligatures were applied to the artery; and in 1 case both artery and vein were ligatured. Transient hemiplegia followed one of the operations in which the artery only was dealt with.

Arterio-venous Aneurysm.—The 48 arterio-venous aneurysms and varices were distributed as follows: common carotid 38, external carotid 6, internal carotid 4.

Concurrent nerve lesions exercised no obvious influence on the course of the cases. In at least 10, signs of paralysis of the cervical

sympathetic were present, and in 2, signs attributed to irritation. In 2, serious lesions of the vagus, one on the right and one on the left side, were discovered at operations, but no signs leading to detection of the injury had been noticed. There may well have been many others in the series. Laryngeal paralysis due to concussion was observed in several cases; in 5, unilateral abductor paralysis indicated injury either to the recurrent laryngeal branch or the trunk of the vagus.

Cerebral complications occurred in 6 of the cases. In 6, hemiplegia was the direct result of the injury to the artery; in 1 it followed anaërobic infection of the wound of the neck; in 1 it was an immediate consequence of ligation of the common carotid artery, and in 1 a secondary consequence due to the detachment of an embolus; in 1 it resulted from thrombosis.

Death occurred in 9 instances (18·7 per cent). In 6 of these it was due to other conditions: cerebral injury 1, anaërobic infection of wound of neck 1, general infection 1, spinal meningitis 2, death under chloroform anæsthesia 1. One patient died from secondary hæmorrhage, 1 from acute cerebral anæmia following ligation of the common carotid, and 1 from cerebral embolism after ligation of the carotid.

Of the surviving 39 patients, 26 were sent home to England in good condition, and of many it has proved impossible to follow the further course.

Fourteen were operated upon, the indications being: secondary hæmorrhage 1, extension of aneurysm 5, expediency 2, remote operations 6. In 6 the operation consisted in ligation of artery and vein above and below the wounds and clearance away of the sac: 4 of the operations were successful, and 2 patients died, both from cerebral complications (anæmia 1, embolism 1). In 1 the sac was left untouched. In 7 cases, all of the remote class, the wounds in the vessels were sutured and the sac removed after the aneurysm had settled down; all these cases recovered, and—as far as could be judged after observation for several weeks—with persistence of the lumen of the vessels; in one, temporary cerebral symptoms followed, due to thrombosis.

It may be assumed that these 12 patients resumed ordinary life. I believe the same may be said about the patients who were returned to England with aneurysmal varices, as these cases usually suffer little inconvenience. Two patients upon whom I operated in 1900 have remained well since; one of them was in command of a battalion and was thrice wounded in the present war.

I have twice watched the gradual close and spontaneous cure of carotid aneurysmal varices.

TREATMENT OF INJURIES TO THE CAROTID ARTERIES.

In the primary treatment of these injuries, the ordinary rules guiding the surgeon in other parts of the body are to be observed. In view, however, of the grave consequences which may ensue in the event of recurrent or early secondary hæmorrhage occurring, very special care must be taken not to overlook an arterial injury, and in the case of a hæmatoma developing when the apertures of entry or exit of the soft parts are of any considerable size, temporary cessation of bleeding should not be regarded as sufficient justification for taking up an expectant attitude. The risks are particularly great should any doubt exist as to the practicability of maintaining the wound in an aseptic condition.

When the wounds of the soft parts are of the minimal type, whether they are through-and-through tracks or the foreign body is retained, if hæmorrhage has ceased, an expectant attitude is preferable; especially if a considerable amount of blood has been lost, if symptoms of shock are present, or if the conditions under which the operation has to be undertaken are not entirely satisfactory. Under any of these circumstances the risk of delay in active intervention is far less than that attendant on sudden occlusion of the carotid vessels at a period when the general blood-pressure is probably low.

When the primary stage has been passed, the indications for operative intervention may be summarized as follows: (1) Secondary hæmorrhage, either from the external wound or from the mouth; (2) Extension of a hæmatoma, whether arterial or arterio-venous in nature; (3) The development of pressure signs such as dyspnœa or dysphagia; (4) For the cure of a traumatic aneurysm.

When secondary hæmorrhage forms the indication, in no other part of the body is it so important to make sure that the source of the hæmorrhage is really from the parent trunk; in not a few cases the common carotid has been occluded when the wound was really situated in the external carotid or one of its branches, and in some of these with fell results. To avoid this unsatisfactory occurrence, even if the ligature has to be applied in haste, it should not be permanently knotted until further investigation has shown that the parent vessel must be sacrificed. When branches of the external carotid are the obvious source of secondary hæmorrhage from the neck, as in cases of fractured jaw, Captain Burrows* has shown that when it is not possible to secure the actual bleeding point, proximal ligature of the branches, especially of the lingual, is preferable to occluding even the

* *British Journal of Surgery*, 1917, vol. v, No. 17, July, p. 137.

external carotid, and this experience, after all, coincides with that afforded by the treatment of hæmorrhage in other parts of the body.

In estimating extension of a hæmatoma as an indication for intervention, it is well to remember that variations in size are not uncommon, and may be observed from day to day in the early stages. These variations may depend on changes in the blood-pressure, on a varying amount of œdema, or on unnecessary movements on the part of the patient, and are not always to be too highly estimated.

Dyspnœa or dysphagia is generally a sign not to be disregarded, and in relation to the former, it may be pointed out that direct treatment of the hæmatoma at once relieves it, and care should be exercised that a preliminary tracheotomy is not unnecessarily undertaken, as has sometimes been the case.

When the existence of a well-localized hæmatoma or false aneurysm, either arterial or arterio-venous, forms the indication, the principal question which arises is as to the most suitable moment for intervention. Spontaneous consolidation is rare in arterial, and I do not believe it ever occurs in arterio-venous aneurysms. The presence of the condition is an actual bar to normal active life, hence ultimate intervention must be the rule. For reasons of economy of time, it stands to reason that the sooner the cure is undertaken the better. At the same time, as far as my own experience goes, reasonable delay under suitable conditions has obvious advantages. The local conditions improve; the collateral circulation adapts itself; while, in addition, delay allows the tissues to resume as far as possible their natural state. The last condition renders the surgeon absolutely free to undertake a plastic operation wherever this is possible, and in the case of the carotid vessels this is a manifest advantage. Speaking generally, I think whenever the aneurysm has fully localized itself, operations should not be undertaken before six weeks to two months have elapsed; and, from the surgeon's standpoint, the later he gets the case after this period, the more likely is he to have a free hand to perform an operation which approaches the ideal from the reconstructive point of view.

Aneurysmal varices often occasion very little trouble or disability to the patient. The most common indications for intervention are the persistence of worrying noise in the head or ears, or great distention of the vein. A large proportion of these cases may be left untouched.

A tentative suggestion should perhaps be made as to the advisability of completely obstructing the common carotid in cases of arterial thrombosis, with a view to stimulating the development of the collateral circulation. In the only two instances I have seen, a definite

improvement in the symptoms appeared to follow, and it cannot be supposed that the procedure is likely to cause any harm.

Mode of Operation.—In recent injuries, the nature, extent, and position of the wound of the neck will probably determine the incision necessary for securing the artery ; but when the operation is one for



Fig. 43.—Left carotid arterio-venous aneurysm. Exposure of jugular vein. The vein completely covers the artery. The characteristic infiltration and thickening of the adventitia of the vein seen in recent cases is well shown.

dealing with an aneurysm, the incision needs to be a very free one, extending the entire length of the anterior border of the sternomastoid. In some instances it may need to be further extended by an incision carried outwards from its centre, or one along the clavicle from its lower

angle, according to whether the upper or lower portion of the neck is the seat of the aneurysm. In difficult cases it may also be necessary to divide the muscles freely; thus, the sternomastoid may be divided well below the entrance of its nerve supply and reflected, the depressor muscles of the hyoid bone may need to be divided, and the omohyoid in most cases where an aneurysm has to be dealt with in the centre of the neck.

This freedom of access is necessary as a precautionary measure when the aneurysm is large, and also to allow the upper and lower portions of the vessel to be exposed for the purpose of applying provisional ligatures to control the circulation and permit the necessary manipulation of the sac if a plastic operation is determined upon.

When the actual field of operation has been exposed by the preliminary incision, it is best to deal at once with the veins crossing the line of the artery. The descending cervical nerve should be spared, if possible. The anterior jugular vein and the common facial vein may need to be doubly ligatured and divided. We are now free to deal directly with the main vessels. If the aneurysm be arterio-venous, the internal jugular vein may be very large, and, especially on the left side, may completely cover the artery (*Fig. 43*). It may also be firmly connected both with the artery and the sternomastoid if the latter has not been divided and reflected. Adhesion will be particularly intimate if the missile has crossed the line of the vessels after perforating the muscle, and it must be remembered that separation of the vein at the point crossed by the track may involve opening up a healed perforation in the wall of the vein.

Both artery and vein are now isolated at the lower and upper parts of their course, and provisional ligatures are passed beneath and around them, or around the carotid alone in arterial aneurysm. When this has been done, the ligatures may be tightened sufficiently to control the circulation without injury to the coats of the vessel, and the exposure of the sac proceeded with.

Arterial Aneurysm.—When the artery alone has to be dealt with, further procedure is comparatively simple. If the case be one of only a few weeks' standing, the sac may be readily separated from the vessel, and the defect in the wall exposed; if the sac be older and firmer, it should be incised and the defect in the arterial wall inspected from within. If the defect is now judged suitable for suture, it will be necessary to further mobilize the artery to facilitate the passage of the stitches, and to reduce as much as possible the local tension when they are tied. During the process of mobilization care should be taken to be certain that there exists in the arterial wall no second wound which has been reopened during the process of freeing the

vessel. It is much easier to overlook a second opening than might be supposed, especially if it is situated on the posterior aspect of the artery and not on exactly the same level as that first found.

If the defect in the arterial wall be judged too extensive for suture, ligatures should be applied on either side of it in immediate proximity to the opening, and tied. One ligature upon the vein is now definitely tied, any remaining provisional ligatures are withdrawn, and the wound may be closed tightly.

Arterio-venous Aneurysm.—The earlier stages of the operation are identical with those described above; but treatment of the aneurysm is a more complicated matter. When the aneurysm is connected with the common carotid trunk, it is easy to abrogate completely the supply of arterial blood. It is less easy in the case of the jugular vein, as branches may reach the vein between the points controlled by the provisional ligatures. These branches must be sought for and controlled before any further step is taken.

If a sac be situated between the artery and vein, it should be laid open and the orifices leading into the two vessels inspected. If the apertures be judged suitable for closure by suture, the vessels are now more freely mobilized, the sac may be cut away, and the openings closed. When the sac is situated on the aspect of the artery away from the vein, it is dealt with in the manner already described for arterial aneurysms. Should this arrangement be found, the direct opening which exists between the artery and vein should be dealt with as if the case were one of uncomplicated aneurysmal varix; that is to say, the aperture should be exposed by freely opening the vein on the opposite side to that upon which the communication with the artery exists, and the adventitious opening dealt with from within the lumen of the dilated vein. Other arrangements may be met with; thus, the opening leading from the vein and artery may communicate directly with a common sac, or the sac may connect the artery directly with one open end of a completely divided vein; some examples are given below.

When the conditions are not adapted to suture, the four provisional ligatures already in position may be definitely tightened, and the sac may be excised. Care must be exercised in the latter procedure that important structures are not damaged; and it should be borne in mind that the sac is a harmless structure, the removal of which is in no sense obligatory.

No material differences exist, except in anatomical detail, whether the internal or external carotid is the seat of the aneurysm. The internal carotid presents the most difficult technical problem when the wound is high up.

Should the original injury have involved the common carotid

trunk immediately below the bifurcation, in place of applying definite ligatures upon the proximal end of the two branches, these may be completely divided, and an end-to-end union made, or a lateral anastomosis may be established, so as to obtain the advantages of communication of the branches of the two external carotids for the cerebral supply through the internal carotid (Duval).

Some of the points involved in the performance of these operations may be best illustrated by the short recital of a few cases, and a glance at *Figs. 25, 30, 42, and 44.*

Fig. 42 illustrates a point in the formation of a part of the wall of an aneurysmal sac by inclusion of the remains of the wall of the artery. *Fig. 44* depicts the conditions which existed in a case of bilateral injury to the vessels, and this case, as one of very great interest and importance, may be shortly detailed.

Case 27.—Bilateral injury of the common carotids. Use of Tuffier tube.

A bullet entered at the anterior border of the lower third of the right sternomastoid, traversed the neck, and emerged just internal to the left sternoclavicular articulation. The inner end of the left clavicle was fractured. No serious primary hæmorrhage followed the wound, and the patient after four days' stay at a casualty clearing station was brought down to one of the hospitals on the lines of communication. The condition found on the fifth day was as follows. A large suppurating wound was present at the root of the neck on the left side, and signs of general toxæmia were of moderate degree. The entrance wound on the right side of the neck was closed and quiescent. A loud arterio-venous bruit, widely conducted, and of which the systolic element was the more pronounced, was heard at the root of the neck and elsewhere. There was no cardiac enlargement, no conducted murmur to the heart, and the pulse was 100, and regular. The patient developed a tetanus antitoxin rash, with some fever; and the streptococcal infection of the wound at the left side of the neck progressed, so that incisions needed to be made. Progress was not satisfactory, and a month after reception of the wound a fresh swelling was noted on the left side at the root of the neck.

On examination, this proved to be an arterial aneurysm, over which a faint systolic bruit was audible. As active infection of the large wound in immediate proximity to the recently developed aneurysm was present, it was deemed necessary to deal promptly with the aneurysm, and on the next day Colonel C. Gordon Watson operated. Professor Tuffier had just sent me some of his silver junction tubes, and as a bilateral arterial injury was present in this case, it seemed eminently desirable to deal as gently with the cerebral circulation as possible. Colonel Gordon Watson therefore introduced a tube, which was retained for three days, and then removed. It is doubtful what advantage was gained by the use of the tube, as it became obstructed within the first twenty-four hours; but the result attained was good, since no cerebral signs developed in spite of the presence of the arterio-venous aneurysm on the other side of the neck.

Unfortunately the general infection from which the patient was suffering

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continued unchecked, he gradually lost strength, developed an acute pericarditis, and a month later he died, death being preceded by a transient loss of power in the right arm.

The condition of the right vagus has already been referred to, also the remarkable reproduction of a solid column of tissue between the retracted ends of the divided left carotid artery.



Fig. 44.—Bilateral injury to the carotid arteries. On the right side, the missile has traversed the artery, vein, and vagus. The sheath of the vagus is distended by clot, and might eventually have formed the boundary of an aneurysmal sac. On the left side, an arterial aneurysm which formed secondarily was operated upon, and a Tuffier's tube was introduced. It will be observed that a column of connective tissue corresponding in calibre with the tube now connects the two extremities of the severed artery. *Case 27.* Under the care of Colonel Gordon Watson, C.M.G.

Case 28.—Arterio-venous aneurysm. Suture of vessels.

Gun. R. Shrapnel wound of right side of neck; missile retained at left side of first dorsal vertebra. An arterio-venous aneurysm formed, not apparently of large size, the signs being indistinguishable from those of a simple varix. The signs were typical, and accompanied by those of right sympathetic paralysis.

Nine weeks after reception of the injury, a type operation was performed as described above. It was found necessary to divide three-fourths of the width of the sternomastoid in order to deal satisfactorily with the lower end of the jugular vein, for the vessels were still somewhat fixed as a consequence of primary infiltration of the vascular cleft with blood. The vein was large, but the surface smooth, and with little signs of reactionary change in the tissue of the vascular cleft.

When the circulation had been controlled, the vein was opened, as no sign of a sac was to be seen from the front. An opening in the back of the vein was disclosed, communicating with a sac lying behind the vessels and in the substance of the prevertebral muscles. Both vessels were now mobilized, and the artery was found to have an oblique slit on its postero-internal aspect, and communicated by this opening with the sac lying behind the vessels. The arterial defect was closed by suture, and the opening in the vein sewn up from the interior of the vessel; lastly, the exploratory incision in the vein was closed, and the repair was completed. The sac was practically left untouched, except that it was separated from the artery (G. H. M.).

It was noted that on the day after the operation the man sweated freely except on the right side of his face. Except for some anæsthetic sickness he made an uninterrupted recovery, and as far as can be judged the vessels have remained patent. The sympathetic paralysis steadily improved.

Case 29.—Arterio-venous aneurysm of left internal carotid artery. Suture of vessels.

Sergt. P. A piece of shrapnel case entered at the left angle of the mandible, and was retained opposite the disc between the third and fourth cervical vertebræ. An arterio-venous aneurysm formed (*Fig. 45*), associated with left sympathetic paralysis. The signs were typical, but it was impossible to determine whether the internal or the external carotid was involved.

Six weeks later the aneurysm was explored; the sac proved to be a junction chamber interposed between the internal jugular vein and the lower end of the internal carotid artery. When the control ligatures had been tightened up, the sac was laid open, but fairly free bleeding took place, the blood apparently being furnished by the ascending pharyngeal and superior thyroid arteries, each of which needed to be freed and controlled by an arterial clamp. The opening in the vein was easily sewn up, but as the field of operation could not be kept free of blood on the arterial side, in place of removing the remains of the small sac, sutures were passed through it, and thus it was plicated and closed (G. H. M.).

The future progress was uneventful, except that some enlargement was found to be present at the site of the sac when the patient had his wound dressed a week later. This enlargement was exaggerated by induration of the surrounding tissues, and over it a somewhat harsh systolic bruit, much increased in loudness by pressure of the stethoscope, was heard.

The patient was up and about at the end of three weeks, and the local condition has steadily improved. I think the plication of the sac was a mistake, although it much facilitated the operation.



Fig. 45.—Arterio-venous aneurysm of common carotid. The small prominent nodule is merely the characteristic thickening around the wound track often seen in the early stages.

Case 30.—Arterio-venous aneurysm. Suture of vessels.

Lieut. A. A bullet wound was followed by prompt development of the aneurysm. The patient was only retained in France for a few days. He remained in hospital for some time, was then discharged, and led an easy life for more than a year. The main trouble experienced was the buzzing noise in the head and opposite ear. No active exertion had been made since the date of injury.

The signs were typical, with associated sympathetic paresis. Fourteen months later an exploration was made. The sac was found to be small and interposed between the two vessels. The whole operation was one of great simplicity on account of the time which had been allowed to elapse before

it was undertaken. The sac was incised, the wound in the vein sewn up, and the same course taken with the artery. Uninterrupted progress ended in complete recovery (G. H. M.).

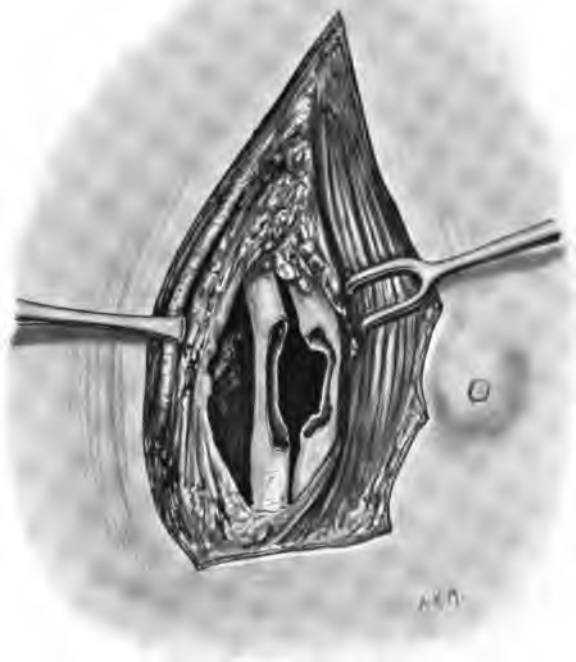


Fig. 46.—The wounds in the vessels of the arterio-venous aneurysm shown in *Fig. 45*. The tubercle has been retracted backwards.

Case 31.—Arterio-venous aneurysm. Suture of artery, ligature of vein.

Gun. C. A fragment of shrapnel case entered just behind the anterior border of the sternomastoid of the left side, and lodged against the vertebræ on the left side of the mid-line. A typical arterio-venous hæmatoma resulted. It was soft and rather extensive, with indefinite margins. Twelve days later it was explored. No definite sac had formed, but the hæmatoma was sufficiently well localized to allow the provisional ligatures to be applied without any great difficulty. When the vessels were exposed, a perforation was seen on the antero-external aspect of the upper third of the common carotid artery, and a laceration of the vein. Troublesome bleeding from the vein necessitated double ligature of that vessel. The artery was mobilized, not without some difficulty on account of the induration of the areolar tissue of the vascular cleft. The visible defect in the wall was then sutured, and the blood allowed to enter the vessel from above. This act was followed

by free hæmorrhage from the back of the vessel. The upper provisional ligature was again tightened, and on examination a second oblique slit in the posterior aspect of the vessel, which had been closed by adhesion to the prevertebral fascia, was found to have been reopened in the process of mobilization of the vessel. This second slit was repaired with some difficulty, and the wound closed (G. H. M.). The patient made an uninterrupted recovery.

Case 32.—Arterio-venous aneurysm. Suture. Failure to cure varix.

Pte. L. Bullet wound of neck. Type minimal wounds of entry and exit, passing from behind the centre of the left sternomastoid to emerge near the mid-line at the level of the cricoid. A typical arterio-venous aneurysm developed at the level of the cricoid cartilage, the sac extending towards the mid-line.

Three months later an operation was undertaken. The soft parts had in great measure regained their normal state, and little difficulty was experienced in defining the sac, which lay to the inner side of the artery. As I felt confident that a direct communication was present between the internal jugular and the artery, I opened the vein as a preliminary procedure. I found no opening. The artery was then mobilized, and separated from the sac, with which it communicated by an elongated slit on its inner aspect. When the interior of the artery was inspected from this opening, a small opening on the opposite side filled with clot was seen. A probe would not enter this aperture, and I was inclined to think it the blocked origin of a superior thyroid branch placed in an abnormal position. The operation was then completed, but as a very long slit had been made in the jugular vein, the provisional ligatures were made definite and the intervening portion of vein was excised (G. H. M.).

Three days afterwards the patient complained of an attack of pain in the neck, and the dressings were removed. Examination showed that the arterio-venous bruit had returned, and the veins at the root of the neck pulsated freely. No evidence existed during the next three months of recurrence of the arterial sac, but the bruit persisted, although the pulsation of the veins at the root of the neck diminished in force. The patient declined any further intervention, and returned to Canada.

Choice of Method.—It is in the case of the carotid vessels that the question of ligature or repair by suture acquires chief importance. The advantages on the side of ligature may be stated as consisting in : (a) Its ease and rapidity of application, suiting it to those cases in which a short operation is a desideratum which can be considered to counterbalance the risks of disturbance of the cerebral circulation ; (b) The fact that the operation is generally applicable, and can be performed in many cases in which suture is impracticable.

Whenever it is determined to ligature the common carotid or its branches, simultaneous occlusion of the vein should always be a part of the operation. It has proved certain that occlusion of the satellite vein is advisable in dealing with the arteries of the extremities, and if the explanation be found in the reduction of the degree of anæmia consequent on interference with the arterial supply, it is clear that

the procedure is doubly advisable in the case of one of the chief sources of the blood-supply of the brain. The few figures I have to offer in the case of this artery are at least suggestive, since they refer to a consecutive series, even if few in number.

	Number	Cerebral Complications
Ligature of artery and vein . .	9	2* (22.2 per cent)
Ligature of artery alone . .	18	5 (27.7 „)

* One of these patients was very exsanguine when operated upon on the second day after receipt of the injury.

Fortunately the common carotid artery is not only one in which a reconstructive operation of repair is advisable, but it is also the easiest artery in the body to deal with, on account of its size, the ease with which its entire course can be exposed, the readiness with which it can be mobilized, and the fact that it gives off no branches except its two terminal divisions. Again, the size and direct course of the internal jugular vein renders it a very easy vessel to manipulate.

It will be noted in the description of the operation furnished above, that the method has been limited to the treatment of injuries of a perforating or lateral character. I may say at once that more extensive injuries may readily be dealt with by resection and end-to-end union of the vessel. I have no personal experience of the length of the vessel which may be sacrificed and yet a safe end-to-end union be effected, but possibly at least three-quarters of an inch may be resected and the union established without difficulty. The applicability of this form of operation depends entirely on the technical capacity of the operator; my own experience of it is limited to the brachial artery, an easy vessel to manipulate; but I have not always been fortunate in avoiding the ultimate occurrence of thrombosis. In the case of the carotid, as has been already pointed out, it is extremely difficult to determine whether occlusion has taken place or not; hence in the short series of cases I have to report I am not prepared to assert that the viability of the vessels was permanently attained, although the results are to all appearance of a satisfactory nature. There is, moreover, nothing to show that anything is lost by the attempt to obtain an ideal result, and suture of the wounded carotid should, in my opinion, always be undertaken if practicable.

The simplest of all the operations is that for the cure of an aneurysmal varix; and if it be undertaken, the rule of approaching the aperture of communication by way of the vein, after establishing provisional control of the blood-current, should always be observed.

WOUNDS OF THE SMALLER ARTERIES OF THE NECK.

The only importance pertaining to wounds of the smaller vessels of the neck consists in the difficulty which may arise in discriminating between aneurysms which may develop in connection with them, and aneurysms originating in wounds of the main trunks. *Cases 12 and 15* illustrate this point with regard to the superior and inferior thyroid arteries respectively, and emphasize the need for careful exploration, lest the main trunk be hastily and needlessly sacrificed.

I have seen aneurysms in connection with the occipital, the facial, and the temporal arteries, but these need no further description.

The vertebral artery requires more detailed attention, for the depth of its situation renders it difficult in many cases either to diagnose the injury or to deal with it surgically. I only came across 3 cases. In 2 of these the aneurysm developed in connection with the commencement of the vessel; in the third the artery had been injured in the part of its course lying upon the arch of the atlas.

Neither of the two cases of injury of the lower end of the vessel I saw were operated upon, as the sac was small, no pulsation was palpable, and the patients appeared to suffer little or no disability. The diagnosis was made upon the softness and apparent depth of the murmur, in both cases a pure systolic one, and the absence of evidence of injury to either the carotid or subclavian artery; in one of them the existence of a fracture of the transverse process of the 7th cervical vertebra, as seen by *x-ray* examination, supported the diagnosis. The third case was operated upon by Colonel Harvey Cushing. The sac was exposed in the sub-occipital triangle, and as it was found impracticable to apply a ligature locally, the sac was plugged, and the artery was secured at the root of the neck. The operation was successful.

With no operative experience on the subject, I am loth to dogmatize upon the best route to choose when a vertebral aneurysm at the root of the neck needs to be dealt with. Should I need to operate on such a case, I should prefer to make the angular incision as for the innominate artery or the first portion of the subclavian artery, and partially or wholly divide the sternomastoid muscle, in order to ensure sufficient room for a comfortable exposure of the sac. If the route from the posterior border of the sternomastoid be chosen, less space is secured, and probably a much wider division of tissues becomes necessary.

SUBCLAVIAN ARTERY.

Twenty-eight cases of injury to the subclavian artery are included in the series. Wounds of this vessel are not met with so frequently in hospitals as those of the carotid or axillary. This depends partly

on the comparative shortness of the course the trunk runs, but also in part on the dangerous nature of the accident. Although situated deeply, and in the greater part of its course protected both by bones and muscles, in its first part it is in very close relation with other great vessels, a concurrent wound of which is probably usually fatal; and further, its relation to the apex of the pleural sac is an arrangement which allows internal hæmorrhage to take place quietly and easily, and to be abundant in amount.

The artery of the right side was involved in 16 of the injuries, and that of the left in only 12, in spite of the longer course taken by the latter vessel. In 24 of the cases in which the nature of the missile is recorded, it was a bullet in 15, and a fragment of shell in 9. Of the wounds of the soft parts, 13 were narrow through-and-through tracks; in 8 instances the missile was retained; in 2 the wounds were large; in one of the patients with a large wound, infection and secondary hæmorrhage proved fatal.

In 7 of the patients (25 per cent) free primary hæmorrhage is noted to have occurred; in this relation it may be added that in 9 more a large hæmothorax complicated the injury. Secondary hæmorrhage from the wound only occurred twice, and in each instance it proved fatal. Extension of the hæmatoma formed the indication for operative intervention in 4 cases.

The complication of hæmothorax does not appear to have materially affected the prognosis in patients reaching the hospitals on the lines of communication; it was present in 10 of the 28 cases (35·7 per cent), 6 times in the right, 4 times in the left pleura, and none of the patients died, although in one instance the blood became infected and an empyema needed to be treated. The association with wounds of the chest was approximately as common in injuries to the axillary artery (20 per cent), but injuries to that vessel do not furnish the blood for the pleural effusion. The same may be the case with the subclavian when the missile enters deeply, or traverses the thorax; but in a certain number of cases the subclavian is the source of the blood which collects in the pleura. I obtained post-mortem evidence of this fact in a case observed during the South African War, and certain points in the clinical history of the patients under consideration support the statement.* First, it may be remarked that none of the subclavian aneurysms in this series was of large size; but when the cases are analyzed, this is a specially well-marked feature in those in which a hæmothorax was present. Of 10 cases of injury to the artery accompanied by a hæmothorax, in only 2 did a well-marked rounded tumour develop;

* See Case 32a, p. 188.

in 3 no aneurysmal tumour or abnormal pulsation was detected, in 2 the signs pointed to local thrombosis of the artery, and in 4 slight or diffuse abnormal pulsation was the only other sign to corroborate the evidence furnished by the presence of a local vascular murmur. Further, in all the cases the local signs were but slightly marked in the initial stage, and tended to increase, and in two of the hæmothorax cases the tumour was not detected until a later date—in one instance only at the end of three weeks. In those instances in which the subclavian really furnishes the blood for the hæmothorax, I think the late development of the tumour finds a ready explanation. The direction of least resistance for the passage of the blood is obviously towards the potential space afforded by the pleural sac, and it is only when a certain degree of distention of this has been reached that any blood will travel into the tissues of the neck. Hence the clot which ordinarily forms the initial boundaries of a hæmatoma is only deposited at a late date, and may not surround any blood-cavity, or a sac may be practically absent.

The second common complication consists in injury to the cords of the brachial plexus. Signs of serious damage to the nerves were present in 7 cases (25 per cent), and in 3 others severe pain in the upper extremity pointed to injury of a minor degree. I have but few details as to the ultimate result in any of these cases, but I doubt if they are as bad as those seen after injuries to the vessels and nerves of the axilla. Of the 10 cases in which nerve implication was noted, 4 were of the vessel in the second part of its course, and 6 in the third part; in three of the latter pain was the only sign present.

In 3 cases a fractured clavicle was present, in 4 a fracture of the upper part of the scapula, and in 1 a fractured humerus and acromion process.

Of the whole series of 28 injuries, 4 (14·2 per cent) were to the first part of the artery, 13 (46·2 per cent) were to the second, and 10 (35·7 per cent) to the third. I think this distribution corresponds fairly accurately with the relative danger attendant upon injury in the three positions.

As to the nature of the lesions of the vessels, in 2 spontaneous thrombosis probably took place; this was evidenced in one by the deposition of an embolus at the bifurcation of the brachial artery, and in the second by signs of arterial obstruction unaccompanied by either swelling, pulsation, or an arterial bruit. In 3 cases operation showed the artery to have suffered complete severance of continuity; and in one of these—discovered during an early exploration of a divided brachial plexus—there was no evidence of any local hæmorrhage having taken place. The form and extent of the injury

in the remaining cases can only be conjectured, but in three operations for arterial hæmatoma it was found that either the vein had been wounded or its continuity severed without the development of an arterio-venous communication taking place. This latter fact is in consonance with the remark made in the general section as to the importance of retention of continuity of the vein, and of its close proximity to the artery, in determining the occurrence of aneurysmal varices or arterio-venous aneurysms.

In 24 of the cases either an arterial or an arterio-venous hæmatoma formed. In 13 of these the signs pointed to a pure arterial injury; in one of these, disappearance of both pulsation and bruit appeared to indicate a spontaneous cure. In 11 cases an arterio-venous communication was established; in only one of these was a large hæmatoma present, and the presence of the typical murmur was an important element in the diagnosis.

Little remains to be said as to the special characters of aneurysms of this artery; the general tendency is to be small, and this is most marked in those in connection with the second portion of the artery. In those of the third portion the posterior triangle offers easier conditions for the formation of a hæmatoma. When the aneurysm is arterio-venous, the large size of the vein, and the powerful suction action exerted on the venous circulation in such close proximity to the upper opening of the thorax, do much to relieve the pressure of the arterial blood-stream, and probably account in considerable measure for the fact that large sacs do not form.

Amongst 23 of the cases, the radial pulse was obliterated in 9, in some of which it returned; while in 14 it was present, but diminished in volume.

The presence of the characteristic murmurs is the most valuable and dependable sign of a wound of the artery or an arterio-venous communication; if these be absent, or disappear in association with obliteration of the radial pulse, local thrombosis may be assumed. In two cases of the series the systolic murmur was transferred to the cardiac apex.

The most difficult point in diagnosis is to distinguish injuries of the first part of the artery from those of the root of the carotid, and on the right side from those of the innominate artery. Careful auscultation for the point at which the local murmur is loudest, and—in arterio-venous communications—observation of which set of veins pulsates, are the main aids; but a certain clinical diagnosis can hardly be established.

Prognosis and Treatment.— Examination of the methods of treatment adopted in this series affords a very restricted amount of information, although, such as it is, the experience furnishes matter for serious consideration.

The great majority of the patients, while under my observation, were treated by rest, and afterwards transferred to England; and I regret being unable to obtain a further history of more than four of these, in spite of the valuable aid given to me by Dr. Young.

One of the patients, in whom spontaneous thrombosis occurred, eventually returned to active service, and was serving with his battalion in France sixteen months later; in this case there was a hæmothorax, but no signs of nerve injury.

A second case was operated upon on return to England, the arterio-venous communication proving to be axillary. No report as to further progress is available, except that the radial pulse had returned four months later, and that discharging wounds were still open.

In a third, a note suggests that in England the surgeon was inclined to attribute the injury to the arch of the aorta. "Loud murmur over region of ascending arch and superior vena cava—*x*-ray examination shows the arch of the aorta to be a narrow one, otherwise there is nothing abnormal to be seen—the patient is very weak and incapable of exertion." In France, a month earlier, I have the note, "loud machinery murmur, loudest over clavicle; conducted to the base of the heart, the neck, and down the limb," and I am still inclined to locate the injury to the right subclavian.

Seven patients were operated upon; in each instance the indication was either hæmorrhage from the wound, or increase in size of the hæmatoma; and in every case a fatal issue followed. In view of the very great danger which attends these operations, the most useful plan is to append a short report of each.

Case 33.—Arterial hæmatoma. Hæmorrhage following removal of retained missile. Secondary bleeding. Death.

A piece of shrapnel case was removed from the left posterior triangle of the neck three days after reception of the wound. The operation was accompanied by free bleeding, which was checked by plugging the wounds.

Cellulitis followed, and on the tenth, twelfth, and fourteenth days a hæmorrhage accompanied each dressing of the wound, which was plugged on each occasion. On the fifteenth day an attempt to reach and ligature the artery was made, but the matted condition of the tissues was such that in the face of incontrollable bleeding the operation had to be abandoned and the wound again plugged. The patient died of exhaustion about twelve hours later. A diagrammatic drawing of the arterial wound in this case is shown in *Fig. 8 c*.

At the post-mortem examination, a large mass of blood-clot was found beneath the clavicle, also suppuration extending into the neck and downwards in the posterior mediastinum. Two inches of the subclavian vein were missing, and the arterial wound was of 'flap' form. Neither arterial nor arterio-venous bruit had been audible during life.

Case 34.—Arterial hæmatoma. Hæmorrhage following removal of retained missile on day of wound. Secondary bleeding. Death.

Pte. C. At the first dressing performed at the casualty clearing station, bleeding followed removal of the plug introduced at the primary operation. The wound was repacked, and the skin brought together over the plug by stitches.

On arrival at a hospital on the lines of communication on the fifth day, the plugs were again removed and no hæmorrhage followed. On the seventh day a copious secondary hæmorrhage occurred; the wound was again plugged, not sufficiently tightly, however, to obliterate the radial pulse. On the seventeenth day hæmorrhage again recurred, and an attempt to secure the subclavian artery was made. The tissues were matted and soft, but a ligature was passed around the third portion of the subclavian, and hæmorrhage was arrested. The operation was very difficult, and some air entered the pleura during its performance. The patient died the same evening from exhaustion and loss of blood.

These two operations merely emphasize the advisability of dealing radically with hæmorrhage from the root of the neck at the primary operation on the wound.

The remaining five operations were all performed for some form of aneurysm. Two of the fatal results occurred in cases operated upon by myself, and I will place these first, as well illustrating the dangers which may have to be faced.

Case 35.—False aneurysm of second portion of subclavian artery. Local ligature. Death from effects of hæmorrhage.

Pte. B. was admitted three days after being wounded by a bullet which entered about the apex of the right posterior triangle and emerged at the back of the shoulder above the posterior margin of the scapula. The entry wound was minimal in size. There was a complete brachial monoplegia. A large, soft, pulsating swelling extended upwards to the level of the top of the thyroid cartilage, raised the sternomastoid slightly, but did not extend beneath the trapezius. The radial pulse was absent. A simple systolic bruit was audible throughout the swelling, but was not widely conducted. The man was very pale and anæmic.

During the next fourteen days complete rest was maintained, and the swelling became much more localized; but on the thirteenth day it was noted to be much softer and apparently increasing. For the latter reasons I decided to operate in spite of the patient's anæmic condition. As a precaution, the innominate artery was first exposed by an incision along the anterior border of the sternomastoid, and a clamp was placed upon it. An incision was now carried from the lower end of the first one, along the clavicle, and a triangular flap raised outwards. The swelling was then exposed and opened. A cavity containing a greenish fluid, bounded by decolorized lymph, was found completely shut off from a deeper swelling by the deep layers of the cervical fascia. The aneurysm was then opened, a procedure which was followed by an alarming rush of blood, controlled only by pressure downwards and inwards towards the transverse processes of the cervical vertebrae. After some trouble the bleeding, which came from the central end of a complete division of the artery in its second portion, was stopped, and it was thought wiser to tie the first portion of the subclavian

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trunk, and remove the clamp from the innominate. No trace of the subclavian vein was seen. The patient was much blanched from loss of blood at the end of the operation, and three hours later he died, in spite of a saline infusion (G. H. M.).



Fig. 47.—Arterial aneurysm developed in connection with a complete division of the second portion of the right subclavian artery. The distal end of the vessel is shown by the dark glass rod. The white rod passes through the original aperture of entrance of the bullet, and indicates its course. The anterior scalene muscle was destroyed in half its width by the bullet. The incision in the sternal portion of the sternomastoid muscle was made for the purpose of applying an arterial clamp to the innominate artery during the progress of the operation on the aneurysm. *Under the care of Dr. Ronald Gray.*

Fig. 47 shows the condition found at the operation. One point, the destruction of half the width of the anterior scalene muscle, the phrenic nerve lying intact on the fascia at the very edge of the remaining part, is instructive, since had the muscle been divided—as was at one moment contemplated during the difficulties of the operation—the nerve might not have escaped. The hæmorrhage came from the return flow in the branches of the first and second parts of the artery.

Special points of interest in this case are, firstly, that the space occupied by the original hæmatoma had become loculated and the loculus shut off, while a typical false aneurysm had developed; secondly, that although both the vein and artery had suffered



Fig. 48.—Skiagram showing size, shape, and position of a fragment of shell which wounded the second part of the right subclavian artery, giving rise to an arterio-venous aneurysm. The resemblance in shape of the fragment to a deformed bullet is of interest. *Under the care of Captain Greaves.*

division, a simple arterial aneurysm developed. I believe this latter to be a far from uncommon result when the vein is completely severed; retraction, thrombosis, and spontaneous closure taking place, while the arterial wound may remain patent. Other examples have been seen.

Case 36.—Arterio-venous aneurysm of junction of second and third parts of right subclavian artery. Death from entry of air into veins.

Pte. W. The bullet entered over the junction of the middle and inner thirds of the clavicle, and emerged at the upper border of the scapula behind.

When admitted to a base hospital the wounds still remained open, but they rapidly healed. On the seventy-fifth day after the original injury there was swelling and pulsation in the posterior triangle of the neck, and pulsation of the small bluish scar overlying the perforation of the clavicle. There was a well-marked thrill in the neck, and the veins in the posterior triangle pulsated, but the tumour was soft, and only partly obliterated the normal hollow of the triangle. A loud and widely conducted machinery murmur was heard on auscultation.

An incision was made along the inner four-fifths of the length of the clavicle, with an angular extension running upwards along the anterior border of the sternomastoid tendon for two inches.

The sternomastoid muscle was divided near its insertion and reflected upwards, and the posterior triangle opened up in its whole width. The carotid and first portion of the subclavian artery were now bared and cleared from the vagus, the phrenic nerve was identified, and a provisional ligature placed around the first part of the subclavian artery. The outer margin and half the breadth of the anterior scalene muscle were divided, and the remainder of the muscle retracted inwards; by this step a second provisional ligature was able to be placed on the artery beyond the origin of the internal mammary artery and the thyroid axis.

The cords of the brachial plexus needed to be freed from the surface of the dilated vein. The vein was greatly distended, as were also the external jugular and some other branches entering it; the latter were tied off, and a provisional ligature was placed on the axillary vein. The outer end of the third part of the artery was now readily secured, and a provisional ligature placed around it.

So far all had gone as regularly as clockwork, and every precaution had been taken except to close provisionally the proximal end of the subclavian vein. The fact that this was adherent and continuous with the opening in the clavicle had not allowed the clavicle to be divided, and had rendered it impracticable to draw the vein fully into view. An attempt was now made to free the vein from its connection to the bone. As this was done, a sound of air entering into the vein was heard. The sound was not loud, neither was there any difficulty in controlling the hæmorrhage from the opening in the vein; but the patient became suddenly ill, in a few seconds the heart's action failed, and although he continued to breathe, he died in a few minutes (G. H. M.).

The only comment to be made on this case is that the accident might have been avoided had a provisional ligature been placed on the innominate vein. The amount of air which entered must have been large, for the exposed internal jugular vein became bloodless, and bubbles of air could be seen moving in it in association with the movements of respiration.

Case 36A.—Arterio-venous aneurysm of the first part of the right subclavian artery. Ligature of the innominate artery. Closure of the orifice of communication by ligature.

Pte. A. Wounded by a small fragment of shell, which entered about the centre of the anterior border of the right trapezius muscle, and was retained in a position unknown. There was free primary bleeding, controlled by the application of a pad and dressing.

When seen fourteen days later, there was widespread subcutaneous ecchymosis, induration in the line of the wound track, and general fullness of the posterior triangle of the neck. A rounded localized swelling was palpable beneath the lower end of the sternomastoid muscle, and thrill and a continuous bruit, of which the systolic element was the more marked, were present. The cardiac apex was in the nipple line, and the sounds could be heard distinct from the bruit. The pulses at the wrist were equal in volume and force, and beat 100 to the minute. The venous roar was audible at the wrist on auscultation.

The patient was kept at rest, and two months later the condition was much improved. The swelling and ecchymosis in the posterior triangle had disappeared, and a local sac lying beneath the sternomastoid in the line of the common carotid artery, and extending upwards for three inches above the clavicle, remained. No enlargement of the superficial veins was present, but the right radial pulse was a little weaker than the left.

On the seventieth day after the injury an operation was undertaken. An angular incision, as for ligature of the innominate artery, but carried outwards for three-quarters of the length of the clavicle, was made, and the sternomastoid muscle was divided one inch above its insertion and reflected. This procedure exposed a thick-walled sac, apparently emerging from the interval between the longus colli and the anterior scalene muscles, and extending upwards as high as the level of the fourth cervical vertebra.

The carotid artery and vagus nerve were freed from the inner margin of the sac, and an attempt made to secure the root of the first part of the subclavian artery; this proved to be impracticable, as the vessel was wide, and implicated in the wall of the aneurysm in this position. Provisional ligatures were therefore placed upon the innominate and the third part of the subclavian artery, and the clearance of the sac proceeded with. The deep aspect of the sac was readily raised from the surface of the anterior scalene muscle, which was widened out, and on its surface the phrenic nerve was exposed. On attempting to free the inner margin of the sac, a wound was made into it, and it then became necessary to tighten up the ligature on the innominate artery. The opening in the sac was controlled by the finger, the sac freed down to its connection with the artery and vein, and a ligature thrown around the junction and tied.

The wound was then closed; the patient had lost a good deal of blood during the latter part of the operation, and a saline infusion was given in the evening, after which he steadily picked up (G. H. M.).

The following day the patient looked pale, and was somewhat drowsy, but he had a pulse of 104 of good volume, and said "he felt fine."

On the evening of the second day he lost power in the left upper extremity, but there was no facial weakness, and the man did not appear to appreciate that his arm was powerless. On the fourth day no trace of the paralysis remained, the anæmia was much less marked, and the pulse and temperature were normal. Stitches were removed at the end of eight days.

On the seventh day a considerable amount of lymph escaped from the wound, and the discharge continued for some five days; the character of this discharge suggested injury to the right lymphatic duct. The temperature, which had never risen since the operation, and the pulse, remained normal throughout, and steady improvement took place. At no time was there coldness or any sign of trouble in the right upper extremity.

The patient made an excellent recovery.

Case 37.—Arterial hæmatoma of left subclavian artery. Proximal ligature of the first portion of the vessel. Subsequent extension of the aneurysm. Death from exhaustion later.

Pte. S. A fortnight after reception of a wound by a bullet—which entered the chest wall over the sternum just to the inner end of the left clavicle, and emerged behind the left shoulder-joint—a soft pulsating swelling, over which a systolic bruit was audible, was discovered.

During the next six days the swelling increased in prominence and extent, filling up the posterior triangle, and operation became necessary.

Captain Greaves resected the inner third of the clavicle, turned it upward together with the sternomastoid, and tied the first portion of the subclavian artery. Eighteen days later the patient was transferred to England.

On arrival, the aneurysm was active and continued to extend, the wound was suppurating, and the patient ill. It was not considered an operable case, and the patient gradually sank and died from exhaustion three months after the date of reception of the injury.

Case 38.—Arterial hæmatoma of first portion of right subclavian artery. Embolism of right brachial artery, Gangrene of hand, Death.

Sergt.-Maj. F. Bullet wound, passing from over inner third of right clavicle to emerge over right scapula. A week later pulsation was noted around the aperture of entry, and a systolic bruit was audible. On the eighth day the hand and forearm became tense and swollen, and incipient gangrene was apparent. The radial pulse was absent, and brachial embolism was diagnosed. On the thirteenth day the local swelling had increased, but the general condition was fair; the wound of exit was suppurating.

On the twentieth day, an attempt to deal with the hæmatoma was made. The clot was found to be infected; the first part of the subclavian was secured with great difficulty, and the patient died shortly afterwards.

Case 39.—Arterial hæmatoma of third portion of subclavian artery. Local ligature of the vessel. Gangrene of arm. Amputation.

Pte. W. Bullet wound, entering just below clavicle, and emerging at back of shoulder. On the second day a pulsating tumour, over which a systolic murmur was audible, was detected. Ten days later the tumour was larger, and it was thought advisable to operate. An injury to both artery and vein was discovered at the point of junction of the subclavian and axillary. Both vessels were ligated above and below the wounds in their walls.

On the twelfth day the hand became blue, although still warm; but with the swelling a rise of temperature and general malaise pointed to septic absorption, and on the thirteenth day the arm was amputated above the elbow.

The post-operative results illustrate almost all the points which require attention: the difficulty of successfully dealing with secondary hæmorrhage from this artery in an infected wound; the danger of risking an operation which may be attended by free bleeding in a patient still anæmic from primary loss of blood; the futility of the operation of simple proximal ligature in the case of a large trunk giving off branches in close proximity to the wounded point; the danger

which exists at the root of the neck of air entering the great veins ; lastly, the possibility of post-operative embolism.

The death-rate in this series amounts to 21·4 per cent of all injuries, and 85·7 per cent in the case of operations. It is true that in four of the cases septic infection played a prominent part, but none the less the great risk which attends these operations cannot be too strongly impressed.

In two cases spontaneous thrombosis appears to have effected a cure ; while, on the other hand, gangrene resulted from arterial embolism in no less than three cases. It is instructive to keep in mind the fact that embolism at the bifurcation of the brachial is a comparatively easy accident to diagnose, while in the lower limb this is not the case, and, moreover, it is not always easy to detect an embolus even on post-mortem examination. These cases, and those already dealt with in the section devoted to the carotid arteries, support the view that embolism may be a more common factor in the production of gangrene of the limbs than is generally recognized.

Mode of Operation.—In any case of subclavian aneurysm, the classical incision for securing the third portion of the artery needs to be considerably elongated towards the mid-line ; and if the first or second portion of the vessel needs to be dealt with, the angular incision, following the anterior border of the sternomastoid to the sternoclavicular joint and then carried outwards along the clavicle, is the most suitable.

The superficial structures having been divided, it is generally better at once to divide the sternomastoid muscle, about one inch above its clavicular attachment. The area to be dealt with is thus fairly well exposed, and the first part of the subclavian or the innominate trunk can be readily secured should it prove necessary. In some cases it becomes then advisable to divide the anterior scalene muscle, exercising due care to preserve the phrenic nerve intact.

The chief difficulty which may now arise lies in the number and size of the branches of the first and second portions of the artery, which may either lead directly into the sac, or will furnish an abundant supply to it even when provisional control has been established of the innominate or the first part of the subclavian, and the third part of the latter vessel. A provisional ligature or clamp placed upon the innominate is in itself practically useless to restrain hæmorrhage from the sac if this be opened, and the same holds good with regard to provisional control of the root of the subclavian artery. This was forcibly demonstrated in *Case 35*, in which instance bleeding from the sac seemed to be almost as free as if no precaution whatever had been taken. It is clear that in this case the sternomastoid and the anterior scalene muscles should have been completely divided before

the sac was opened, and then much of the loss of blood which led to a fatal issue might have been avoided.

The need to exercise care with regard to the recurrent laryngeal nerve and the thoracic or right lymphatic duct, while manipulating in this region, may be mentioned in passing, and the care necessary in dealing with the veins.

The experience gained in *Case 36* shows that in approaching arterio-venous aneurysms of the second part of the artery, it is best to place a provisional control on the innominate vein while freeing the first part of the subclavian, should the latter have acquired adhesions. The subclavian vein itself is usually very much dilated, and forms the major part of the tumour, and the branches are also large. The latter are easily secured and divided between ligatures, and as a rule this precaution should be taken as soon as the branches are fully exposed.

One point is worthy of further mention. Is it better to divide the clavicle or not? In the majority of cases, unless the junction of the subclavian and axillary arteries requires to be exposed, it is quite unnecessary if the sternomastoid be divided; section of the bone increases the severity of the operation, and entails risk of injury to the aneurysmal sac or the veins. I think the procedure should be reserved for cases of exceptional difficulty, and rarely resorted to.

My own experience leads me to regard operations for arterio-venous aneurysms in this region as the most difficult and dangerous of any that can be undertaken.

Case 32a.—Intrathoracic wound of left subclavian artery. Hæmothorax. Arterial hæmatoma. Embolism of brachial artery. Gangrene of hand. Amputation. (*Omitted from p. 177.*)

Sergt. W. Wound of entry in left posterior triangle, large exit near angle of left scapula. When seen at the end of the week, a large hæmothorax had developed, and a loud blowing systolic murmur was audible over the course of the subclavian artery. No pulsation was palpable. A day later, the hand became blue and cold, pulsation of the radial artery was extinguished, but not that of the brachial.

The patient had been obliged to remain three days in the trenches after being wounded, and he was suffering considerably. He was anæmic, and short of breath. Considerable ecchymosis was still present around the wound of entry.

In view of the man's condition an arteriotomy was not considered advisable, the hand became gangrenous in the anterior third, and the hæmothorax supplicated.

The hæmothorax was drained, and an amputation performed through the lower third of the forearm. A good recovery was made, and the man returned home in good condition, but the ultimate fate of the hæmatoma is unknown.

*CHAPTER IX.***VESSELS OF THE UPPER EXTREMITY.****AXILLARY ARTERY.**

FIFTY-FOUR cases of injury to this artery are dealt with in the series, and in 40 of these some form of aneurysm developed. The incidence on the two sides of the body is about equal: of 48 of the cases, 27 were on the right and 21 on the left side of the body. 15 were the result of bullet wounds, and 39 of injuries by fragments of shells. With regard to distribution over the length of the vessel, amongst 52 injuries, we find 17 (32·6 per cent) were of the first part, 14 (26·9 per cent) of the second part, and 21 (40·3 per cent) of the third part.

It will be observed that the series contains a very large proportion of aneurysms. This depends upon two conditions: first, the wounds of the soft parts were for the most part of a comparatively slight nature; and secondly, axillary aneurysms, except of the third part, are rarely dealt with at an early stage, hence the great majority of them reach the hospitals on the lines of communication or the base. For the same reasons, the histories show that primary hæmorrhage had rarely been free, and secondary hæmorrhage was not a frequent complication; the latter occurred in 13·3 per cent of all the cases, and in only one led to a fatal issue.

Special conditions exist in the case of the axillary vessels which influence the occurrence of either primary or secondary hæmorrhage. First, the wounds in cases which reach the back lines are usually of the slight traversing character, or those in which the missile is retained. In only three instances in this series were the wounds of the surrounding soft parts of any considerable extent—which points to the conclusion that large wounds of the axilla accompanied by lesions of the great vessels are often fatal.

The second condition which affects the occurrence of hæmorrhage is the disposition of large nerve trunks parallel to and surrounding the vessel. The importance of this anatomical arrangement in promoting spontaneous arrest of hæmorrhage from large vessels has already been referred to in the general section (p. 27), as also its influence in aiding permanent closure of wounds of the arteries. This feature is strikingly illustrated in the series of injuries

under consideration. Thus, amongst the 54 cases, we find no less than 10 instances in which permanent obliteration of the artery was effected spontaneously: in all without the occurrence of serious hæmorrhage, in several with practically none, and in only one with evidence of the formation of a traumatic aneurysm—which underwent spontaneous cure—taking any part in the process. It is difficult to say what grade of injury was present in these lesions; but we know, from experience gained in operations undertaken for exploration of the nerves in the axilla, that they are often of a severe character, since considerable lateral wounds, and even instances of complete severance, have been met with. The liability of the axillary artery to injuries of a contused character is sufficiently explained by a glance at its relations to the walls of the cavity in which it lies; we have the humerus on the outer side, the margin of the scapula behind, the ribs on the inner aspect, and the clavicle in front, all furnishing opportunity for crushing of the artery between the missile and the bony skeleton.

I think it must be assumed that spontaneous obliteration of the axillary vessels is perhaps more common than even these numbers suggest, because such injuries can be very readily overlooked in their early stages; in fact, attention was often first called to them, not on account of suspicion raised by local circulatory signs, but by the absence of the radial pulse discovered in the course of examination of patients in whom the lesions of nerves were the prominent feature. In connection with this question of spontaneous closure of wounds of the axillary artery, it is of interest to note that in two cases, during exploration of the nerves in the axilla, a vessel large enough to take in great measure the place of the normal artery was discovered. It is unfortunately not possible to say whether this vessel was a result of canalization of the temporarily obliterated trunk, or whether it was a new anastomotic formation.

The second special characteristic of injuries to these vessels is the co-existence of injury to the nerve trunks. This combination is very frequent, and in view of the close association of the vessels and nerves, it appears remarkable that the latter can ever escape simultaneous injury. Amongst our 54 cases, serious nerve complications are noted in 23 instances (42·59 per cent). These varied from complete brachial monoplegia to injury to a single nerve or a general disturbance of sensory function; but, as will be seen later, permanent disability is a very frequent consequence. The musculo-spiral and the median nerves are those most prone to isolated injury, the former as a result of its position directly behind the artery, and the latter as a result of its mode of formation by two heads which surround about half of the circumference of the vessel.

Partial lesions of the median are not uncommon as a result of this anatomical arrangement.

The third special feature of axillary injuries lies in the frequency with which the missile which injures the artery enters or traverses the thorax. In our series a considerable hæmothorax complicated the arterial injury in 20 per cent of all the cases. This complication is one to be specially borne in mind in contemplating early surgical intervention for the vascular injury, because the escape of a large quantity of blood into the thoracic cavity produces an anæmia very unfavourable to the performance of an operation which may involve the occurrence of further hæmorrhage.

Signs of Injury to the Axillary Vessels.—The signs of contusion and obliteration of the artery may be shortly summed up as consisting in extinction of the radial or brachial pulse, absence of any local vascular bruits, an immediate interference with the motor power of the limb apparently greater than the severity of the injury should warrant, an exaggeration of the results of injury to the nerves; and later, an unfavourable influence in the further progress of the nerve lesion.

In a large proportion of the injuries (40 out of 54), one of the forms of hæmatoma or aneurysm followed. The aneurysm in our series was purely arterial in character in 24 instances, and arterio-venous in 16. In 9 of the latter a sac was certainly present; in 7 the condition was one of aneurysmal varix, for the formation of which the anatomical arrangement is particularly favourable.

The early signs in these cases consist in a considerable degree of general swelling of the limb, combined with loss of power and sensation, which latter may be often much greater than the actual severity of the nerve lesion would seem to warrant. The loss of function may be mainly due to nerve concussion, and may be present when no serious or destructive lesion of the nerves has been caused; in such cases the symptoms clear up rapidly. The general swelling of the limb depends upon the effusion of blood into the axilla and interference with the venous return. The radial pulse is usually diminished in volume, sometimes absent altogether.

The local swelling varies in extent and appearance according to which portion of the trunk is involved. When this is the first portion, the blood in the hæmatoma stage usually gives rise to a more or less ill-defined flattened swelling obliterating the subclavicular fossa, and tends to spread over the pectoral muscle and towards the median line. Widespread ecchymosis is not uncommon.

When the lesion is of the second part of the artery, the resulting tumour is of a more localized character, rounded in outline, and apt not to spread beyond the confines of the borders of the pectoralis



Fig. 49.—Arterial aneurysm of the second portion of the left axillary artery. The aperture of entry of the bullet is seen in the outer part of the deltoid region, small and typical. The bullet itself was retained under the small prominences, due to the presence of subcutaneous blood-clot, seen over the sternum; note also the ecchymosis in this region. The anterior wall of the axilla projects as a large dome-like cavity. The wrist-drop, due to injury to the musculospiral nerve, is well shown. *Under the care of Capt. Fitzmaurice Kelly.*

minor, by which muscle it is bound down and confined. When the sac reaches any considerable size, it is readily palpable in the axilla.

Hæmatomata of the third portion are apt to be more irregular in outline; they may spread along the vascular cleft into the arm in the line of the main vessel; or the extravasation may take the line of some of the branches, most commonly that of either the circumflex or the subscapular. If the circumflex, great subdeltoid swelling may develop; if the subscapular, the effusion travels to the chest wall, and may collect both on the surface and beneath the scapula.

Determination as to whether the main trunk or one of its branches is at fault may be a matter of considerable difficulty, and operative exploration alone may clear up the point. The subscapular artery is the one which most often gives rise to confusion. I have twice had occasion to operate in such cases. In one, a hæmatoma in connection with the second part of the artery was simulated, as the effusion was limited at the lower margin of the pectoralis minor; further, the radial pulse was absent. Exploration showed the wound to be of the subscapular branch close to its origin, and absence of the radial pulse proved not to be the result of pressure, but of obliteration of the main trunk following contusion of its walls. In the second case, the effusion had followed the line both of the subscapular artery and that taken by the missile, and was most abundant over the chest wall and around the scapula. In this instance a pre-operative correct diagnosis was made; but it is of interest to note that this patient had complete brachial monoplegia, which suggested a lesion of the main arterial trunk rather than of a branch. The subsequent history of this patient was of a slow general recovery of nerve function from above downwards, suggesting that concussion and temporary local pressure were responsible for the monoplegia. At the end of six months, however, recovery was very far from complete.

The local vascular bruits are well marked; they may be very widely distributed over the chest, and down the arm. The resonating factor afforded by the chest allows the murmur to be heard over the whole præcordial region, but as a rule the sounds of the heart can be heard quite distinct from the aneurysmal bruits. In four cases in our series a distinct systolic murmur replaced the normal first sound; two of these cases were arterial and two arterio-venous in nature. In both the arterial cases the bruit was heard at the apex, and loudest at the base of the left ventricle. In the arterio-venous cases, in one the systolic murmur was audible both at apex and base of the heart, in the other it was limited to the base and the apex of the left ventricle, as is the rule with purely arterial lesions.

In one patient, an axillary varix was present as well as an arterio-

venous hæmatoma of the inferior thyroid artery, the latter being at first mistaken for a carotid injury.

Prognosis and Treatment.—In the matter of prognosis, injuries to the axillary artery have an unfavourable aspect second to none in the body. *Quoad vitæ*, we find 4 deaths amongst 54 cases (7·4 per cent). Two of the patients died from the combined effects of a large primary hæmorrhage and a large hæmatoma, and loss of blood consequent upon an operation undertaken at an early date ;



Fig. 50.—Skiagram showing fragment of shell on chest wall, and smaller fragments in entry end of wound track, which gave rise to the development of an aneurysmal varix in the third part of the right axillary artery.

one of these accidents might perhaps have been avoided by allowing a longer interval to elapse before dealing with the hæmatoma ; but the second operation was undertaken for urgent and imperative signs. One patient died as a result of secondary hæmorrhage, and one from acute post-operative tetanus.

As has been already dwelt upon, spontaneous arrest of hæmorrhage is common in injuries to this artery. It is in the ultimate results attained that the unfavourable prognosis asserts itself.

It is a remarkable fact that in our series the most consistent and persistent loss of functional capacity of the limb was often seen in those instances in which primary spontaneous thrombosis had preserved the patient from most of the early dangers of a wounded

artery. Amongst the ten cases here recorded, in two the artery is known to have been completely severed by the missile, but in the remainder it is impossible to say what grade the primary injury reached, or what extent of the arterial wall was destroyed. Reasoning from the evidence offered by the anatomical findings in injuries of this class to the carotid arteries, we may assume that in some instances the lesion was not of an extensive character. In all the cases the radial pulse was primarily obliterated, and in the majority a good radial was not re-established during the period that the patients were able to be followed. In four instances both the radial and the brachial pulses were impalpable, and in these the primary injury must be judged to have been extensive. Only in one of the 10 cases of traumatic thrombosis did the patient escape without a concomitant nerve lesion, and in this instance the thrombosed artery lay at the bottom of a large open wound; this vessel eventually gave way secondarily, giving rise to a secondary hæmorrhage which necessitated ligature. Of the remaining 9 patients, 5 returned to England with persistent complete brachial monoplegia; of the others, one proved to have suffered division of the median, ulnar, and musculo-spiral nerves; in one the musculo-cutaneous nerve was divided and the remaining nerve trunks were fixed by cicatricial tissue; in one the posterior cord and its branches were alone affected; and in one, in whom general diminution of sensation and tingling were present, the radial pulse returned at an early date. I regret that I have been unable to trace these patients further, but general experience does not warrant the expectation that any great improvement took place.

Amongst 22 patients in whom combined arterial and nerve lesions were followed by the formation of aneurysms, the results seem little superior. In 9 of these the radial pulse was abolished, in 9 it was diminished in volume, and in 1 both radial and brachial pulsation was impalpable. In only one case of axillary varix was the blood-pressure in the injured limb equal to that in the sound one, and in this instance the lesion was the result of a bayonet stab, and not a gunshot injury. The nerve symptoms present in these cases were as follows: complete brachial monoplegia, 7; signs of injury to median and ulnar nerves, 8; to median alone, 8; to ulnar alone, 2; to median, musculo-spiral, and ulnar, 1; to musculo-spiral, musculo-cutaneous, and ulnar, 1; general anæsthesia, 1; anæsthesia in the area supplied by seventh cervical root, 1. Only one of these patients recovered sufficiently to return to active service, the great majority of the remainder were discharged from the service as permanently unfit.

It is not only from the point of contemporaneous injury to the nerves in the axilla that the vascular injuries are liable to be followed

by unsatisfactory results. From the purely vascular aspect also, obliteration of the artery is apt to be followed by imperfect results. It is rare not to observe a cold cyanotic hand after ligature of this artery, and this evidence of depressed vitality may persist for considerable periods of time. Some loss of volume in the muscles of the limb is also common, as much as one inch in the forearm and half an inch in the arm. It is always the terminal segments of the limb which suffer the more severely.

Arterio-venous aneurysms and aneurysmal varices often give rise to little change during the period the modified arterial circulation is not interfered with. In the case of the aneurysms ultimate operation is necessary, but in that of the varices it is best avoided if possible. It has always been known that these conditions give rise to less serious signs of venous obstruction in the upper than in the lower extremity; but observation of a large number of cases has shown that venous obstruction may develop more frequently than has been supposed. I have seen cases which clinically exhibited the signs of a pure varix, in which the condition of the peripheral veins called for operation; in one of these a tendency to enlargement of the veins also existed in the uninjured limb, and there can be little doubt that personal idiosyncrasy in this respect is a matter that must not be lost sight of.

METHODS OF TREATMENT ADOPTED IN THE SERIES OF CASES UNDER CONSIDERATION.—A considerable variation in the mode in which the cases included in this series were dealt with is apparent. This has depended on an imperfect realization in the early days of the war of the true lines which should be followed; but these have now crystallized out in definite form as the result of increased experience.

The third part of the subclavian artery was ligatured in continuity in 7 instances. Twice this measure was adopted as the sole one. In one of the cases the operation was performed to check primary hæmorrhage from the first part of the artery. The patient was removed to a hospital on the line of communication twenty-four hours later, and arrived in bad condition. The whole limb was swollen, pale, and cold, and suggested a state of incipient gangrene. With rest and care during the next seven days the limb improved, and actual gangrene was ultimately limited to the little finger and the last two joints of the thumb. In the second case the operation was undertaken as a measure of proximal ligature for an arterial aneurysm of the third part of the axillary artery. The aneurysm was eventually cured, but a soft fluctuating blood tumour, surrounded by indurated tissues, persisted for a couple of months, and considerable wasting of the arm occurred.

In 3 cases ligature of the third part of the subclavian was combined with distal ligature of the third part of the axillary artery.

In one of these the procedure was successful. In two it failed. In one of the latter a permanent arterio-venous communication was left, although at the time of operation the decrease effected in the blood-current caused a temporary disappearance of the thrill and murmur. In the second, persisting hæmorrhage from the opened-up cavity in the axilla had to be controlled by plugging, the wound being sutured secondarily at a later date.

In two cases the subclavian was ligatured for the treatment of secondary hæmorrhage occurring after local ligature of the axillary artery. In both of these a successful result was attained.

In only one case that I saw had the wound in the artery been subjected to primary suture. This operation had been performed by Major Ozanne, and at the end of fourteen days pulsation in the brachial artery was normal in volume. It was unfortunate that in this instance a wound of the forearm had necessitated a simultaneous ligature of the radial artery, so that we had not the more stringent test of the pulse at the wrist to go by.

In an arterial aneurysm of 23 months' standing, which sprang by a broad base from the artery, I removed the greater part of the adventitious sac, and by sewing its base attempted to reconstruct the artery. This operation was a failure from the ideal point of view, although a good result was obtained as far as curing the aneurysm and preserving a useful limb was concerned. The radial pulse returned in this case in eight days. In one instance in which I closed the communication between the artery and vein, by suturing the opening from the laid-open vein, a perfect result was attained.

I have only the record of one case of wound of the axillary treated by the introduction of a Tuffier's tube. It was not a success; the radial pulse disappeared two hours after insertion of the tube; the latter was removed at the end of forty-eight hours, and the two ends of the vessel were closed by ligature. Secondary hæmorrhage occurred on the tenth day, and the artery was again ligatured; but the bleeding recurred at the end of two days, and the patient succumbed. Infection of the wound was responsible for this fatality.

Four cases were treated by double ligature and division of the intervening part of the artery as a primary measure, and all did well; the same may be said of five out of eight cases in which the same procedure has been adopted for the cure of aneurysms, with the reservation that has been foreshadowed as to the ultimate result which commonly follows occlusion of this artery.

The causes of death in the three fatal cases have already been given above.

In 7 cases the artery and vein were tied simultaneously, and in 5 the artery alone. The only case of gangrene following ligature

of the axillary artery was included in the latter number; but it must be remarked that in this instance one of the heads of the median nerve had been divided, and injuries to this nerve are particularly dangerous from the point of view of the nutrition of the limb.

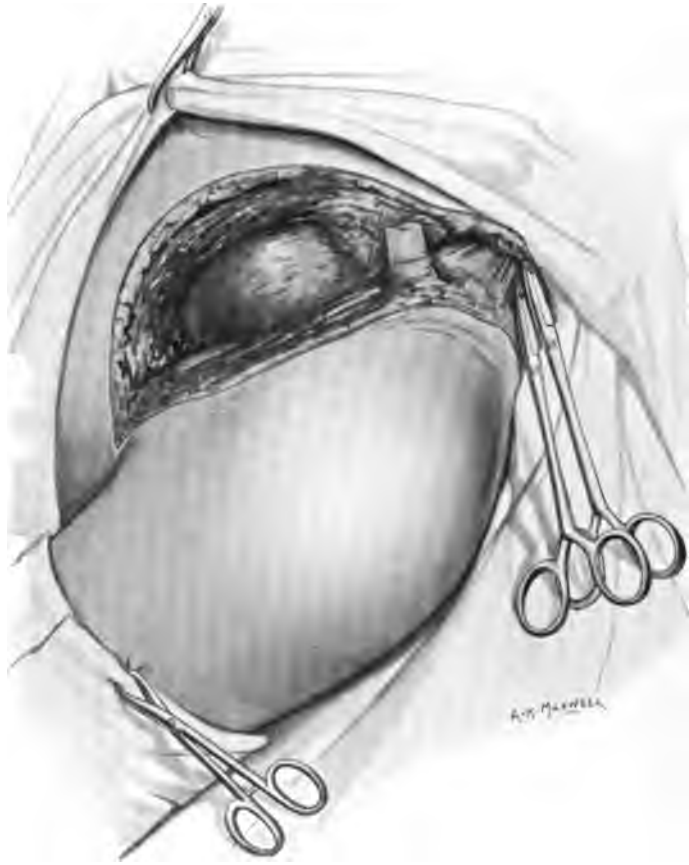


Fig. 51.—External surface of arterial aneurysm developed in connection with the second portion of the axillary artery. The arm has been placed at the side. *Captain Santos.*

Injuries to this vessel which require operative intervention should always be dealt with locally. The same procedure is advisable whether the first or second portion of the artery needs to be tied.

When a hæmatoma or an aneurysm requires to be attacked, the first step consists in the application of a provisional ligature to the third part of the subclavian artery to ensure absolute control of the proximal circulation. This preliminary is advisable in every case, although compression of the subclavian may be relied upon when the aneurysm is a small arterial one on the third portion of the axillary. Compression is, however, a poor substitute for the efficient control



Fig. 52.—Wound in second portion of axillary artery responsible for the aneurysm shown in *Fig. 51.* *Captain Santos.*

and the confidence engendered by a provisional ligature, while in arterio-venous injuries compression may be an actual source of difficulty and danger by augmenting venous hæmorrhage. In no other situation is venous hæmorrhage likely to be more free and difficult to control than here; and, in addition, the risk of entry of air into the veins has to be borne in mind. Even when the subclavian is controlled, the number of collateral branches springing from the

axillary artery may furnish sufficient blood to render it difficult to keep the field of operation free for such a procedure as suture of the wounded trunk.

The second step consists in carrying an incision from the centre of the clavicle down over the pectoral region to the level of the commencement of the brachial artery. The pectoral muscles are then completely divided, in order to gain a satisfactory exposure of the vessels in their whole length, and ensure the safe separation of the surrounding nerve trunks. When the operation is undertaken after the lapse of weeks or months, and persisting signs of nerve lesion are present, the obvious necessity of exploring the nerve trunks and freeing them from adhesion, or possibly repairing damage, adds a second reason for adopting this measure beyond that of avoiding hæmorrhage or of curing an aneurysm.

The pectoralis major is divided from the surface; if it be thought preferable, the pectoralis minor may be freed by blunt dissection from the axillary fascia before proceeding to divide it. A cephalo-jugular vein, if present, should be preserved, in view of the possibility that the axillary vein may need to be tied later. Branches and trunk of the acromio-thoracic artery, and the cephalic vein, should also be spared. The artery is now exposed, and a distal ligature is applied as a provisional measure. In recent cases, when the connective tissue is infiltrated with blood, it is necessary to exercise caution that the median nerve is not overlooked and damaged.

The actual seat of damage to the artery can now be investigated, and if the operation be an early one, the vessel will be either sutured or ligatured as may seem best. If the artery needs to be ligatured, the axillary vein should also be occluded.

If a false aneurysm of any standing needs to be dealt with, the wall of the sac is usually readily separable, and when it has been freed, the nature of its communication with the main trunk can be investigated. If the connection be broad, suggesting an extensive defect in the arterial wall, the greater part of the sac may be removed, retaining a portion, which may be sutured, and thus the viability of the artery maintained. If the connection be a small one, the whole sac is removed and the defect in the arterial wall sutured. The latter, is, in my experience, much the more likely to prove a successful procedure.

Prior to removal of the sac, it is often convenient to place either provisional ligatures or clamps on the artery in immediate proximity to the aneurysm. This measure has the double advantage of not only eliminating a number of branches which may supply blood and thus render the operation of suture less easy, but it also shortens the period for which it is necessary to maintain control by the first

provisional ligature on the third part of the subclavian, and minimizes the chance of damage to the wall of that vessel.

A word of special caution needs to be uttered with regard to the process of removal of the sac; in two instances in my own operative experience a spread-out head of the median nerve has formed an integral element of the wall of the aneurysm, and needed to be separated with very great care; in another case operated upon by my colleague, Captain Z. Mennell, the trunk of the musculo-spiral nerve was similarly disposed. The numerous branches of the axillary artery form another troublesome element in dealing with these aneurysms, and it may prove necessary temporarily to control one or more of them. Obviously they should never be divided, even when suture is chosen, as certainty cannot be ensured that thrombosis may not convert the operation into one of occlusion.

The remaining special feature of axillary operations is the great difficulty which may be met with in controlling venous hæmorrhage when the first part of the axillary vein has been the seat of injury. In one of my own operations, the first I undertook, I unfortunately trusted to digital compression of the third part of the subclavian artery for control of the arterial circulation; the artery was secured above and below the aneurysm without difficulty; but the vein, which had been completely severed, had retracted beneath the clavicle, where adhesions had formed which held the lumen widely open with a trumpet-shaped mouth. The vein was eventually secured, but the patient died the same evening as the result of the loss of blood he had sustained during the operation. In a second case, which ended more happily, the artery having been ligatured, persisting venous hæmorrhage had to be controlled by the insertion of a plug.

Any further details in the performance of operations on arterio-venous aneurysms—the manner of dealing with the sac or the actual communication between the vessels—are carried out on the lines laid down in the general section on this subject.

BRACHIAL ARTERY.

In spite of the great frequency of injuries to this vessel, our series only contains 43, and amongst them are a very large proportion of accidents. It was, indeed, for the most part only what may be called serious cases that came under my special observation; hence this section offers little matter for statistical deduction, although it affords illustration of most of the complications that occur in the course of treatment of injuries to the brachial artery.

202 GUNSHOT INJURIES TO THE BLOOD-VESSELS

The incidence on the two sides of the body, amongst 35 of the cases, is—right 20, left 15. Eight injuries were to the upper third of the vessel, 8 to the middle third, and 15 to the lower third.

The proportion of cases in which primary hæmorrhage is said to have been free is comparatively large, 12 out of 43 (27·8 per cent). Secondary hæmorrhage occurred in 6 (13·9 per cent). Nerve complications occurred in 10 cases (23·25 per cent); in 6 of these the median was the trunk injured, in 2 the musculo-spiral, in 1 the ulnar, and in 2 all three nerves were involved.

In only 4 was the humerus fractured; but this number gives little idea of the frequency with which fractures of the humerus are complicated by injury to the artery. Again, only one was complicated by a hæmothorax, in spite of the notorious frequency of association of wounds of the arm and the chest.

The number of wounds caused by bullet and fragments of shell is practically equal. A somewhat large proportion of extensive wounds, and a small one of retained missiles, occurred.

The most striking feature in the hæmatomata and aneurysms is the great preponderance of the arterial variety. Thus, of 25, 12 were pure arterial sacs, only 1 an arterio-venous aneurysm, and 5 were aneurysmal varices. The explanation is no doubt found in the fact that a wound of the artery of any considerable extent is probably generally accompanied by complete division of one or other of the venæ comites, the latter being comparatively small in consequence of the large size of the more distantly situated cephalic and basilic veins. One case afforded a good illustration of a method by which early establishment of an arterio-venous anastomosis may be prevented. In this instance the small fragment of shell case which had wounded both vessels was lodged in the opening in the vein, and hence only an arterial hæmatoma formed.

The rarity with which an arterial murmur is transmitted to the heart from a local lesion in the arm, has been already remarked (p. 54). In this series transmission was met with only once, and the peculiarity of the cardiac murmur which was heard during a routine examination of the chest led to the discovery of the varix. The latter was of old standing, the result of a shot-gun accident six years previously, and the condition had not given rise to any disability. The case also affords an illustration of the fact that transmission of a local murmur may be a permanent phenomenon.

In 5 cases injury to the brachial artery was followed by traumatic thrombosis and obliteration; in one of these a severe ischæmic condition of the limb developed. Probably some of these cases would have passed unnoticed had it not been for the fact that

each of them was accompanied by signs of a more or less severe lesion of the nerves. In two cases the median was affected, in one the ulnar, in one the median and musculo-spiral, and in one there was complete loss of both motion and sensation in the limb below the wound, the track of which passed immediately at the junction of the anterior axillary fold with the arm. The patient with musculo-spiral paralysis is the only one I have been able to trace at home; he was discharged from the service as permanently unfit eleven months after the injury. The conditions, after all, are very like those which exist in the case of the axillary artery. In a few cases, not included in these numbers, I have seen a thrombosed portion of the



Fig. 53.—Raspberry-like excrescence on brachial artery exposed in an open wound, on fourth day after injury, illustrating the possible occurrence of secondary hemorrhage or the development of an aneurysm as the result of incomplete destruction of the arterial wall.

brachial artery resected. Apart from the common association of thrombosis with injury to the nerves, the condition is not one of great importance.

Nothing special needs to be said regarding diagnosis of injuries to this artery; but an interesting case is mentioned in the next section, in which a varix of the median basilic vein at the bend of the elbow, which I thought to be in communication with the brachial, proved to be connected with the interosseous artery (p. 206).

Prognosis and Treatment.—Apart from combined injuries of the artery and the nerves of the arm, wounds of the brachial artery, with subsequent obliteration of the trunk, would seem to be accidents of small importance. In the few cases which I have had the opportunity of examining months after the injury, however, an

appreciable loss of volume of the limb below the site of the occlusion of the vessel, and a lowering of the distal blood-pressure, have been present. Yet the men were back on active service, not complaining; and mere examination of the affected limb, without comparison with the uninjured one, would have warranted the surgeon in claiming a perfect result.

Of the 38 cases in which the artery was not already occluded by thrombosis, 24 were treated by ligature, and 6 by suture of the artery; the remaining 8 cases passed from my observation at an early stage.

Ligature.—Of the 24 cases of ligature, 17 were of the artery alone, and 7 of both artery and vein.

Among the 17 cases of ligature of the artery, there were 6 cases of gangrene, and 1 case occurred among the 7 in which the artery and vein were tied.

Of the 17 operations, 5 were primary, with 3 cases of gangrene; 12 were secondary, also with 3 cases of gangrene.

Of the three cases in which gangrene followed primary ligature, in one the hæmorrhage had been very copious and pallor was extreme, the vessel was tied in an open wound with the aid of local anæsthesia, arterial gangrene started in the fingers, followed by gas gangrene, and the arm was amputated; in a second, the patient was very severely wounded, lay out in the cold, the other arm and one leg were amputated for destructive injuries, and the ends of the fingers were lost; in the third case, arterial gangrene of the fingers was followed by gas gangrene, and amputation was performed.

Of the three cases in which gangrene followed secondary ligature, hæmorrhage was the indication in all. In two of them the median nerve was injured. In two, digits only were affected; in the third the gangrene spread up the anterior surface of the forearm. Amputation was successfully performed in each.

In the only case of gangrene following ligature of artery and vein, the gangrene extended only to the base of the terminal phalanges. Suppuration of the forearm afterwards necessitated amputation.

The indications for ligature of the artery alone were: primary hæmorrhage 5, secondary hæmorrhage 5, arterial hæmatoma 6, aneurysmal varix 1 (a failure). The indications for ligature of artery and vein were in all cases arterial hæmatomata.

As to the permanent results, I have only knowledge of two, and these returned to duty.

Suture.—In 6 cases wounds of the vessel were sutured. In 3 the wound was resected on account of its extent, and end-to-end union was established. The first, a primary operation, failed, as the union gave way on the tenth day and the vessel required to be liga-

tured; the suture had torn from the distal end of the vessel. In the second, the operation was performed on the nineteenth day; the pulse was maintained; on the fourth day the blood-pressure in the periphery was 90 mm., against 125 mm. on the sound side; on the twenty-fourth day it was 127 mm., against 140 mm.; the man is now working in a colliery. In the third, the operation was performed on the twenty-second day; the radial pulse failed at the end of forty-eight hours, and returned on the fifth day, on which date the peripheral blood-pressure was 80 mm., against 127 mm. in the sound limb; the patient has returned to Australia.

In 3 cases lateral suture was performed. In the first a long vertical slit in the artery was closed in the horizontal line; the radial pulse was suppressed at the end of twenty-four hours, and returned in seven days; the man rejoined his regiment four months later. In the second, a lateral suture of half the circumference of the artery was performed on the fourteenth day by Captain Greaves; the radial pulse was maintained, and on the tenth day the peripheral blood-pressure was equal to that of the sound limb. In the third, a varix for which proximal ligature had been performed unsuccessfully twenty-three months previously, a type operation was performed by Mr. Edred Corner, but the vein was utilized to supplement the arterial suture; the radial pulse (possibly already an anastomotic one) was retained, but three weeks later the peripheral blood-pressure was only 60 mm., against 135 mm. on the sound side.

This small series affords one absolute failure, but it must be borne in mind that the giving way of the line of union followed transport and removal of the splint. There were two good results, one of them ideal. In three cases the results were not materially better than those of ligature.

A word remains to be said regarding the occurrence of such a large proportion of gangrene after ligature. There are two or three special reasons to explain this. In the first place, unfortunately the arm is an easy place to apply a tight tourniquet. In several of the cases this had been done, and in one it was probably responsible for the subsequent gangrene. In one case exposure to cold and exhaustion was at any rate ancillary, if not the sole cause. In two cases secondary gas gangrene developed, a sequence which has always been possible, and is greatly favoured by occlusion of a main trunk. In both of these patients, however, anæmic gangrene of the fingers developed prior to and independently of the extending infective gangrene.

It may be worth mentioning that high division of the brachial artery was seen several times. In one case in which it had been hoped to repair the lower part of the vessel, and in which resort had to be

had to ligature, it was noted that the radial pulse was unaffected. Had the operation of suture been practicable, the condition would not have been suspected, and an ideal result would have been claimed which might not have been really justified.

In three of the cases of gangrene the median nerve had suffered injury, and there is no doubt whatever that damage to this nerve is a very important contributory cause to the occurrence of the accident.

It seems unnecessary to give any detailed description of the appropriate methods of operation. A free incision, care of the nerve trunks, and sufficient mobilization of the artery without division of branches, if either suture or ligature be contemplated, are the only points of importance. The artery is a very convenient one for either resection and end-to-end junction or lateral suture, and in suitable cases repair should be preferred to occlusion. Arterial hæmatomata or arterio-venous aneurysms should always be operated upon. In cases of aneurysmal varix, the surgeon exercises his own judgement, but in many cases there are no signs or symptoms which warrant interference.

VESSELS OF THE FOREARM.

Wounds of the radial or ulnar arteries are common, but they do not call for any special description; the pulse at the wrist is rapidly re-established after a wound of one of the vessels, and interference with the nutrition of the hand is usually negligible.

In consequence of the small calibre of the vessels, complete severances of continuity are common; while for the establishment of an aneurysm or arterio-venous communication, either the injury must be slight or the missile very small. Traumatic aneurysms on these vessels, therefore, are not common.

It is rather interesting to note how loud arterio-venous murmurs may be in consequence of the superficial situation of the arteries in the lower half of the forearm, and for the same reason the murmurs may be very much changed in character by pressure exerted by the bell of the stethoscope.

One case may be quoted to illustrate the difficulty which often exists in locating the actual position of an arterio-venous communication and determining the vessels involved. The wound was caused by a fragment of a bomb which entered exactly in the centre of the elbow-crease of the right arm. An aneurysmal varix resulted, and was disregarded until a wound of the elbow-joint was received nearly two years later. The elbow became ankylosed at a right angle, and the limitation of movement may have been responsible for enlargement of the varix, in so far as it interfered with the normal mechanism of

the venous circulation. A varix the size of a pigeon's egg had developed in the median basilic vein; this pulsated freely, and I assumed that a direct communication with the brachial artery as it lay beneath the bicipital fascia was present. On dissection, the varix was readily lifted from the surface of the brachial, and it became evident that the pulsation and thrill were both conducted from a vein of the forearm, probably the deep median. This vein and the interosseous branch of the ulnar artery were ligatured, and pulsation and thrill were permanently abolished.

Quadruple ligature of the vessels and excision of the sac is the form of operation applicable to arterio-venous aneurysms, and excision and double ligature of the artery for the arterial variety.

CHAPTER X.

VESSELS OF THE LOWER EXTREMITY.

FEMORAL VESSELS.

THE femoral vessels afford the largest series of injuries, 170 in all. The incidence on the two sides of the body was about equal: of 117 of the cases, 56 were injuries to the right and 61 injuries to the left thigh. A very great majority of the lesions were caused by fragments of shells, although during the first months of the war this was not the case, and bullet injuries were frequent. It is noteworthy that increase in the proportional number of arterio-venous to arterial aneurysms corresponded in date with the change in the nature of the missile causing the wounds of the vessels.

A history of profuse primary hæmorrhage was rare amongst the patients who reached the hospitals on the lines of communication; it is only noted to have occurred in 18 out of 150. The same remark holds good amongst the small number of cases treated at the casualty clearing stations which are quoted here.

Amongst 75 cases in which the nature of the wound of the soft parts is specially recorded, in 43 it consisted of a limited through-and-through track; in 18 the missile was retained; and in only 14 was the wound large and extensively lacerated. Complications are not a striking feature. Thus, in only 15 was a fracture of the femur present. It may, however, be remarked that a large addition to this number would be probable were the cases of fracture of the femur sifted for arterial complications. Associated injury to nerves was also rare; perhaps the most common was injury to the great sciatic trunk in wound tracks passing from before backwards. It was surprising to notice, in the course of operations on the superficial femoral artery, how rarely either the long saphenous or the nerve to the vastus internus had been injured.

Thrombosis.—In 20 cases there was reason to believe that thrombosis had ensued after the infliction of either contusion or wound of the vessel; and as this sequence is of very considerable interest, as bearing not only upon the question of spontaneous arrest of hæmorrhage, but also on that of definite spontaneous cure of wounded arteries, the small series is worthy of analysis. The evidence

rests in part on clinical investigation, in part on ocular proof by direct observation in wounds.

It will be well to deal first with the instances in which the diagnosis depended upon clinical investigation alone. In seven the evidence consisted almost solely of the disappearance of a local arterial bruit, or the combination of this with a transmitted murmur to the heart.

Case 40.—An officer received a small through-and-through wound of both thighs. It was originally thought that one femur had been fractured, but this assumption was negated by *x*-ray examination. Four days later, examination of the heart showed the apex to lie in the nipple line, the pulse to vary from 80 to 90, and auscultation disclosed a loud bruit audible over the base of the heart. This murmur had been likened to that dependent on pericardial friction, but the bruit really consisted of the typical loud venous roar, with systolic exacerbations. The first sound was replaced by the systolic bruit, while the second was loud, pronounced, and quite clear.

On examination of the thigh, ecchymosis was seen over the triangle of Scarpa, but there was little or no swelling, and neither thrill nor pulsation could be detected. The posterior tibial pulse was present. On auscultation, a loud venous roar and a comparatively soft systolic bruit were audible over the commencement of the superficial femoral artery, and conducted in both directions. The presence of an arterio-venous communication was therefore demonstrated, and the presence of both sets of murmurs was corroborated by at least three experienced auscultators.

Fourteen days later I saw this patient in London; the local murmur had then completely disappeared, no pulsation or thrill could be detected, and the tibial pulses were present; but a faint systolic bruit persisted at the apex of the heart for a few days longer. The patient was kept at rest in bed for a further period of three weeks, and then allowed to move about; no recurrence of any of the signs took place.

Case 41.—A sepoy, with a fracture of the femur just below the trochanters, was found to have a systolic bruit audible over the course of the femoral artery just below Poupert's ligament, and no pulsation could be detected in the vessel. This bruit persisted for three weeks, but two months later it had disappeared, and both the tibial pulses were palpable.

Case 42.—Pte. W. A through-and-through track traversed the upper third of the thigh; no pulsation was palpable in the femoral artery, and a local systolic bruit was audible. The dorsalis pedis artery was pulsating, but not the posterior tibial. Seventeen days later the bruit had disappeared, and the œdema of the foot, present at the time of the first examination, had subsided.

Case 43.—Pte. R. A through-and-through wound traversed the thigh just below its centre. A tense pulsating swelling was present in the adductor region. On the fourteenth day all pulsation had disappeared, a soft venous bruit was audible, and the tibial pulses were present. On the twentieth day neither pulsation nor bruit could be detected.

Case 44.—Pte. S. Small wound of left thigh. After being dressed, the patient was sent back to the trenches. Five days later a small tense swelling was detected over the junction of the middle and lower thirds of

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the superficial femoral artery, and a local systolic bruit was audible at this spot. Two days later the bruit had disappeared, and the patient was shortly afterwards evacuated to England.

Case 45.—Pte. T. Through-and-through track in thigh, and a fracture of the femur. The thigh was much swollen, but the posterior tibial pulse was present. A systolic bruit was audible at the apex of the heart. Sixteen days later the swelling of the thigh had much diminished, and the cardiac bruit had disappeared.

Case 46.—Pte. W. Shell wound of thigh. The wound bled freely primarily, and the patient controlled the hæmorrhage by tying a tourniquet around the limb. The man lay out for two days, and when brought in to the casualty clearing station an arterio-venous communication was diagnosed. A week later a systolic bruit was still audible at the cardiac apex, but the local signs had disappeared.

The above 7 cases might perhaps be more accurately classed under the heading 'spontaneous healing,' but local thrombosis is none the less the necessary part of the process of cure. It will be noted that, in the last two, the presence of a cardiac bruit was relied upon as evidence of a local lesion of the vessels. This sign has been so often substantiated in my own experience by the discovery of a definite local lesion that I consider that its importance should never be discounted.

In the remaining 13 cases, ocular demonstration of complete thrombosis of the artery was afforded; in 5 it was seen and palpated in the floor of a large open wound, in 7 it was seen during the performance of operations, while in the thirteenth case a contused artery, still viable, was associated with a completely divided vein. In two instances a wounded vein was associated with a thrombosed artery, and in two a wounded artery was associated with a thrombosed vein.

Putting aside the significance of thrombosis as an element in the process of spontaneous cure, its chief interest lies in its relation to the occurrence of secondary hæmorrhage, to its importance as a stage in the development of secondary traumatic aneurysms, and to the risk of embolism and its attendant consequences.

Secondary hæmorrhage occurred in 5 out of the 13 cases under consideration, on the fourth, sixth, eighth, tenth, and fourteenth days respectively. It is obvious that septic infection is as a rule responsible for the accident, and in one of the five patients gas gangrene was the actual cause; but, as has been repeatedly pointed out, secondary hæmorrhage may result from the separation of an aseptic slough. Experience has therefore amply demonstrated the wisdom of excising the thrombosed portion of any artery exposed in the original wound or met with during the performance of an operation. The difficulty of correctly estimating the actual degree of damage to the wall of the vessel by external inspection may be great or insuperable; but

in some cases it may be readily gauged. Thus, an artery may look as if "it had been rubbed with a coarse rasp"; while in an instance such as that figured on p. 10 (*Plate I*), the small dark spot seen on the outer surface of the vessel gave little indication of either the degree or extent of the lesion.

In this small series two instances are included in which a local bulging of a partially damaged wall was seen; in one the inner coat was bulging through a defect in the adventitia like the inner tube of a bicycle tyre bulging through a hole in the cover (Lieut.-Colonel Cowell); in the second (*Fig. 6*, p. 14) a small local bulge due to a defect in the inner coat at the upper limit of a vertical wound was exposed during an operation for suture of the wound in the artery. The prognostic significance of the latter observation, made at a period of four months after infliction of the injury, is perhaps not great; but the former illustrates well the condition which may precede the occurrence of either secondary hæmorrhage or a tardily developing traumatic aneurysm.

Secondary embolism was met with only once in the series; the embolus was arrested at the point of bifurcation of the popliteal artery, and occasioned gangrene of the foot and leg.

Nature and Distribution of Wounds of the Femoral Vessels.—Little need be said specially as to the nature of the wounds in the walls of these vessels. In the great majority of the instances which come on to the operating table, these are of the lateral variety. Amongst 22 cases in which primary ligature was performed, 14 lateral wounds, 3 perforations, and 5 complete severances were met with. In 45 cases in which operations were undertaken at a later date, 31 lateral wounds, 7 extensive lateral wounds approximating complete severances, 5 complete severances, and 2 perforations were found. Perforations have become rarer with the increase in frequency of wounds caused by shells. These, too, are apt to be followed by the development of aneurysmal varices. A number of the latter would have escaped notice as far as this series is concerned, since it deals mainly with cases in which early operations were undertaken.



Fig. 54.—Wound of superficial and deep femoral arteries, the profunda displaced inwards; the opening into the sac behind the vessels is seen, margined below by the insertion of the adductors.

Of 150 cases, the wounds of the femoral vessels were distributed as follows : upper third, 45 ; middle third, 65 ; lower third, 40. Certain portions of the arteries are specially liable to serious injury. Thus, the common femoral is fixed at its origin, and again by the profunda branch, which ties it firmly in position. At the latter spot wounds are frequent, and apt to be severe. In three cases I saw the deep femoral completely cut off from the main trunk, and in several it was wounded in combination with the superficial branch. A good example is furnished by *Fig. 54*. During its course through Hunter's canal the superficial femoral is firmly supported throughout by muscles and the aponeurotic roof of the canal, so that the vessel can scarcely escape a missile traversing its course. The most dangerous spot of all is the extreme lower end where the artery lies in the so-called adductor canal, and here the additional risk of wound by a fragment of a fractured femur also exists. The short trunk of the deep femoral artery is also held very firmly in position by the circumflex branches.

Signs of Wounds of the Femoral Artery and its Branches.—Hæmatomata in connection with wounds of these vessels reach the largest size of any met with in the body, those forming in connection with the axillary artery being the only ones which approximate in size and holding capacity.

From the regional point of view, wounds of the main trunks may be divided into three classes :—

1. Those in which the common, the superficial, or the deep femoral may happen to be wounded while enclosed within the confines of the triangle of Scarpa. It is not infrequently impossible to determine which of the three vessels is implicated, as the extravasated blood in either case may fill the triangle, obliterating the normal concavity or replacing it by a broadly convex swelling. When the wound of the common femoral is near its commencement, the blood may find its way up beneath Poupart's ligament and suggest that the external iliac artery is the vessel implicated. Subcutaneous ecchymosis is often widespread in wounds in this situation.

2. When the superficial femoral is wounded within the confines of Hunter's canal, a swelling of elongated outline forms along the antero-internal aspect of the thigh ; it is firm and tense, rarely extends into Scarpa's triangle, and subcutaneous ecchymosis is rare. A special feature of this hæmatoma is the part taken by the sartorius muscle in contributing to its boundaries. The muscle, beyond stretching longitudinally, widens out laterally, so that it may often be preferable, when trying to expose the artery, to cut through the fibres of the muscle rather than to displace it.

3. When the wound is a track passing through the adductor muscles from the front of the thigh, blood travels into the adductor



Fig. 55.—Orifice of entry of a bullet which caused a common femoral arterio-venous aneurysm. The minimal size of the aneurysm can be appreciated by regarding the outline of the groin. The cutaneous ecchymosis over the adductor region still persists, while the papular form of the orifice of entry, with its central depression, so characteristic of such wounds during the process of absorption and contraction of the underlying blood-clot, is well shown. *Under the care of Captain Martin.*

compartment, forming a second large sac connected to the anterior one by a very narrow neck or channel. The blood in the posterior segment of this bi-sac usually coagulates early, and rarely forms a part of a traumatic aneurysm, should this form.

Hæmatomata in connection with Wounds of the Branches of the Femoral Trunks.—*Profunda Femoris.*—Wounds of the profunda are probably far more common than the numbers furnished by lists of injuries to the femoral arteries would suggest, for there is no doubt that in many instances a clinical diagnosis of wound of the common femoral artery is arrived at, when the deep femoral is really the vessel which has been injured.

This series includes 6 cases in which isolated injuries to the profunda were disclosed by operation. Of these patients 3 died, and of the 3 who recovered, 2 were eventually discharged from the service as permanently unfit, and in the third the limb was in far from good condition. A brief abstract of the histories will perhaps best serve to explain this very unsatisfactory experience, since isolated occlusion of the profunda involves the least serious interference with the circulation of the limb of any of the three trunks.

Case 47.—Pte. F. was admitted with a shell wound of the thigh, one and a quarter by one inch in size, three inches below the mid-point of Poupart's ligament, and apparently superficial in nature. The wound was fairly clean on admission, there was some swelling of the thigh, no pulsation, and the tibial pulses were normal.

Two days afterwards there was a marked increase in anæmia, associated with great increase in the size of the thigh, and the development of pulsation and a systolic bruit. The swelling extended from the level of the anterior superior spine to the middle of the thigh. A temporary elastic ligature was applied to the common femoral artery, the swelling was incised, and two pints of clot were evacuated. A lateral wound was discovered on the outer side of the origin of the deep femoral artery; a ligature was applied below this, and the common femoral artery definitely closed also. After four days' satisfactory progress, gangrene of the toes set in, and a few days later the man succumbed to a general toxæmia.

Case 48.—Pte. G. was admitted with two wounds, one penetrating the right chest, the second traversing the buttocks and wounding the rectum. A large hæmatoma was present in Scarpa's triangle. During the following week the temperature rose (reaching 103°), with occasional rigors, and the hæmatoma showed signs of breaking down.

Under spinal anæsthesia the suppurating hæmatoma was incised; it extended deeply through the obturator foramen, and the common femoral vessels were felt pulsating in its anterior wall. On the same night a severe secondary hæmorrhage took place; this was controlled by placing a ligature on the common femoral artery, but the patient died a few hours later. A subsequent examination of the limb showed the deep femoral artery to have been completely severed at its origin from the common femoral. It had no doubt been thrombosed, but the clot had given way as a result of secondary infection.

Case 49.—Pte. G. A slit shell wound was present above the inner third of Poupart's ligament. There was no history of primary hæmorrhage, but Scarpa's triangle was now filled by a large clot which pulsated *en masse*. There was no bruit audible on auscultation. The tibial pulses were absent, the foot was red, and there were some patches of ecchymosis upon it. Pulse 108, temperature 102.5°.

A provisional diagnosis of wound of either the common femoral or external iliac artery was made. During the next four days the clot showed signs of commencing disintegration, and the mass decreased in size, the foot meanwhile commencing to mummify.

On the seventh day a secondary hæmorrhage occurred, and the external iliac was ligatured in continuity. Hæmorrhage recurred two days later, and was arrested by placing a second ligature on the common femoral artery. The patient died shortly afterwards from the combined effects of hæmorrhage and septic absorption. The profunda was found to be completely cut off from its origin.

Of the remaining three cases, which recovered, in one secondary hæmorrhage, and in two extension of the hæmatoma, formed the indications for the operative intervention which was a means of clinching the diagnosis. In one case the wound was actually a lesion of the back of the common femoral at the point of origin of the profunda, and all three trunks were tied. In the second the profunda was tied locally, and later the common femoral for the arrest of secondary hæmorrhage on the tenth day. In the third, a case of compound fracture of the femur, the profunda was tied locally for secondary hæmorrhage occurring on the sixth day. The ultimate result in these cases is given above.

Consideration of these histories illustrates the uncertainty in diagnosis which attends injuries to the profunda artery, and what is more important, the influence exerted by an incorrect diagnosis on the treatment and subsequent course of the cases. A few points help in arriving at a correct opinion, but they can only be regarded as affording circumstantial evidence, thus: (1) The direction of the wound track, as indicated by the situation of the apertures of entry and exit, taken into consideration with the attitude of the body and limb when the wound was received, or the position of a retained missile; (2) Determination of the point at which the arterial bruit is loudest; (3) The retention of practically normal tibial pulses. The result of my own experience is to lead me to approach any hæmatoma in Scarpa's triangle with an open mind, and in no case of urgency to apply more than a provisional control to the common femoral artery until ocular demonstration has shown that vessel to be the one wounded.

Circumflex Branches.—What has been said regarding the trunk of the profunda femoris applies equally to the cases of injury to the circumflex branches, and here again 7 cases were accompanied by a mortality of 3.

In these instances, however, the mortality was not so directly influenced by the preliminary diagnosis. In all three fatal cases direct local ligation of the wounded branch was effected; one patient, suffering from a serious fracture of the femur, died from the combined effects of hæmorrhage and shock; a second as the result of repeated secondary hæmorrhages from an infected wound; and the third from causes of which I am ignorant.

Certain small points may aid in locating a wound to one of the circumflex branches. The size of the hæmatoma is absolutely no guide, for quite as much blood may be extravasated as if one of the larger trunks had been wounded. The same points already enumerated under the heading of the profunda should be taken into consideration; and beyond these it should be borne in mind that the extravasation tends to follow the course of, and correspond with that of, the vessels

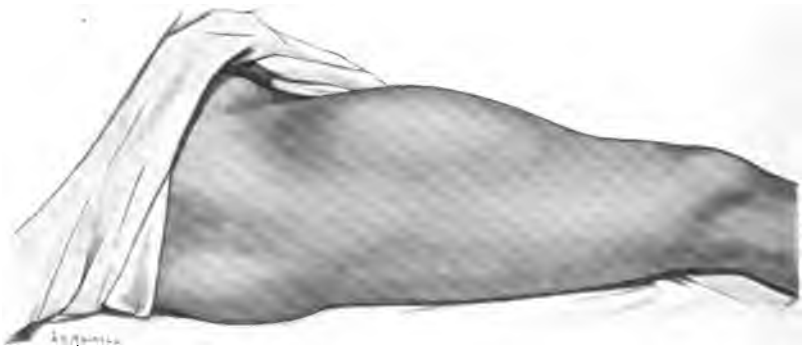


Fig. 56.—Wound of internal circumflex artery, with secondary extension along the line of the external circumflex.

themselves. Thus, a wound of the internal circumflex may lead to the development of a hæmatoma in the adductor region, although the compartment has not been traversed by the missile; and, generally speaking, the swelling indicative of the hæmatoma tends to spread widely in a transverse direction to the long axis of the thigh (*Fig. 56*).

These special points may be illustrated by the following case:—

Case 50.—Pte. A. Type bullet wound, the aperture of entry being situated one inch below Poupart's ligament, and over the line of the right femoral vessels; that of exit was in the right buttock.

On admission, a diffuse swelling occupied Scarpa's triangle, pulsation was strongest just below the aperture of entry, a localized thrill was palpable in this position, and a machinery murmur, not very widely distributed, was

audible. The apex of the heart was in the left nipple line, and a systolic murmur was audible here.

The patient was kept at complete rest, and the diffuse swelling gradually localized itself to the inner side of the femoral vessels. The walls of the sac increased in firmness, and the tibial pulses were maintained throughout. The comparative distal blood-pressure in the two limbs, taken a month after reception of the injury, was—right 120 mm. of mercury, left 150 mm. Meanwhile the physical signs remained unaltered, and the strength of the purring thrill in the femoral vein appeared to point to a direct communication between the main artery and vein.

At the end of two months a sudden increase in the size of the hæmatoma took place, and this now extended outwards to the right margin of the thigh (*Fig. 56*), and the femoral vessels could be felt to be beating independently along the inner aspect of the blood sac. The murmur audible over this new extension was almost purely systolic in character.

An incision was made extending from just below Poupart's ligament for six inches downwards, so as to allow a provisional controlling ligature to be placed on the common femoral artery. When the ligature had been placed upon the vessel, a second trunk was felt pulsating beneath, so that it was clear that a high division was present, and a ligature was passed around the second trunk.

The sac was now cleared and opened, and the two trunks were found to be both located upon its anterior wall. From the outer side of the deep trunk two branches of about equal size originated, and the wound was found to be in the upper of these. A ligature including the satellite vein was applied on either side of the wound, and when the provisional control on the main trunks was released, no bleeding or recurrence of the thrill and murmur followed. (G. H. M.)

The sac proved to consist of two segments, the primary one following the course of the internal circumflex artery into the adductor compartment, the later one tracking outwards in the line of the external circumflex branches.

After an uneventful course the patient was evacuated to England. The ultimate result was not considered sufficiently satisfactory for the man to be returned to active service, but he resumed his occupation as a miner, and has had no further trouble with the limb.

Prognosis and Treatment.—The total mortality amongst 170 cases of injury to the femoral vessels amounted to 23 (13·5 per cent). In several of the patients associated injuries were concerned in the ultimate issue. Deaths followed injuries to the common femoral in 5 instances, to the superficial femoral in 10, to the profunda in 3, and to the circumflex branches in 3. In 14 of the 23 fatal cases an operation was performed for direct treatment of the wound of the artery. In the remaining 9 cases, 1 died from exhaustion consequent on the primary hæmorrhage accompanying the injury, 3 after exploratory operations, 2 after amputation of the limb, 1 from hæmorrhage resulting from incautiously opening a large hæmatoma without having previously established provisional control of the main trunk, and 1 from causes of which no details are available.

In the case of 93 of the 170 patients, operations were performed

for the ligation of one or other of the femoral arteries. The operations were distributed as follows:—

Common Femoral—Cases, 14; cures, 2; recoveries, 5; deaths, 7. In 9 cases the artery alone was tied; amongst these, gangrene of varying extent followed in 4, and 6 of the patients died. In 5 cases the artery and vein were occluded simultaneously; amongst these patients, gangrene of varying extent occurred in 3, and 1 died.

Superficial Femoral.—Cases, 79; cures, 52; recoveries, 20; deaths, 7. In 25 cases the artery alone was tied; amongst these patients, gangrene of varying extent developed in 4 (16 per cent), and 4 deaths (16 per cent) occurred. In 54 cases the artery and vein were tied simultaneously; amongst these patients, gangrene of varying extent developed in 7 (12·9 per cent), and 3 deaths (5·5 per cent) occurred.

If the two series be combined, we have a total of 98 operations, with 19 cases of gangrene (20·4 per cent), and 14 deaths (15 per cent). Amongst those cases in which the artery alone was tied, the incidence of both local gangrene and of death was considerably the greater. Thus: Artery alone, 34; gangrene, 8 (24·5 per cent); deaths, 7 (20·5 per cent). Artery and vein, 59; gangrene, 10 (16·9 per cent); deaths, 7 (11·7 per cent).

The causes of death in the 14 cases following operation were as follows: Septic infection, 1; gas gangrene, 3; primary hæmorrhage, 1; operative hæmorrhage, 1; secondary hæmorrhage, septic infection, and exhaustion, 8.

If the cases in which ligation was undertaken as a primary measure or during the first two days be taken separately, the results attained are as follows. For the purpose of this computation two small series of cases are available, one of 25 selected from the 170 cases already considered, and one of 18 obtained from reports furnished by surgeons working at casualty clearing stations. These are set out separately in the subjoined table, because they offer definite evidence as to the better results attained by primary operation when it is practicable.

PRIMARY LIGATION OF SUPERFICIAL FEMORAL ARTERY.

	Hospitals on lines of communication, 25 cases	Casualty clearing stations, 18 cases*
Gangrene ..	10	1
Gas gangrene ..	1 (not fatal)	1 (fatal)
Amputation ..	5 (1 death)	4 (1 death)
Deaths	1	1

* Also two cases of ligation of common femoral; no complications

If both sets of cases be taken together, with a view to obtaining an average result of the work extending over the whole line, we have 45 cases of early ligation of the artery, amongst which gangrene occurred 11 times (24·4 per cent), 9 amputations had to be performed (20 per cent), and 2 deaths occurred (4·4 per cent).

In 15 of the 45 cases the artery alone was tied; amongst these gangrene occurred 5 times (33·3 per cent), and there was no death. The remaining 30 were treated by simultaneous ligation of the artery and vein; amongst these gangrene occurred in 6 (20 per cent), and death in 2 (6·6 per cent).

THE OCCURRENCE OF GANGRENE FOLLOWING INJURIES TO THE FEMORAL ARTERIES.—Amongst the 170 cases, gangrene of a varying extent followed injuries to the femoral vessels in 36 (21·1 per cent).

Pre-operative Gangrene.—In 11 instances gangrene was a direct result of the injury alone. In 2 the injuries involved the common femoral trunk, and in both the foot and leg were involved. In 7 instances the wound was of the superficial femoral; in 2 the toes only were involved, in 1 the whole foot, in 3 the foot and leg, and in 1 isolated patches of skin alone were implicated. Thrombosis was followed by gangrene twice; in one case this was limited to the foot, in the second both foot and leg were involved.

Post-operative Gangrene.—Gangrene followed the application of a ligation in 25 cases; but in 4 of these the gangrene was due to anaërobic infection. In the remaining 21 cases the gangrene was of the anæmic type; but it must be added that at least half the number of patients were suffering from the effects of septic absorption from their wounds, and in 8 of them attacks of secondary hæmorrhage formed the indication for occlusion of the artery. The common femoral was the seat of ligation in 6 of the patients; in 1 the gangrene did not extend beyond the toes, in 2 the whole foot was involved, and in 3 both foot and leg. The superficial femoral was the seat of ligation in 15 cases; in 6 the gangrene did not extend beyond the toes, in 1 half the foot was involved, in 1 a limited slough formed in the sole, and in 6 the foot and leg were implicated.

It will be observed at once that the extent of the gangrene was not a wide one on the whole; in less than half (9 out of 21) did the process involve the leg. It should also be noted that involvement of the leg seldom surpassed the dangerous area—i.e., the junction of the middle and lower thirds, the point where the arterial supply is normally least abundant. In fact, the gangrene of the leg was often patchy, involving the leg in this area and often the heel, with patches of skin still retaining vitality intervening. Two further influencing factors also need to be taken into consideration: (1) The patients had often lain out on the ground for hours or even days, sometimes

with a self-applied tourniquet on the limb; and (2) A large proportion were suffering from septic infection of varying degree, or were the subjects of multiple wounds. When all these unfavourable conditions are considered, I do not think the incidence of 20·5 per cent can be regarded as a surprising one. In this particular series, moreover, a decided fall in the incidence of gangrene corresponded with a generally improved method of primary wound treatment, showing the influence likely to be exerted by septic absorption.

The presence of the tibial pulses at the ankle, regarded as an indication of the persistence of a column of blood circulating in the main trunk, must always be of importance; but in the early stages of injuries to the femoral artery it is no proof of an enlarged collateral circulation. When existent, it is promptly extinguished by ligation of the main vessel, and no evidence has been obtained from the cases under consideration that the previous existence of a pulse guarantees an earlier return after the operation. On the other hand, the disappearance of the tibial pulses while a case is under observation is a serious sign of increasing pressure and obstruction, especially if at the same time an arterial murmur which has been present disappears. Under these circumstances surgical operation is imperatively demanded, and may stave off impending gangrene and save the vitality of the limb.

Resort to ligation has not, however, proved of great service in the complete preservation of the limb when signs of impending gangrene have reached a serious degree. The operation has proved most satisfactory in those instances in which pressure by large collections of extravasated blood, especially when coagulation has taken place, are exerting pressure both on the main trunk and the collateral branches. In one or two instances the line of threatening gangrene has been seen to recede somewhat, and thus the eventual amputation has been able to be carried through a lower point. Some further remarks upon this subject will be found in the section devoted to the popliteal artery.

Arterial Hæmatomata and False Aneurysms.—Arterial hæmatomata developed in 36 instances, and in 27 of these it was necessary to operate in the early stages.

Six of the patients (16·6 per cent) died, 1 from secondary hæmorrhage, gangrene, and exhaustion, 2 as the result of septic absorption and secondary hæmorrhage, 1 from hæmorrhage occurring during the operation, 1 from gas gangrene, and 1 from septic infection of the peritoneal cavity. Nine of the patients were able to be transferred to England without operation. It will be noted that in this particular the arterial injuries compare unfavourably with the arterio-venous, as, in the latter, 25 out of 51 patients were able to be transferred to

England without operation. The series thus supports the statement made in the general section of this essay; for analysis shows that extension of the hæmatoma, secondary hæmorrhage, and secondary inflammation—all conditions associated with the degree of tension existent in the hæmatoma—are far more common in pure arterial hæmatomata. Again, routine examination of the distal pulse shows this generally to be more diminished in volume, or more frequently abolished when the lesion is purely arterial in character.

The indications for operation were: pre-operative gangrene in 3 of the patients, secondary hæmorrhage in 2, extension of the hæmatoma in 5, and local inflammatory changes in 2. Primary or secondary amputation was performed in 3 cases (8·3 per cent); in one of the patients the vascular lesion accompanied a severe compound fracture of the femur. The artery alone was tied 18 times; post-operative gangrene followed the operation twice, and all the fatalities occurred in this series. The artery and vein were tied simultaneously in 6 cases, and in one instance the artery alone was tied because the vein was already thrombosed.

Arterio-venous Aneurysms and Aneurysmal Varices. — Arterio-venous communications were permanently established in 51 instances.

Of these patients 7 died (13·7 per cent), 4 without operation, and 3 after ligation of the vessels. The 4 non-operative deaths resulted, in 1 as a result of general septic infection dependent upon a suppurating amputation stump of the opposite thigh (*Fig. 57*), in 1 from septic absorption in combination with severe primary hæmorrhage, and in 2 from complications which were not recorded.

In 15 cases treated in the early stage, the operation consisted in quadruple ligation and removal of the sac. The indications for intervention were in 2 instances secondary hæmorrhage, in 6 extension, in 4 the large size of the hæmatoma, and in only 1 was the operation done in the settled false aneurysm stage.

Aneurysmal varices were treated by quadruple ligation and excision in 7 instances, with invariable success; 3 of the patients rejoined their regiments within a few months. The operations for arterio-venous hæmatoma were followed in 2 instances by anæmic gangrene necessitating amputation of the leg. Three of the patients died, 2 from anaërobic gangrene, and 1 without any obvious cause beyond shock being discovered at the autopsy.

Of the remaining 11 men who were operated upon, I have been unable to obtain any subsequent particulars, except in the case of one who was discharged from the service as permanently unfit for military duty. Neither have I been able to obtain any further details of the 25 men who were transferred to England prior to operation.

Of the whole 79 patients in whom the femoral artery was

ligatured, I have been able to trace only 15 to their ultimate issue. Of these, 7 were returned to duty (three of them subsequently being killed on the field of battle within a few months), and 8 were discharged from the service as permanently unfit for military duty.



FIG. 57.—Femoral arterio-venous aneurysm. The dilated vein is laid open, and within are seen the termination of the profunda vein and the arterio-venous channel. The aneurysmal sac is of the small typical form wedged into the angle between the two trunks.

Some of the latter are, however, earning their living in civil occupation, even in such work as a miner's. I feel no doubt, moreover, that a large proportion amongst those on whom primary operations have been performed will eventually suffer little inconvenience. None the less it is obviously a rare event for the limb actually to regain its full normal volume and strength.

After-results.—Circumstances have not allowed a full investigation of the after-results which have come under my notice; but a short *résumé* of the conditions which have been observed may be useful. I have had the opportunity of examining a number of men in England in whom either the artery or the artery and vein have been ligatured abroad. An inspection of the limb in such cases, at a period of from two to three weeks after occlusion of the artery, fully warrants a report as to their good condition. As the patient lies in bed, the injured limb, in fact, often appears the better of the two. It is as large as or larger than the uninjured limb, and also retains the normal outline of a well-developed member. This appearance does not depend on subcutaneous œdema, at any rate not sufficiently to be demonstrable by making pressure pits with the tip of the finger. On palpation, the explanation is found in the condition of the muscles. The muscles of the calf of the uninjured limb will have acquired the loss of tone which inevitably follows disuse; while those of the limb in which the artery has been tied are abnormally firm and retain their outline fully. The muscles exhibit, in fact, the condition characteristic of the early stages of muscular ischæmia, the degree varying in individual cases. In some instances this is almost the only phenomenon which attracts notice; in others a varying degree of stiffness of the ankle-joint and the articulations of the toes is superadded.

Examination of the tibial pulses rarely reveals a volume in any degree reaching the normal. There is great difficulty in determining what should be considered a normal date for the re-appearance of a palpable pulse in the posterior tibial artery at the ankle, or in the dorsalis pedis artery. There is also a great variation in the capacity of the individual surgeon to determine the presence or absence of slight pulsation. The surgeons at some of the casualty clearing stations have made a small number of observations on this point. A palpable pulse was reported to have reappeared in 7 cases out of 25—at the end of twenty-four hours in 1, at the end of four days in 2, at the end of eight days in 1, and at the end of nine days in 3.

For purposes of comparison, 20 cases observed in London may be taken. In 7 of these the pulse was palpable at the end of three, seven, fourteen, sixteen, twenty-six, fifty-two, and ninety days respectively; but these dates may not really correspond with the actual day on which the pulse returned; moreover, a recently-returned pulse is often very variable in strength, and not constantly present. The negative results are therefore of more real value. Of these there were 13. Amongst these no palpable pulse was present at the end of three days in 2, or in the others after ten, fourteen, twenty, twenty-six, thirty-one, thirty-two, forty-one, fifty-eight, eighty-two, one hundred and sixteen, and one hundred and sixty-two days

respectively. Of the 13 cases in which the pulse remained absent, in 2 instances limited gangrene had occurred, but in the remaining 11 the foot was apparently in good condition.

With resumption of the upright position on the part of the patient, a certain amount of œdema always develops; this is rarely persistent, but it may last for weeks or months. The severity of the primary injury and the amount of cicatricial tissue in the limb are potent factors in the amount of trouble caused by œdema, and cases in which a fracture of the femur has accompanied the arterial lesion are the most unfavourable.

The peripheral blood-pressure rarely if ever equals that of the uninjured limb; in all the cases I have examined it has been from



Fig. 58.—Skiagram showing a retained shrapnel ball in the adductor region of the left thigh which had wounded the vessels and given rise to a common-femoral arterio-venous aneurysm. *Captain Greaves.*

20 to 60 mm. of mercury lower than that of the sound side. The diminution after ligature of the artery, moreover, is considerably greater than that caused by the presence of an aneurysm. Although the blood-pressure tends to rise with the lapse of time, I have seen no case in which it reached the normal. The temperature of the foot remains lowered, and it is doubtful whether the foot ever becomes as resistant to external changes of temperature as is normal.

The degree to which loss of volume of the limb may attain is variable. In my experience, rapid severe wasting has only been seen in early operations, or in patients the subjects of infection. It is rare, and practically never occurs after remote operations. A permanent loss of volume of the limb of a slighter nature, however,

follows occlusion of the main artery even in the most satisfactory cases. In such, a loss of circumference of the calf of from half an inch to one inch will be found on measurement.

Grave trophic changes in the foot, of the degree not uncommon in the hand, are distinctly rare in my experience, a fact which supports the theory of the almost invariable dependence of such changes on associated nerve injury.

Suture of the Femoral Vessels.—This series contains only 9 operations, 1 of the common femoral, and 8 of the superficial femoral artery; 3 of the operations were undertaken in the primary stage, 3 were intermediate, and 3 were remote.

The three primary operations afford little information, for two of them were of a complicated nature. In one the suture was of an arteriotomy wound which had been made for the evacuation of a thrombus following a contusion; recurrence of the thrombus ensued. The second (Captain Gabe) illustrates the dangers to which a promising primary operation may be exposed; the patient arrived at a hospital on the lines of communication on the fifth day, after suture of a lateral wound of the femoral artery, with an excellent posterior tibial pulse; besides the wound of the thigh, multiple wounds of other parts of the body were present, and the patient succumbed after a few days to an acute general infection. The third case (Captain Cowell) was a success; a lateral wound of the artery as it lies in Hunter's canal was closed by stitches, and the line of union strengthened by a flap of tissue obtained from the aponeurotic roof of the canal; viability of the artery was retained.

The three secondary or intermediate operations afforded successful, if not perfect, results.

Case 51.—Arterial hæmatoma of seven days' standing. A definite, stiff sac had formed around a lateral rent in the artery almost amounting to a complete division. A double row of sutures, the second implicating the adventitia alone, was inserted, somewhat restricting the lumen of the vessel. The tibial pulse was diminished in volume, but was persistent. On the fourteenth day the peripheral blood-pressure was determined as 90 mm. of mercury in the injured to 140 mm. in the sound limb. An uneventful recovery took place, but it has not been possible to trace the patient since he left France. (G. H. M.)

Case 52. (Colonel Gunn).—Arterial hæmatoma, developing secondarily on the twelfth day, in a patient with a fractured femur. Exploration revealed a through-and-through perforation of the artery. The two apertures were closed by suture and an uneventful recovery took place. No observation of the peripheral blood-pressure was made.

Case 53. (Major Hope).—Secondary hæmorrhage occurring on the third day from a small shell-wound. A rent a quarter of an inch long was sewn up, and the fragment of shell removed from Hunter's canal. The posterior tibial pulse persisted, but in reduced volume.

Of the three remote operations, one died.

Case 54.—Aneurysmal varix of six months' standing. This man had been returned to duty after being wounded six months previously; the arterio-venous communication had not been discovered. The man was sent down the line because he complained of pain when marching. A vertical slit in the side of the superficial femoral artery was closed by suture, and the femoral vein was tied (*see Fig. 6, p. 14*). Prior to the operation the peripheral blood-pressure in the two limbs was equal at 140 mm. of mercury. After the operation it fell to 125 in the sound limb, and 110 in the affected one. The tibial pulse was retained, but was smaller in volume than that of the sound limb. (G. H. M.)

Case 55.—Arterial aneurysm of the common femoral artery of six weeks' standing. The bullet, which had entered above Poupart's ligament, passed downwards, and wounded the common femoral artery on its posterior aspect. The sac dipped into the iliopsoas muscle. The sac was separated from the artery, and the opening in the vessel closed. Early thrombosis took place at the site of suture, and the posterior tibial pulse was obliterated; but the patient made a good recovery. (G. H. M.)

Case 56.—Arterio-venous aneurysm of superficial femoral artery at the apex of Scarpa's triangle. Vertical lateral slits in the artery and vein were closed by stitches. The wound, which communicated with an unhealed sinus in the buttock, was acutely reinfected by streptococcus, and the patient succumbed to toxæmia on the ninth day, after an attack of secondary hæmorrhage.

The series is small for drawing any wide conclusions, but it shows that in four of the operations the viability of the vessel was maintained, while in three it was certainly not. In no case was an ideal result attained, as estimated by the volume of the posterior tibial pulse and the peripheral blood-pressure in the limb. The two fatalities were in no way dependent upon the nature of the operation performed, and the second could certainly have been avoided had not the presence of a deep sinus in the buttock been overlooked.

The Use of Tuffier's Tubes.—In 5 cases an attempt at temporary maintenance of the circulation was made. In two instances success was attained. In one of these the tube was left in position twenty-one days (Colonel Kidd); the pulse persisted continuously, and on the sixtieth day the peripheral blood-pressure in the affected limb stood at 120 mm. of mercury as against 135 mm. in the sound one. In the second case (Captain J. Fraser) the tube was retained for seventy-two hours, and the patient was evacuated later with a persisting pulse. In two unsuccessful cases, the limb in one became gangrenous and had to be amputated after twenty hours; in the second the tube was retained six days, when gas gangrene supervened, and the patient succumbed after an amputation. The fifth case was one in which traumatic thrombosis having occurred, the artery was incised, the clot evacuated, and a tube introduced. A fresh thrombus formed in three hours, and the artery was tied.

The Lines of Treatment to be followed in dealing with Cases of Injury to the Femoral Vessels.—The three methods for dealing with these injuries have been practically illustrated in the preceding paragraphs. It remains to consider shortly what may be the indications for the choice of either.

When the conditions as to wounds of the soft parts, operative facilities, and the general state of the patient are good, lateral wounds and traversing perforations, if the character of the defect in the wall of the vessel is suitable, may be sutured.

When the lesion is of a more extensive character, the question of resection and end-to-end union may be considered. The choice of this method will probably depend on the individual proclivities of the surgeon. In certain positions—for example, the immediate neighbourhood of Poupart's ligament, close to the origin of the profunda, or at the extreme lower end of Hunter's canal—it is difficult to mobilize the vessel sufficiently to allow of its being united with technical ease, and I do not think the method should be chosen. In other parts of the course of the vessels the technique is comparatively simple; but further experience is needed as to the ultimate results of end-to-end union before it can be confidently recommended. It should not be adopted in any case where the patient is liable to early transport.

When the character of the lesion of the arterial wall precludes any idea of essaying repair, the introduction of a Tuffier's tube may be considered. Major-General Wallace has suggested this as advisable as a means of lessening the risk of the supervention of gas gangrene, the occurrence of which is so highly favoured by limitation of the blood-supply to the periphery of the limb.

The operation of ligature is applicable in any case; it requires less perfect surroundings and equipment than either of the other methods; it takes less time to perform on a patient suffering from shock or the effects of loss of blood; and it is likely to hold the field as a routine procedure. The results given above indicate that simultaneous ligature of the artery and accompanying vein should be the rule; also, that when only a strand of the arterial wall remains, this should always be divided, to allow of retraction of the ligatured ends of the vessel.

In the intermediate stage, the majority of the injuries are best treated either by ligature or by the introduction of a Tuffier's tube.

In the remote or late stage, suture should be the invariable aim of the surgeon. The junction tube is unnecessary, as the collateral circulation may be relied upon; while ligature can always be resorted to if suture is found to be impracticable after the lesion has been exposed.

Remarks on the Operative Procedures for Dealing with Injuries to the Femoral Vessels.—Operations for injuries to these vessels are required more frequently than for those for any others in the body; and it may be laid down as a general statement that with the exception of operations upon the arteries at the root of the neck, which possess special dangers of their own, no operations call for more capacity and resource on the part of the surgeon than those in the thigh. It is true that the mere placing of a ligature upon the femoral artery is one of the simplest and most straightforward procedures in surgery; but gunshot injuries to the vessels of the thigh, especially in the region included between the origin of the profunda artery and the mid-point in Hunter's canal, may demand all the skill and resource of the experienced surgeon, to secure the main trunks or wounded branches of the intricate network found in this situation. Provisional ligatures placed upon the common and superficial femoral arteries may often exert but little influence in restraining hæmorrhage when the collateral supply derived from the branches of the internal iliac passing to the buttock is freely developed; and it behoves the operator to be careful how he occludes any factors in this supply except when absolutely necessary, as far as the eventual nutrition of the limb is concerned if the main trunk needs to be ligatured. I have seen the resources of a good operator taxed to the uttermost on several occasions in dealing with hæmorrhage from a second wound of the profunda or one or more of its branches, and even then eventually he has been compelled to be satisfied with forcipressure and perhaps a plug, to restrain severe and persisting hæmorrhage.

The first point which arises in any procedure is as to the best method of maintaining provisional control of the main trunks. In the case of the common femoral artery, a provisional loop applied to the external iliac artery is the method of choice. The artery may be approached across the peritoneal cavity, or an extraperitoneal operation may be performed. The former is the simpler and more rapid method, the latter avoids obvious risks, and is generally to be preferred. I have employed the rectus sheath incision, and displaced the peritoneum, as in the search for the ureter. If time or the surrounding conditions render provisional ligature of the external iliac inadvisable, recourse can be had to an indiarubber tourniquet of tubing the size of the finger applied around the waist. I have twice used this method with success, and have seen no ill result follow.

When the position of the field of operation allows, an Esmarch's tourniquet may be applied to the thigh. This method is generally preferable, as it permits the wounded vessel to be approached safely; the provisional ligature, if necessary, can be placed nearer to the wounded spot, less trouble results from blood brought to the trunk

by collateral branches; and, should the lesion prove to be one only suitable for treatment by ligature, unnecessary interference with the artery is avoided.

The incision made in the line of the artery needs to be free—six, eight, or more inches in length. The long saphenous vein should be carefully preserved, in view of the fact that the deep vein may probably require to be occluded. The sartorius muscle may be displaced in the usual manner; but in recent cases where a large hæmatoma is present in Hunter's canal, it is often better to go through the muscle. If the collection of extravasated blood be large, the vessel is liable to be displaced in the direction of least resistance, and will therefore most likely be found in either the inner or the anterior wall of the cavity.

Certain anatomical variations should be kept in mind; thus, a high division of the common femoral is not unusual. I have twice come across it in these operations. Unless recognized, one may unwittingly leave the profunda uncontrolled. A second not infrequent source of confusion lies in the origin of the external circumflex branch from the femoral trunk; if this arrangement be present, the profunda lies more internally than usual, and cannot be got at from the outer side of the superficial femoral as is usually the case. Great care should be taken to spare this branch from injury; and the same caution is needed with regard to the anastomotica magna when the lower part of Hunter's canal is being laid open. The latter point is especially important when it becomes necessary to divide the tendon of the adductor magnus, as it may be, when the artery is wounded in the lower part of the adductor canal.

The most trying cases to deal with are those in which the wound is of either the common or superficial femoral trunks in immediate proximity to the origin of the profunda; in these instances the passage of a ligature around the profunda is often a matter of great difficulty. The amount of blood which may escape from the distal end of a divided profunda artery, brought from the anastomoses with the branches of the internal iliac, is surprising.

When the vessels have been wounded in the course of a track passing antero-posteriorly in the thigh, an hour-glass sac is common. The connecting opening in the insertion of the adductors is often small, but the cavity in the adductor compartment may extend widely to the back of the thigh. The blood and clot should be carefully removed, but, as a rule, no further measure is needed; and it is not advisable to drain such a cavity to the back of the thigh except in exceptional cases. The conditions may be different when the wound is one of the profunda at a small distance from its origin; under these circumstances the sac may be wholly accommodated in the adductor compartment.

The bifurcation of the common femoral provides an angle which favours concomitant wound of both vessels should the missile pass between them; this fact must always be borne in mind in exploring an injury in this position. *Fig. 54* illustrates an injury of this class. Should the wound be situated in the angle itself, it may sometimes be easier to anastomose the two vessels than to close the two openings separately by suture.

In all early cases, the rule that no ligature should be placed definitely upon the main trunk until the surgeon is sure that the bleeding does not come from one of the branches, must never be departed from. In dealing with arterial hæmatomata or aneurysms in which the vessel communicates with the sac by two separate openings, closure of the artery by terminal suture is preferable to ligature, as by this means interference with the vascular cleft is avoided.

The above observations refer almost purely to operations undertaken in the early stages; operations for the treatment of definite false aneurysms or arterio-venous lesions are easier, and require no further description than that afforded by the remarks in the general section.

Lastly, a word may be said regarding isolated injuries to the femoral vein. Hæmorrhage from these wounds is as a rule arrested spontaneously; but in some instances this is not the case, and a very extensive hæmatoma, and great swelling of the thigh, may develop. The possibility of this lesion being the only one must always be borne in mind, especially, in my experience, when the swelling of the thigh is great and diffuse. The cases often present great operative difficulty; first, in localizing the wound; and secondly, in applying the ligature, since a wounded vein is much more difficult to clear than the stronger-walled artery.

POPLITEAL ARTERY.

Injuries to the popliteal vessels enjoy a more evil reputation in regard to their primary consequences than those affecting any other artery of the limbs; and in their ultimate results they hold a position comparable to that of the axillary.

The series under consideration consists of 85 cases. The incidence in the two limbs was equal: thus, of 50 injuries, the vessels of the right side were involved 24 times, those of the left 26 times. In the early stages of the war a considerable number of injuries by bullets were met with, but during the latter three years the proportion of shell injuries was overwhelming. Among the cases reaching the lines of communication, associated extensive wounds of the soft parts were rare; thus, amongst 50 cases, in 22 the wounds were limited through-

and-through tracks, in 4 the wounds were large, and in 24 the missile was retained.

Primary hæmorrhage is noted to have been severe in 14 cases (16·4 per cent), and secondary hæmorrhage necessitated operative intervention in 12 (14·1 per cent).

The local injury to the vessels tends to be severe in type. The liability to severe injury to the artery, and to associated lesions of the artery and vein, as also the serious consequences which result, depend in great measure on the local anatomical arrangement. The walls of the popliteal space are particularly firm and resistant in every direction. The nature of the floor—formed by the bones—exposes the vessels not only to risk of contusion, but also to penetration by fragments of bone; the lateral boundaries, held together by the stout popliteal fascia, and in great part tendinous in nature, are very tense when the knee-joint is fully extended; and the fascial roof is unusually strong and inelastic. Hence, when effusion of blood takes place into the space, the pressure exerted upon both the main trunks and their branches is very considerable.

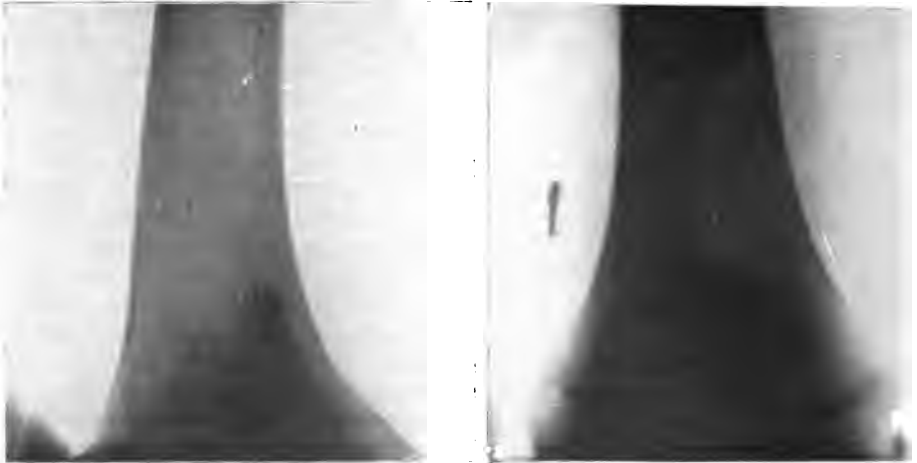
The vessels, both on their entry and on their exit from the space, are very firmly fixed in position by the fibrous arches formed by the insertion of the adductor magnus, and the origin of the soleus, respectively. Further, the artery is immobilized by the articular branches, both laterally, and anteriorly by the azygos branch. Lastly, the relation of the artery and the vein is a particularly intimate one. The state of tension induced by full extension of the knee-joint accounts for the wide gaping which accompanies extensive lateral wounds; this causes these injuries to simulate complete severance closely, and no doubt favours the occurrence of primary hæmorrhage.

Contusion of the Popliteal Vessels.— This form of injury accompanies a large proportion of all wounds; and, while tending to prevent or oppose the occurrence of primary hæmorrhage, yet, by occasioning thrombosis, it takes a prominent place in giving rise to an unfortunate issue in many cases. Thrombosis of the artery was the prominent feature of 7 of the cases in this series, and in all of these except one, gangrene of the limb necessitating amputation was a direct consequence. In two instances the popliteal vein had suffered a penetrating injury, and in one of these it was ligatured primarily; in each case the tibial pulses were extinguished at an early moment, and in both gangrene of the leg was established on the sixth day; the artery in one of the cases is depicted in *Fig. 12*. In two cases secondary hæmatomata developed, on the thirteenth and eighteenth day respectively; in both the tibial pulses were impalpable, and amputation became necessary, in one instance for the removal of the gangrenous limb, and in the other on account of

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toxæmia secondary to the large infected wound of the popliteal space. In the fifth case, in which a fracture of the femur was present, gangrene commenced to develop on the fifth day, the obvious signs corresponding in their appearance with the transference of the limb from a Wallace-Maybury to a McIntyre splint; in this instance the vessels had suffered complete division, and up to the occurrence of the gangrene the blood-supply had been maintained by a greatly enlarged vertical collateral chain, which in turn had undergone thrombosis; this chain had formed a superficial trunk which the surgeon likened to the popliteal artery itself in size. The sixth case was one of thrombosis secondary to contusion by a shrapnel ball; the tibial pulses were absent, and gangrene began to develop on the second day; on the fourth day the limb was amputated, but the patient died six days later from toxæmia. In the seventh case secondary hæmorrhage occurred on the third day, and the artery and vein were ligatured; on the tenth day the leg and foot became gangrenous, and amputation was performed; the posterior tibial artery and vein were found to be occluded throughout their course by a recent thrombus; the anterior tibial vessels were patent.

Wounds of the Popliteal Vessels.—A note of the form of the vascular wound is recorded in 49 cases. In 32 (65·3 per cent) it



Figs. 59, 60.—Skiagraphs showing the position, shape, and size of a fragment of shell which had wounded the popliteal artery and given rise to the formation of an arterial aneurysm. *Captain Greaves.*

was lateral in type; in 19 of these an associated injury to the vein was present, in two instances a through-and-through perforation, and

in one traumatic thrombosis due to contusion. In 15 instances (30·6 per cent) complete severance of continuity was noted; in 8 of these the vein was wounded, and in 1 thrombosed.

It may be remarked here that some observers report cases as complete division of the artery where a narrow strand of the wall really persists; and in this relation it may be noted that amongst the 32 cases of lateral wound just quoted, at least 10 are included that might have been regarded as complete divisions by some operators.

Only two through-and-through perforations are recorded (4 per cent), and experience would lead one to expect this to be the case in the presence of such a large proportion of injuries caused by fragments of shells. In two instances the missile remained lodged within the artery, and controlled hæmorrhage until it was removed; the missile was in one instance a fragment of shrapnel case, in the other a German bullet; the latter is depicted in position in *Fig. 16*, p. 28.

Complications of Injuries to the Popliteal Vessels.—The complications most often met with are: hæmarthrosis or synovial effusion into the knee-joint; small localized fractures of the femur or tibia; and lesions of the popliteal nerves. This series affords rather meagre information on these points, a circumstance which depends on the fact that, in the early history of these cases, in the majority the vitality of the limb is the all-absorbing moment. In only two cases was a major fracture of the femur present; this was complicated in one instance by gangrene necessitating amputation, and in the other by an infected hæmarthrosis which ceded to a single aspiration. None of the minor fractures took any serious part in the clinical course of the cases. The knee-joint is noted to have suppurated and led to amputation twice in the early and twice in remote stages. In 10 cases synovial effusion was a prominent feature, but led to no ill result. It is somewhat remarkable that injuries to the popliteal nerves are mentioned in only 5 instances, 4 of the more fixed external, and 1 of the internal. Some lesions were undoubtedly overlooked; but, on the other hand, the wounds in the majority of instances were narrow through-and-through tracks, taking a more or less transverse or oblique course; hence they were unlikely to involve the internal popliteal nerve, which runs a superficial course in the centre of the space; in large open wounds of the popliteal space this nerve is often involved.

Clinical Characteristics of Injuries to the Popliteal Vessels.—In no other position in the body are the signs of an arterial lesion so prompt and obvious. In at least two-thirds of the cases the tibial pulses are extinguished at an early date; coolness of the limb, and pallor or cyanosis and swelling of the calf, are commonly early and well-marked signs. When the pulses are present at the ankle, they

are diminished in volume; in my experience a good tibial pulse is rare, except in cases of immediate formation of an aneurysmal varix or a small arterio-venous hæmatoma.

The situation is one in which the application and prolonged retention of a tourniquet is likely to be particularly harmful, not only as causing deprivation of the arterial supply, but also in causing œdema. Unfortunately, the application of a tourniquet to the lower third of the thigh is not only an easy procedure, even to the patient himself, but it is also particularly effective, and hence the more to be dreaded. It is not at all uncommon in these cases to meet with the persisting line of constriction due to the use of a tourniquet put on by the patient or one of his mates.

The swelling consequent on extravasation of blood involves chiefly the calf; it is rare for the blood to travel along the course of the anterior tibial vessels into the anterior compartment. In some cases the œdema is very abundant, and may simulate blood extravasation; it does this the more easily, since extravasation into the calf lies in a space which allows extension to its extreme limits, and anything like a marginal boundary of clot, such as develops in the thigh, is usually absent. A marked degree of cyanosis suggests associated injury to the vein; but it may be said that clinically it is generally impossible to be certain that an isolated lesion of the vein is present, since the signs may be identical with those of a wounded artery. There is little doubt that isolated injuries to the vein are more common than the number included in this series would suggest, and unless accompanied by thrombosis of the artery, the injury may not cause any serious consequences.

The lesions most liable to be overlooked are direct aneurysmal varices. I have twice seen this happen where one small wound, amongst several distributed over the lower extremity, happened to have implicated the vessels. In other instances a perforating wound of the knee-joint may attract the main attention of the surgeon and the associated vascular lesion escape detection. Such varices are often attended by no signs except the local murmur and thrill. The importance of auscultation in such injuries is evident, as it certainly prevents any chance of the lesion being missed. Transmission of the local systolic murmur to the cardiac apex was noted in more than one-third of the cases of arterial or arterio-venous hæmatomata, and may sometimes lead to the discovery of an unsuspected arterial injury.

Arterial and arterio-venous hæmatomata of the popliteal vessels offer some special characters. The first of these is the diffuse nature of the primary swelling, which tends to invade the whole space and give rise to a general heaving type of pulsation like that observed

when a spontaneous aneurysm has commenced to diffuse. A second peculiarity lies in the difficulty which attends any attempt to determine with certainty by clinical examination whether the primary injury has involved the artery alone, or both artery and vein. Thus, in four of the cases under consideration, the presence of a purely systolic bruit caused the hæmatoma to be diagnosed as arterial; yet at the operation the vein was found to be either extensively lacerated or completely severed. This difficulty is by no means confined to the popliteal vessels, especially if the vein be severed, but it is certainly more commonly encountered. Delayed development of the hæmatoma is also more commonly met with in this situation, pulsation and bruit appearing at the eighth, tenth, or a later day—in fact at much the same period that the wall of the artery might give way and a secondary hæmorrhage occur. This is probably to be explained by the facts that primary thrombosis of a severely-contused vessel occurs, and that, except in the upper and the lower part of its course, the vessel receives little direct support from muscles, and there is no opportunity for adhesion to neighbouring structures. The primary blood effusion spreads in one direction only, downward into the calf, but the blood effused between the two layers of the muscles of the calf never takes any part in the eventual false aneurysm, and seldom or never pulsates in the early stage, since the dividing neck formed by the arch of the soleus is too narrow to allow the wave to pass freely. The presence of pulsation in the calf suggests that the wound is of the posterior tibial artery.

The fact that such a large proportion of injuries to the popliteal vessels require early treatment, much limits the number of fully-developed traumatic aneurysms, or even well-localized hæmatomata. In this series only 28 out of 85 can be said to have passed beyond the wounded artery stage. Of these, 11 were arterial hæmatomata; 12 were arterio-venous hæmatomata; and in 5 the clinical signs suggested aneurysmal varix.

Amongst the 11 arterial hæmatomata, 6 early operations were called for, and only 5 amongst the 17 obvious arterio-venous lesions, evidence in favour of a statement made in the general section as to the more dangerous nature of the pure arterial lesion. It will be convenient to detail shortly in this place the nature of these operations and their results.

Six operations on arterial hæmatomata:—

Case 57.—Wound of artery, ligature on the tenth day, eighteen days later the patient was evacuated to England in good condition. There had been some effusion into the knee-joint which had given rise to no anxiety. Two months later the knee-joint suppurated and amputation became necessary. A year later the man was discharged from the service, permanently unfit for military duty.

Case 58.—Ligature of artery on the eleventh day. Two months later the foot and leg were in good condition, but there was no tibial pulse, and some effusion in the knee-joint. At the end of four and a half months an arthrectomy was performed, and the man was finally discharged as permanently unfit for military duty eleven months from the date of the accident.

Case 59.—The artery was ligatured on the fifth day for extension of the hæmatoma. The immediate result was good, but no further information is forthcoming.

Case 60.—Artery ligatured on the sixth day; the immediate result was good, but no further information is forthcoming.

Case 61.—The artery and vein were ligatured on the twenty-fifth day for extension with disappearance of the pulse. The immediate result was good, but the man was discharged as permanently unfit for military duty five months later, as a consequence of concurrent injury to the external popliteal nerve.

Case 62.—Ligature of artery and vein on the fifth day for threatening gangrene. Immediate result good.

Five operations on arterio-venous hæmatomata :—

Case 63.—Artery and vein ligatured on the ninth day. An amputation for rapid gangrene was performed forty-eight hours later, and the patient died.

Case 64.—Ligature of artery and vein on the third day; swollen tender limb and good tibial pulses. Immediate result good.

Case 65.—Ligature of artery and vein on the ninth day. Immediate result good. Four months later the man went on furlough able to walk two miles.

Case 66.—Ligature of artery and vein on eighth day; anterior tibial pulse palpable, the posterior absent. In this case the wound in the artery was not localized, and a month later an aneurysm developed. The femoral artery was then ligatured in Hunter's canal, and the man finally rejoined, sixteen months after the injury.

Case 67.—Ligature of artery and vein for an aneurysm of three months' standing; there were signs of serious venous obstruction, and feeble tibial pulses. The immediate result was excellent.

Aneurysmal Varix.—Only one case was operated upon. The artery and vein were tied, the varix excised on the nineteenth day, and a fragment of shell removed. The immediate result was good.

These results speak for themselves without further comment. It will be observed that only two of the patients are known to have rejoined their battalions on active service.

Gangrene.—The incidence of gangrene is enormously high, and this would appear to be due to two factors: first, that injuries to this artery tend to be very severe; secondly, that the collateral circulation is not a very efficient one. This may in part depend on the fact that the viability of no trunk artery in the body is more interfered with by posture than the popliteal, hence compensation

by the collateral circulation is constantly called into action under normal circumstances. The articular branches of the popliteal on which it mainly depends are, however, so fixed in the early part of their course that dilatation beyond that called for under normal conditions is not easy. The great enlargement of the vertical chain which follows occlusion of the trunk, especially that along the great sciatic nerve, seems to favour this theory. In one of the cases under consideration, at an amputation for gangrene following ligature, a vertical vessel approaching in size the popliteal itself was found, in which recent thrombosis had taken place.

Extinction of the peripheral pulse is notably frequent in these injuries; thus, of 48 cases, the posterior tibial pulse was extinguished in 36 (75 per cent), and present, usually in diminished volume, in 12 (25 per cent).

It has been suggested that pressure on the vessel by blood extravasated in the popliteal space is responsible for the obstruction; but operative exploration has not substantiated this view. On the other hand, when the extravasation reaches the calf in abundance, there is no doubt that the pressure exerted on the peripheral circulation is a potent factor in the causation of gangrene. The occurrence of thrombosis is another element to be kept in mind. Some remarks are made later as to how far threatening gangrene is likely to be modified by opening the popliteal space and ligaturing the injured vessel.

Consideration of the cases included in this series indicates that the occurrence of gangrene is considerably influenced by the situation of the wound of the artery. Thus, of 60 cases, we find: injuries to the upper third 15, gangrene 3 (20 per cent); injuries to the middle third 25, gangrene 10 (40 per cent); injuries to the lower third 20, gangrene 7 (35 per cent).

The incidence of gangrene in the whole series of 85 was 39, or 45.8 per cent. In 21 cases (24.7 per cent) the gangrene commenced before any operative interference; in 18 instances (21.1 per cent) it followed an operation. In all of the cases except two the gangrene was purely anæmic in type; in one of the two exceptions the anaërobic gangrene was certainly secondary to arterial gangrene, and in the other probably so.

The gangrene was usually of an extensive character, necessitating amputation of the thigh; thus, in the 21 cases in which gangrene supervened independently of operation, in 2 only was it limited to the foot. Among the 18 post-operative cases, we find it was limited in 2 cases to the toes, in 3 to localized patches on the feet, in 3 to the whole foot, while in 10 it extended to the leg.

My records show 25 amputations to have been performed in

France, of which 24 were of the thigh and 1 of the leg. Of the 25 patients, 3 died (or 7·6 per cent). These numbers are not, I believe, accurate; in any case they are unreliable as to the ultimate number of either amputations or deaths, as I have been unable to trace a large proportion of the cases in England.

Prognosis and Treatment.—As has already been set forth, the frequency with which gangrene follows injuries to the popliteal vessels is the overwhelming factor in determining the fate of the limb. The ultimate results, in cases of which the period immediately following operation is not unsatisfactory, are far from encouraging. I have only succeeded in following up 15 of the cases included in the series, and I cannot, perhaps, better illustrate the common course of events than by shortly quoting the reports obtained.

Case 68.—Primary ligature of artery and vein. The immediate result gave no cause for dissatisfaction. At the end of four months, the man was reported “convalescent, but still requiring a good deal of massage.”

Case 69.—Primary ligature of artery and vein. Sent to England on the twenty-third day. A week later a residual abscess was opened in the popliteal space. Suppuration progressed, and the vitality of the foot failed. Amputation of the thigh was performed, and at the end of seven months the man was discharged from the service as permanently unfit.

Case 70.—Primary ligature of artery and vein. The immediate result was satisfactory, but three months later the report says, “the knee is contracted, and the muscles of the leg are weak.” Seven months later the man rejoined the Flying Corps.

Case 71.—Arterial hæmatoma, extension on the twenty-first day, popliteal artery ligatured. The immediate result was satisfactory; but one month later the man is reported to have an acutely flexed knee; three months later the limb was amputated for a suppurating knee-joint; and at the end of thirteen months the man was discharged from the service as permanently unfit.

Case 72.—Arterial hæmatoma. Popliteal artery and vein ligatured on the eleventh day. The immediate result was good. Six months later an arthrectomy of knee was performed, and at the end of four months the man was discharged from the service as permanently unfit.

Case 73.—Arterial hæmatoma. Ligature of popliteal artery and vein on the thirteenth day. Immediate result good. Five months later the movements of the knee-joint are reported to be restricted in range, and the foot to get cold and numb at times. The patient left on furlough, so he may possibly have rejoined.

Case 74.—Arterial false aneurysm. Extension took place at the end of four weeks. The man was discharged as permanently unfit five months later, the disability depending on concurrent injury to the external popliteal nerve.

Case 75.—Arterio-venous hæmatoma. Ligature of popliteal artery and vein on the fifteenth day. Five months later the man was discharged on furlough with the report that he could walk two miles.

Case 76.—Arterio-venous hæmatoma. Ligature of the popliteal artery and vein on the eighth day. Seventeen days later the femoral artery was ligatured in Hunter's canal for recurrent pulsation in the popliteal space. Eleven months later he went on furlough, and ultimately rejoined his regiment.

Case 77.—Arterial hæmatoma. Ligature of femoral artery in Hunter's canal at the end of three weeks. The man is reported as up on crutches at the end of six weeks, with the foot a little blue. The foot improved, and ten weeks later the patient was sent to a convalescent home.

Case 78.—Wound of popliteal artery. Primary proximal ligature of femoral in Hunter's canal. Eight months later the man was still under treatment for dropped foot.

Case 79.—Wound of popliteal artery and vein. Primary proximal ligature of femoral in Hunter's canal. Three years later, ulcer of the leg, and persistent arterio-venous aneurysm in popliteal space.

Case 80.—Primary ligature of artery and vein. Immediate result good. Two months later no tibial pulses were present; the knee could not be quite extended; there was some œdema; and the leg ached. A year later the patient was discharged from the service as permanently unfit. Could not walk more than a mile.

Some further ultimate results will be found under the headings of "Tuffier's Tube" and "Suture" (pp. 241, 242).

There is, I think, no reason to believe that the above ultimate results are altogether untrustworthy, in spite of their small number. We may infer that 6 men rejoined their regiments, and that 7 were rendered permanently unfit, 2 chiefly as a result of existing injury to the external popliteal nerve. When it is borne in mind that 45 per cent of the men suffering from these injuries had already been eliminated by the occurrence of early gangrene of the limb, and that at least 6 (7 per cent) of those who survived to reach the lines of communication died there, the ultimate prognosis may be regarded as unhappy in the extreme.

The first point to be taken into consideration in the treatment of injuries to the popliteal vessels is the question as to whether, in view of the unfavourable prognosis both with regard to the immediate vitality of the limb and the ultimate results, a more active attitude should be assumed in the face of the primary injury. The cases under consideration, although not collected with the purpose of specially elucidating this question—since as far as I know no surgeon has taken the line of ligaturing the vessels primarily as a routine method—yet shed some light on the subject. In every instance primary ligature was undertaken for persisting hæmorrhage, and 28 cases are included. Of these, 16 are obtained from the series of 85, and 12 from direct reports furnished by casualty clearing stations. In 20 cases both artery and vein were occluded, with 6 cases of gangrene; in 8 the artery alone was ligatured, with 2 cases of gangrene. Consideration

of the combined series shows that, of 28 cases, in 8 (28·5 per cent) gangrene is known to have occurred, and 7 patients (25 per cent) were subjected to amputation. It must be added that, as regards the 12 cases in which reports from casualty clearing stations have been utilized, 2 patients were so ill as to need blood transfusion, and in only 2 does the history after operation extend beyond a few days to a week; hence the numbers may be more favourable than was actually the case. None the less the apparent reduction of the general incidence from 45·8 to 28·5 per cent affords food for reflection, and a trial of subjecting every patient to operation, who can be retained for a week in a casualty clearing station or advanced hospital, appears worth making.

The next question is that of the power of prompt ligation of the vessels to avert impending or commencing gangrene. It has already been pointed out that pressure from extravasated blood upon the trunks or collateral branches can seldom be held responsible; further, that hæmorrhage extending between the two layers of muscles of the calf is an important element. In the series there are 8 cases bearing upon this question, which seem worthy of brief quotation.

Case 81.—Admitted on third day, type through-and-through track, tibial pulses absent, foot cool and dusky in colour. Ligation of popliteal artery. Definite gangrene of the tips of the toes, and a patch on the under surface of the heel, developed; a week later the gangrene commenced to extend, and amputation of the thigh was performed.

Case 82.—Through-and-through track. On the third day the tibial pulses were absent, the foot dusky in colour but not cold. The artery was ligatured. The vein was uninjured, and there was no clot in the popliteal space. On the fifteenth day gangrene of the foot was absolute, and amputation of the thigh was performed.

Case 83.—Through-and-through track. Tibial pulses absent—limb cold on the third day. On the fourth day the popliteal artery was ligatured. The wound suppurated and general infection developed, necessitating amputation on the twenty-first day.

Case 84.—Open wound of popliteal space. Tourniquet left on for some hours. On the fifth day no tibial pulses were palpable, and the foot and lower third of the leg cold and anæsthetic. The artery was ligatured. The vein was thrombosed, and there was no massive clot in the popliteal space. Gangrene progressed, and the limb was amputated on the eleventh day.

Case 85.—Through-and-through track. Fractured femur in lower third. Infected hæmarthrosis. On fifth day absent tibial pulses and incipient gangrene extending to mid-leg. Ligation of artery, localized hæmatoma of moderate size. The gangrene receded, and eventually only the anterior half of the foot mummified. The knee did well with simple aspiration. The patient, an Indian, refused a Syme's amputation. (G. H. M.)

Case 86.—Retained small shell-fragment. Arterial hæmatoma. On the fourth day the hæmatoma commenced to extend, the tibial pulses were

absent, and the foot was cold and marbled. The popliteal artery was ligatured, and the condition improved during the next three days. The patient was sent to England, and the further progress is unknown.

Case 87.—Retained small shell-fragment. On the third day the foot was cold and pulseless. The artery and vein were ligatured, and the foot was saved.

Case 88.—Retained small shell-fragment. On the fifteenth day the arterial hæmatoma commenced to extend. The tibial pulses were present but feeble, the calf much swollen, and the foot cold. The artery and vein were ligatured, and the foot was saved.

The first 5 cases may all be called failures; the 6th and 7th were successes, the 8th was a late operation, and can scarcely be considered to belong to the class, as time for considerable compensation by the collateral circulation had elapsed. The small series, however, negatives the idea that local pressure is the chief cause of gangrene, and it encourages the surgeon neither to be simply expectant, nor to hurry on to amputation.

Ligature.—Ligature of the vessels was performed in 48 of the 85 cases.

Indication for Ligature	No. of Cases	Gangrene	Amputation	Died
Primary hæmorrhage	19	8	5	—
Secondary hæmorrhage	8	3	3	1
Pre-operative gangrene	5	5	3	—
Hæmatoma, arterial	6	1	—	—
Hæmatoma, arterio-venous	5	—	—	1
Removal of missile	4	1	1	—
Wound of popliteal vein.. ..	1	1	—	—
Totals	48	19	12	2

In 24 cases the artery alone was ligatured; of these, 11 suffered arterial gangrene (45·8 per cent) and 2 gas gangrene.

In 24 the artery and vein were ligatured simultaneously; of these, in 6 (25 per cent) arterial gangrene occurred; but as in two of the latter incipient gangrene was the indication for operation, the percentage may really be fairly considered 16·6 per cent.

Tuffier's Tube.—In 6 cases a Tuffier's tube was tied in. In 4 of these no gangrene occurred; in 1 the result is uncertain. It will be observed that no case is included in which clotting did not occur rapidly. I think this may be partly due to the fact that introduction of the tube into the distal end of the vessel is often difficult, and

needs a good deal of manipulation. My own feeling is that the method is always worthy of trial if suture is impracticable, especially in recent injuries.

Case 89.—Arterio-venous hæmatoma explored, ninth day. Tuffier's tube introduced in artery and vein tied. Wound eventually suppurred. Ultimate result, discharged permanently unfit. No record of tibial pulse but foot was painful at times.

Case 90.—Retained shell-fragment. Arterial hæmatoma extension on ninth day. Longitudinal tear of artery and of vein, but the latter was thrombosed. Small tube introduced and removed on the fourth day; it was obstructed in less than twenty-four hours. The leg and foot did well. Five months later the man was reported to be getting about on furlough, but with some restriction of movements of the knee, and with a numb foot 'at times.'

Case 91.—Single wound, followed by severe primary hæmorrhage. Tube was tied in on the third day; the absent tibial pulses did not return. The condition of the foot improved, but I have no knowledge of the ultimate result.

Case 92.—Arterial hæmatoma. Operation on the eighteenth day. The artery was almost completely divided. A tube was tied in and retained three days, pulsation returning in the tibial pulses. The patient made a good recovery (section of clot from tube, *Plate IV*). (G. H. M.)

In 2 cases reported from casualty clearing stations, pulsation in the tibials lasted in one for forty-five minutes only, and in the second the tube was left for five days. In neither of the cases did gangrene supervene.

Suture of Wounds of the Popliteal Vessels.—In 5 cases wounds in the artery were sutured:—

Case 93.—Operation on sixth day. A long ragged wound closed by vertical suture; on the next day the anterior pulse was good. The wound of the soft parts was an extensive one; it suppurred, and the patient eventually died. Thrombosis of the artery is probable, as secondary hæmorrhage did not occur. No other details are available.

Case 94.—Operation on seventh day. A ragged hole in the artery was sutured vertically. The pulses returned, and on the thirty-fifth day the blood-pressure in the leg was equal to that on the sound side. (Lieut.-Col. Kidd, C.A.M.C.)

Case 95.—Operation on the third day for recurrent hæmorrhage. A lateral wound in the artery was sutured, and the tibial pulses returned. On the eighteenth day the pulses were still retained. The blood-pressure in the injured leg was 99, in the sound one 119. A secondary hæmorrhage occurred on the twenty-third day; the wound was reopened, and the vessel found to be thrombosed. A double ligature was applied, and the patient made a good recovery. (Lieut.-Col. Kidd, C.A.M.C.)

Case 96.—Operation for primary hæmorrhage. Wounds on the anterior surface of both artery and vein sutured. Three weeks later the patient arrived in London with a practically normal foot and good tibial pulses.

Ten days later the pulses had disappeared, but the foot and leg remained in good condition, with slight œdema (1 in. increase of circumference of calf). (Capt. Gordon Taylor.)

Case 97. Operation on seventh day. Arterio-venous anastomosis established; transverse wound of posterior surface of artery immediately above bifurcation sutured transversely. Pulses present at end of operation and persisted. Ten days after the operation the blood-pressure in the two legs was equal (110 mm.). (G. H. M.)

Case 98. Arterial hæmatoma. On the twelfth day the swelling increased, and the popliteal space was explored. A lateral opening in the artery was closed by suture, and the sac plicated. At the end of a month the patient came to England, and two months later he was still in hospital with weakness of the muscles of the leg.

This small series is suggestive, as in no instance did gangrene occur, and in the death which took place the wound of the soft parts was responsible. In Nos. 2 and 5 the result was apparently ideal; in Nos. 3 and 6 it was good; and the same must be said regarding No. 4, although there is no doubt the vessel eventually suffered thrombosis.

The results recorded above speak in favour of suture of the vessel when the wound is lateral; some evidence is offered in support of the use of Tuffier's tubes, and also in favour of a more frequent resort to primary ligature. It is an undoubted fact that in this series the immediate results improved in connection with two changes—first, a better initial wound treatment; and secondly, the adoption of simultaneous ligature of artery and vein.

Lastly, with regard to the operations. Whichever method is adopted, the central posterior incision, extending from 1 in. above the upper angle of the popliteal space to 1 in. below the lower angle, should always be used; the internal incision never gives sufficient access. The external saphenous vein must often be ligatured; but care should be taken that its communicating branch to the internal saphenous is not injured. The internal popliteal nerve should be held aside, either with a gauze or thin rubber loop, and not with a steel retractor. Great care should be exercised in freeing the nerve that the anastomotic chain accompanying it be not injured, as the integrity of these small vessels is of first-rate importance; if for any reason—as in removing a Tuffier's tube—the nerve be exposed a few days after the main trunk has been obstructed, a vessel comparable to the radial in size is felt beating within the nerve sheath. No branch of the main arterial trunk should be damaged, if possible. When the injury to the artery is in the central part of its course, and the vessel is ligated and divided, care must be taken to make sure that the open end of the azygos articular branch is attended to, as otherwise it may be a source of secondary hæmorrhage. When the

lower part of the trunk needs to be sutured, the main operative trouble is usually a multitude of small veins entering the parent trunk, and time is saved by dealing with these promptly.

It would seem unnecessary to emphasize the importance of not allowing the knee-joint to become flexed during the early after-treatment; but neglect of this elementary rule is much more frequent than would be expected, and leads to very troublesome after-results, and prolongs the period of treatment enormously.

THE ARTERIES OF THE LEG.

These vessels, little loved by the candidate at an examination in operative surgery, have acquired a no more agreeable reputation with the military surgeon when they may happen to be the seat of a gunshot injury.

A wound of either the anterior or posterior tibial artery might be expected to prove an accident of minor importance; but this is far from being the case. A traumatic aneurysm of either variety is not a common thing to meet with in the hospitals on the lines of communication or at the base, and they form the smallest section in the series of cases under consideration. The number of instances which came under my observation is indeed so meagre as to furnish no opportunity for making any statistical remarks whatever upon them.

The reasons for this are not far to seek. The vessels themselves are not of large size. Beyond this, they bear such a close relation to the bones of the leg that vascular wounds are rarely uncomplicated. Even if no fracture exists, another peculiarity—the fact that both anterior and posterior tibial arteries are situated in spaces which are especially apt to retain extravasated blood from a wounded artery and thus to subject the other tissues within the space, including the collateral branches, to injurious pressure—makes these injuries particularly dangerous. The last condition, again, renders even a moderate amount of gas formation in the presence of an anaërobic infection a source of early and very acute danger. Lastly, as a result of the large part of the mass of the leg which is occupied by bone, extensive lacerated wounds of an explosive character often accompany the injuries to the tibial vessels.

The comparative rarity of traumatic aneurysms, therefore, is to be attributed to the infrequency of isolated injuries, the degree of tension which is apt to develop when the arteries are wounded, and the frequency with which the wounded vessel lies in a large wound which does not offer conditions favourable to the formation of a sac. The illustrations (*Fig. 22*, p. 59) in the general section of this essay,

however, show that an aneurysmal sac may often be in process of formation when its presence is not expected; and the fact that these small sacs were evacuated together with a large mass of coagulum, supports the description there given of their mode of development.

Signs of Wounds of the Tibial Arteries.—The anatomical conditions above referred to, account also for such special characters as the signs possess. The most common result of a wound from which the blood does not escape externally is the diffusion of the extravasation, either through the greater part of the compartment containing the anterior group of muscles; beneath the fascia covering the deep muscles, or throughout the interspace between the two layers of the muscles at the back of the leg. Thus, either a tense swelling of the front of the leg, or a greatly swollen calf, is developed. The pressure is often such as to involve more or less the whole length of the main trunk; hence the pulses at the ankle are early abolished.

It must be remembered also that great swelling of the calf, or of the anterior region, respectively, does not necessarily indicate that the corresponding vessel is the seat of the lesion; for not infrequently the blood from a wounded anterior tibial artery may pass in the line of the track made by the missile through the interosseous membrane, or the reverse state of things may take place when the posterior tibial is wounded. Again, either form of swelling of the leg may develop in connection with a wound of one of the branches of the trunks, and may exercise sufficient pressure to obliterate the pulse in just the same way as if the main vessel were the seat of injury.

The diffuse hæmatomata formed in this manner may pulsate at first, and later become solid as a result of coagulation of the large collection of blood.

Under these circumstances, it must be realized that the diagnosis of the existence of a wound of the main vessel, and location of its site, are not always easy. The readiest and surest method of investigation in case of difficulty is by auscultation, as the characteristic murmurs of either an arterial or an arterio-venous injury are rarely absent. I have detected a wound of the peroneal artery by this method when the anterior and posterior tibial arteries had both been tied in a large wound; in regard to this case—in which, by reason of the free exit which existed for the bleeding, no tension had developed—it is remarkable that only after ligature of the third artery did signs of gangrene develop. In the case of multiple wounds in the leg, the existence of a systolic murmur in the cardiac region may also help in making a diagnosis. A conveyed murmur from this region is present in something like a third of all arterial wounds.

In contrast with the above description, a small well-localized traumatic aneurysm may develop; and in one case I saw two

arterio-venous communications, within two inches of each other, formed between the posterior tibial artery and veins at the lower third of the leg. A still more striking example of a localized lesion was a definite arterial hæmatoma in connection with the external plantar artery, the wound in the vessel being partly blocked by the external plantar nerve.

Prognosis and Treatment.—I am sorry to be unable to give any estimate of the number of limbs which have been lost, or the number of deaths which have occurred, consequent on wounds of these arteries; but I know it to have been a large one, quite incommensurate with the size of the vessels involved. This question is of importance only with regard to the primary treatment of the injuries, and points to the necessity of rapidly relieving the tension of the limb by incision and direct treatment of the wound in the vessel. In the surgery of this war, moreover, injury to no vessels has more clearly exemplified the sinister influence of interference with the main blood-supply on the occurrence of anaërobic gangrene; hence all such injuries are to be regarded with suspicion.

Secondary hæmorrhage is very common, both as a result of contusion and thrombosis, of non-penetrating wounds of the arteries, and following infection; and in no situation is it more necessary to deal promptly with even insignificant escapes of blood in the course of treatment of the cases.

Little need be said regarding the treatment of false aneurysms of either variety. The ordinary lines laid down in the general section suffice to meet any case. It may, however, be pointed out that when a wound of the anterior tibial artery is situated in close proximity to the spot at which the vessel pierces the interosseous membrane, the surgeon must be prepared for difficulty in securing the upper end of the artery, and even a separate posterior incision may prove to be necessary. Again, when a large collection of coagulated blood is deposited between the layers of muscles of the calf, a central incision is preferable to the classical lateral incision for securing the posterior tibial artery.

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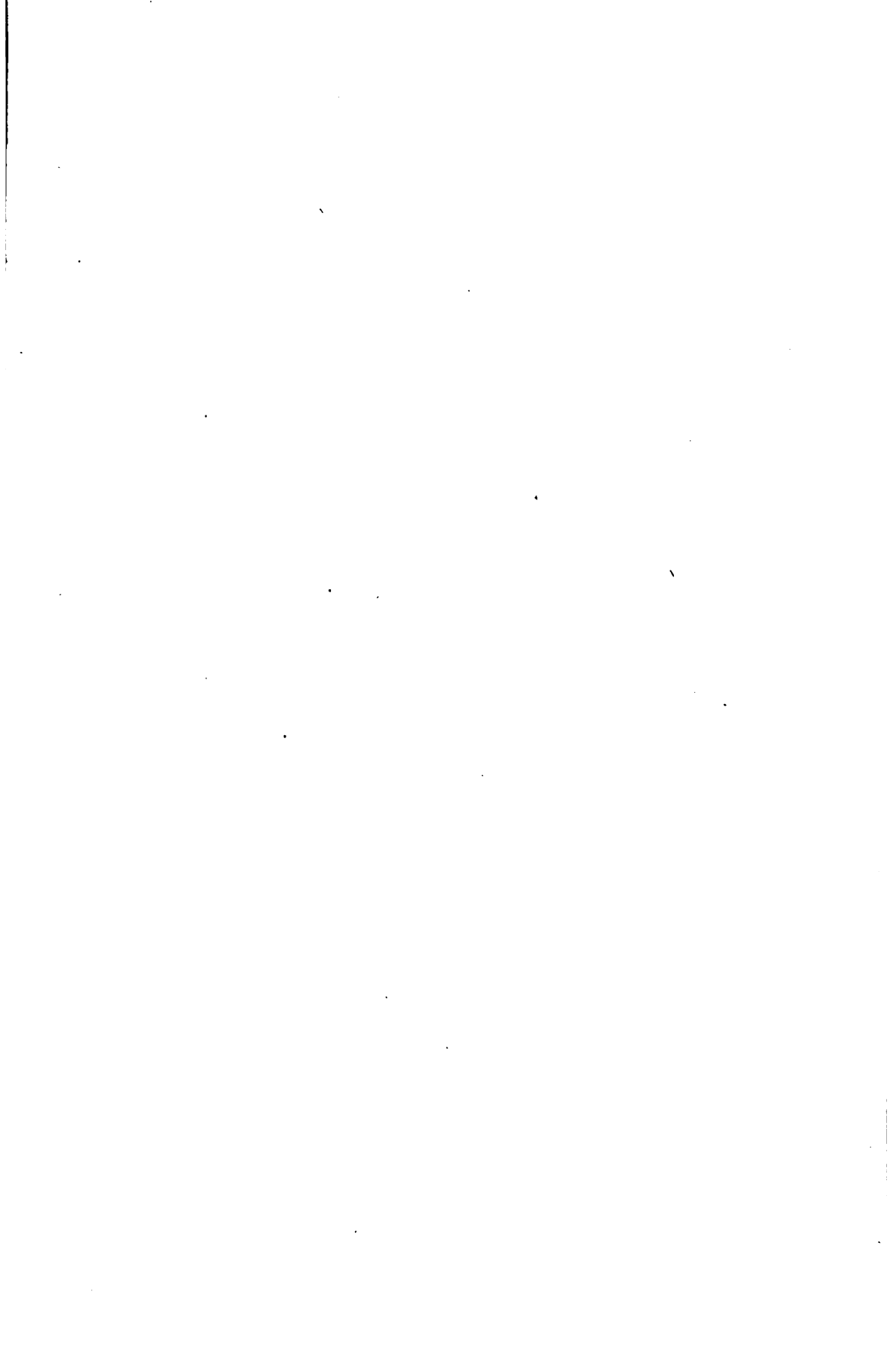
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