To A. D.

THE HEART RHYTHMS

BY

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CONTENTS

INTRODUCTION

The object of this book is not to present anything new in regard to the cardiac rhythms, but to separate them from the intricate mass of information concerning instruments, curves, cardiac physiology, etc., in which they are often buried, and to consider the rhythms themselves as a whole, and in relation to each other, but apart from all other functions of the heart. In doing so they stand out as a very simple and definite mechanism, which when once understood can never be forgotten.

The general plan of this book was developed in 1912 after studying in London, was used in the next year in teaching at the Peter Bent Brigham Hospital, Boston, and since then in connection with lectures in pharmacology at Johns Hopkins University. On account of various requests during the past ten years to publish this plan of the heart rhythms the book has finally been completed.

The lack of a clear understanding of the rhythms of the heart among well informed clinicians and students is quite surprising but easily accounted for. The subject is of fairly recent development, only a very meager knowledge being had before the advent of the electrocardiograph in about 1910. Up to this time the polygraph was used by a few people and it was possible for even the most experienced to interpret only a part of their curves, and the whole subject was entirely out of reach of the busy practitioner. The electrocardiograph cleared up the heart rhythms at once. It is this fact which has been generally overlooked, and which makes such a book as this possible. The subject of heart physiology is of course in its infancy, as is the cause of the heart beat, etc., but the rhythms of the heart as such are simply the time relations of contractions of auricles and ventricles and these have been satisfactorily worked out.

It is now possible to present a diagrammatic scheme of the heart divided into four areas from which impulses for contraction can arise. As these areas comprise the entire heart, no other points of origin of impulses can exist. A scheme of heart rhythms on the basis of point of origin of impulses can then be worked out which must include all rhythms. Given a few (five) functions of cardiac muscle, rhythms may be calculated by a mathematician with no other knowledge of the heart. There will be a limited number of rhythms, and each of them has been found to occur clinically. With such a scheme it is impossible to forget the rhythms as they can always be worked out. Any curve or tracing obtained from a patient can be referred to this process of analysis, and can be classified at once, Finally one has a clear mental picture of the limits of cardiac rhythms and will not waste time over each new curve imagining that he has some totally new rhythm.

The clinical value of a knowledge of these rhythms is of far greater importance than those not understanding the rhythms realize. The actual diagnosis cannot be made without the use of an instrument, in many cases by the electrocardiograph only, which is a cumbersome, expensive and complicated instrument quite out of reach from a financial point of view of the general practitioner, but which should be part of the equipment of every hospital. The polygraph, a small portable instrument, can however be used by anyone, and should come into more general use. It is of absolutely no value without a complete knowledge of the cardiac rhythms. The reason for this is that the polygraph gives no characteristic curves for the auricle and an interpretation can be made only by careful plotting of time relations, while in the electrocardiogram the auricular and ventricular impulses are shown by complexes of characteristic shape and can be recognized at once. Besides this in many cases only incomplete information can be obtained by a polygraphic tracing and a diagnosis made by exclusion only, which is impossible when the limit of rhythms is not definitely known. The instrument is much harder to use intelligently than the larger electrocardiograph and the cupboards of many a practitioner probably hold one of these discarded machines. An intelligent understanding of the rhythms themselves apart from other heart functions, instruments, and curves, gives one a basis on which to reason out a case, and will allow every practitioner to treat his patients more intelligently whether the diagnosis is made from feeling the pulse, taking a sphygmographic or polygraphic tracing, or an electrocardiogram.

The book is divided into two parts. It is hoped that the first will be found *readable*, and from it one can obtain an intelligent understanding of the heart rhythms. In the second part a very brief outline of the electrocardiograph and the taking of electrocardiograms is given. It is assumed that anyone using such an instrument would require a much more detailed knowledge than the scope of this book allows.

The polygraph however is taken up at length. With a clear understanding of the heart rhythms, this instrument is of great clinical importance, and is well worth a careful study. Its use requires care, and as many curves can be diagnosed by exclusion only it is essential to have a knowledge of *all* the rhythms before a diagnosis can be made. Although this requires considerable careful study it is hoped that the pointing out of the few essential factors necessary for the taking of a curve, here given, will simplify this apparently complex subject.

References, names of authors and investigators, have been left out to avoid confusion. The book is written with the purpose of arranging the great mass of information which has grown out of years of work by many investigators; and presenting it in as concise a form as possible in order that it may be more widely used in the study and treatment of those suffering from disorders of the heart. The student or reader who wishes to go further will find each phase discussed in detail in many excellent books on the subject.

I wish here to express my thanks to the Arthur H. Thomas Co. and The Cambridge and Paul Instrument Company, Limited, for their courtesy in allowing me to use cuts of their instruments.

P. D. L.

Baltimore, August 1, 1921.

PART I

CHAPTER I

The Development of Our Knowledge of the Heart Rhythms

THE PULSE

Probably the first interest in heart rhythms came from "taking the pulse." This usually meant feeling the pulse wave in the radial artery at the wrist, and we find very early records of fast, slow, and irregular pulses, but these were taken as signs of the patient's condition and little attention was paid to the reason for and the mechanism of their production. The pulse was easily felt and gave the physician perhaps as much information as any single examination does. By it he was able to tell whether the heart were beating regularly or irregularly, fast or slowly, whether each beat were large and forcible, or small and weak, and whether beating against the normal, high or low pressure. It was an important examination, but did not explain the cause of these different rhythms. If we represent the circulation as in figure 1 it will be seen that the radial pulse, or any other arterial pulse, is a direct index of left ventricular contraction only, as this is the one heart chamber pumping blood into the aorta, the right auricle emptying into the right ventricle, the right ventricle into the lungs, and the left auricle into the left ventricle. A study of the pulse alone gives then no idea of what the auricles are doing, but, as we shall see later, when the relationship between ventricular and auricular contraction is once understood, it is possible to infer by feeling the pulse what is going on in the auricles, so that a knowledge of the pulse is at present even more valuable than before.

THE SPHYGMOGRAPH

The first careful study of the pulse was made by using an instrument called the "sphygmograph," with which the pulse waves could be recorded (see fig. 2). This was done by placing a tambour with a rubber membrane, in the center of which was a button, on the wrist in such a manner that the button pressed on the radial artery. This tambour

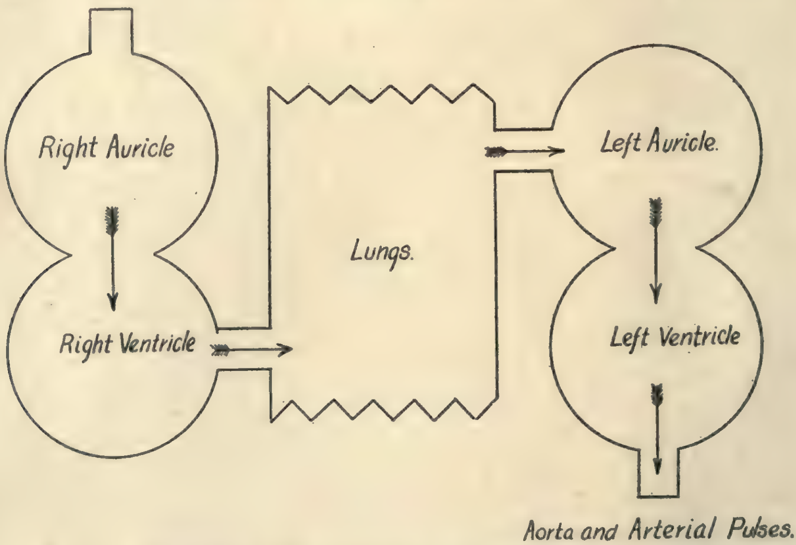


FIG. 1. Diagrammatic representation of the heart showing that the arterial pulse is an index of left ventricular contraction only.

was connected by a rubber tube with a second tambour, to which a lever recording on a smoked drum was attached. Each pulse wave compressed the air in the tambour, and transmitted this wave to the lever, which recorded the pulse in a continuous curve. The time was also recorded, usually in one-fifth second intervals. Such a sphygmographic curve is shown diagrammatically in figure 3. With this instrument the time of left ventricular contraction could be recorded very accurately. The shape of the curve had little significance as it depended on the instrument used, and its adjustment to the wrist, but two points in the curve

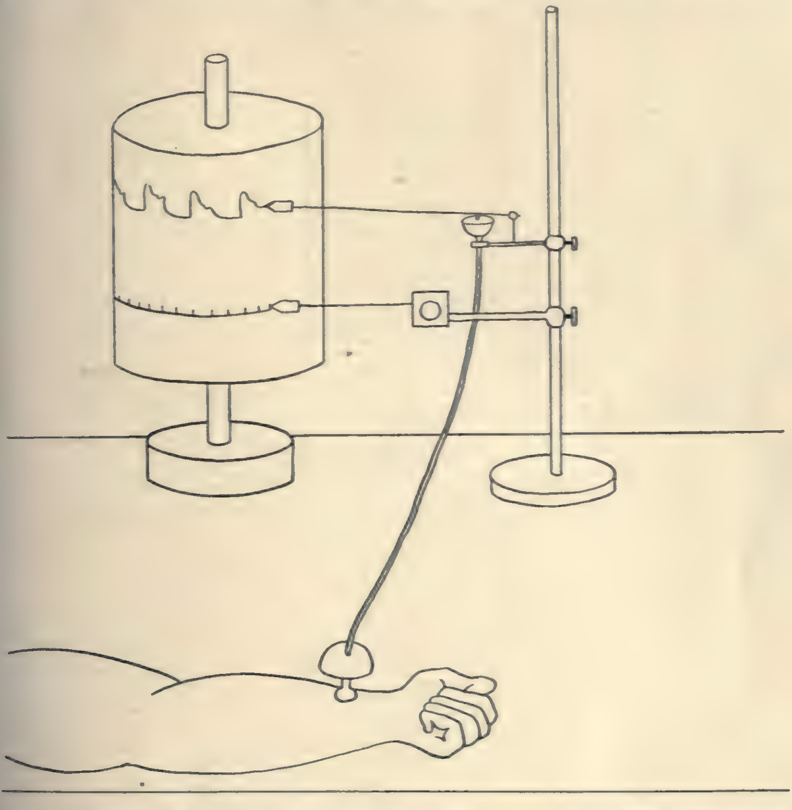


FIG. 2. Showing the principle of the sphygmograph. The tambour placed over the radial artery transmits an air wave to the tambour and recording lever which records the pulse wave on the revolving drum. A time marker is shown which is essential for the interpretation of these curves.

were found to be of great importance: the first of these (*1*) the beginning of the upstroke, being an index of the beginning of left ventricular contraction, and the "dicrotic notch" (*3*) (a discussion of which will be found on page

(69) marking the end of contraction. The end of the upstroke (*2*) has no significance, as it depends upon the inertia of the lever. If a light delicate instrument is used, the lever will follow approximately the true pulse curve, while if it is heavy it will fly up, making a sharp peak which is very different from the true curve.

The sphygmograph was an advance over simply feeling the pulse but it gave us an index of left ventricular contraction only.

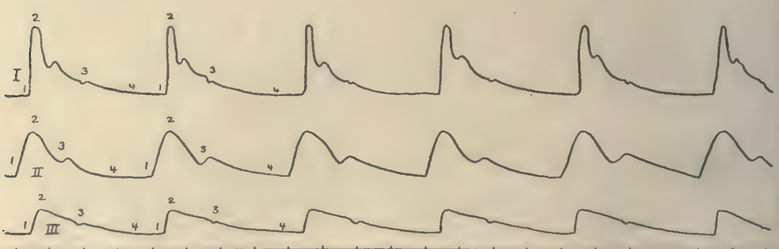


FIG. 3. A diagrammatic representation of various forms of sphygmographic tracings. The beginning of systole (*1*), and the dicrotic notch (*3*), the end of systole are the only points of importance. The points (*2*) and (*4*) are variables depending on the instrument used, conditions of blood pressure, etc., and may be entirely disregarded.

THE POLYGRAPH

A great advance over the sphygmograph was made by simultaneously recording the radial pulse, the venous pulse in the neck, and the time, with an instrument called the "polygraph." This apparatus recorded the pulse in exactly the same manner as the sphygmograph, while a second similar recording device, placed over the right jugular vein, recorded the pulse waves in this vessel. In a normal case under good conditions, curves similar to those in figure 4 were obtained. The beginning of left ventricular systole is shown in the radial pulse curve, and by a corresponding wave *c* in the venous curve, the end of systole by the dicrotic notch in the radial curve, and the downstroke v in the venous curve. One other wave (a) is seen in the venous tracing, which occurs one-fifth of a second before each ventricular systole. This was found to be due to contraction of the auricles, so that with this instrument

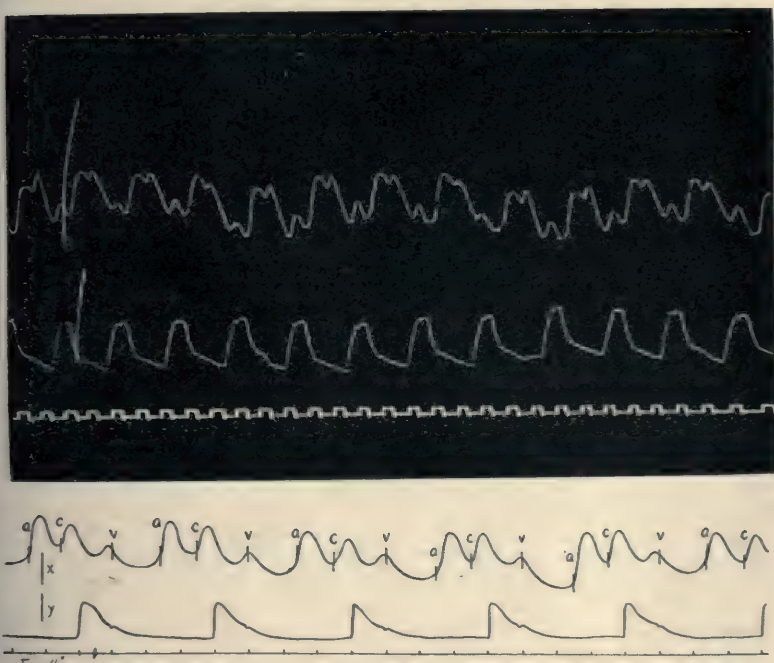


FIG. 4. The upper curve is an actual polygraphic tracing. The lower one a diagrammatic representation of one. It is seen that while the sphygmographic tracing shows ventricular beats only, the venous tracing shows auricular as well as ventricular beats. The points (a) showing auricular contraction, and the points (c) and (v) showing the beginning and end of ventricular systole.

it is possible to record auricular as well as ventricular beats. But difficulties were encountered which made this apparatus less simple than it appeared to be. In some cases where the patient moved or coughed, other waves appeared in the venous curve as shown in figure 5 and in still other cases as in figure 6 no auricular waves appeared at all. It soon became evident that the venous pulse gave a very uncertain curve. Taken by itself the curve has no characteristic waves as the radial curve has. It is then of no value alone but only when taken in relation to a curve in which definite points are known, as the radial curve. It is possible to plot the beginning and end of systole, definitely

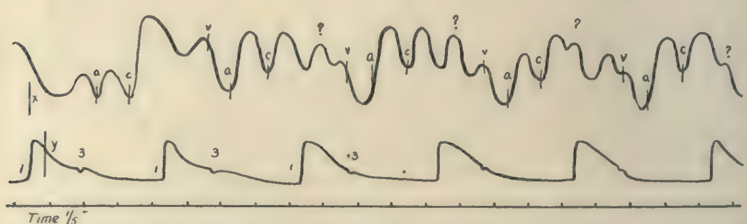


FIG. 5. This curve is given to show that the interpretation of polygraphic curves is not simple. Besides the auricular and ventricular waves other waves may occur from movements of the patient or the instrument, and these can be told from the auricular and ventricular waves only by careful plotting of known points in the curve.

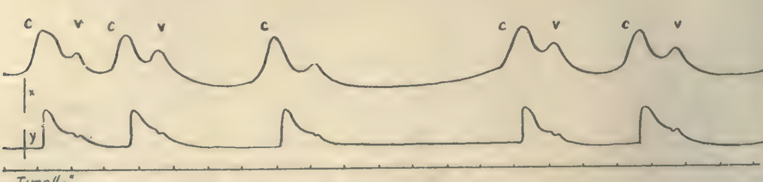


FIG. 6. In this polygraphic curve no auricular waves appear at all, in which case one is not certain whether the auricle is beating or whether the curve is simply badly taken.

shown in the radial curve, onto the venous curve, marking where the beginning and end of systole come in this curve. In this manner the waves which are of ventricular origin are found, and we can look about for other waves which might be caused by contraction of the auricles. In some cases these waves are very clear, in others absent or obscure, and though by careful study a great advance was made in our knowledge of pathological rhythms by the use of this instrument the whole subject was uncertain, and too difficult for anyone but an expert.

THE ELECTROCARDIOGRAPH

The instruments of which we have thus far spoken recorded mechanically the pulse waves which follow heart beats. In the electrocardiograph we have an instrument of an entirely different character, which has nothing to do with the actual contraction of the heart, but records the *impulses* for these contractions. The principle is a simple one although the instrument is of formidable appearance. It is based on the fact that for a muscle to contract a stimulus is necessary, and when this stimulus arises, whether it be of nervous, mechanical, or chemical nature, an electrical difference of potential is set up in the muscle just before its contraction. It is unnecessary here to go into the theory of this electrical disturbance, the important point being that it takes place a fraction of a second *before*, rather than as the result of contraction, and we speak of it as an "impulse" for contraction. Such a distrubance occurs when any muscle contracts, and as the heart is a large muscle it causes a relatively large disturbance. These changes of potential can easily be recorded by placing the patient's hands in jars of salt solution connected by wires to the electrocardiograph. This is simply a very sensitive galvanometer, or instrument for measuring small electrical changes and an apparatus for recording them photographically. The simplest form of galvanometer is one in which a coil of wire is placed about a small compass. When there is a flow of electricity through the coil, the needle of the compass moves out of its normal position, and when the current ceases the needle swings back again. All these simple instruments need a relatively large current to affect them, and the chief trouble comes from the inertia of the recording device, for example the needle of the compass, which takes some time to swing back to its original position, and so is capable of recording only currents which occur at fairly slow intervals. In the electrocardiograph an Einthoven galvanometer is used, which is made on a different principle from the compass galvanometer. Here the movable part is a microscopic thread of quartz called a "string," which is suspended vertically in a strong magnetic field. When a minute current is passed through it, the "string" is deflected, or really bent laterally. As the string is supported at both ends, has a very small mass, and moves only a fraction of a millimeter, it has very little inertia, and can record impulses up to many hundred times per minute. These records are obtained by making the string opaque with a coating of silver, placing it in a beam of light which throws a vertical shadow, magnified by a microscope, onto a metal plate in which there is a horizontal slot. This slot allows only a point of shadow to pass through to a moving photographic plate or film, on which the point of shadow writes in a continuous curve. The apparatus is shown diagrammatically in figure 7.

When curves are taken of a normal individual with this apparatus they are found to be of the following character (fig. 8.)

Two distinct curves, or as we call them, "complexes" are seen to occur at regular intervals. The first complex, *P*, is a small upright curve. The second complex, *QRST*, consists of a high vertical curve *QRS*, followed by a slight depression, and then another lower and broader curve *T*. Careful analysis shows that the first complex *P* is caused by auricular contraction, and the second complicated curve or *QRST* is of ventricular origin. The advantage of the curves obtained with this instrument over those of the polygraph will be seen at once. In the polygraphic curves, the radial tracing gives ventricular beats only, and the venous curve gives nothing characteristic, nothing which

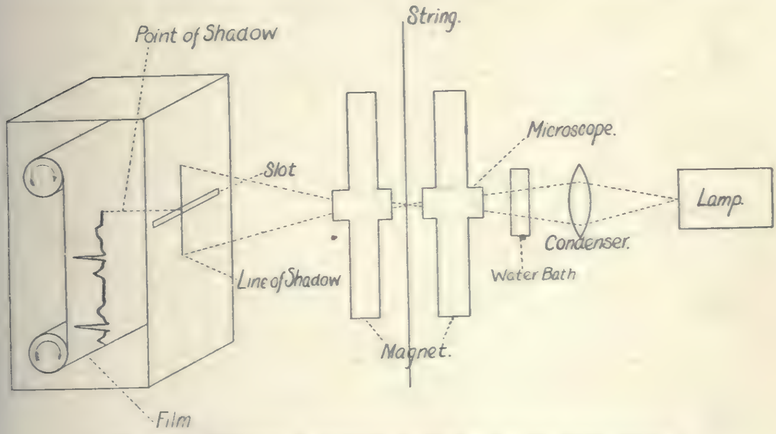
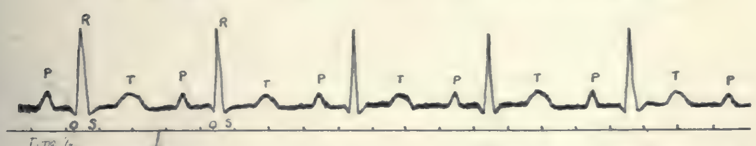
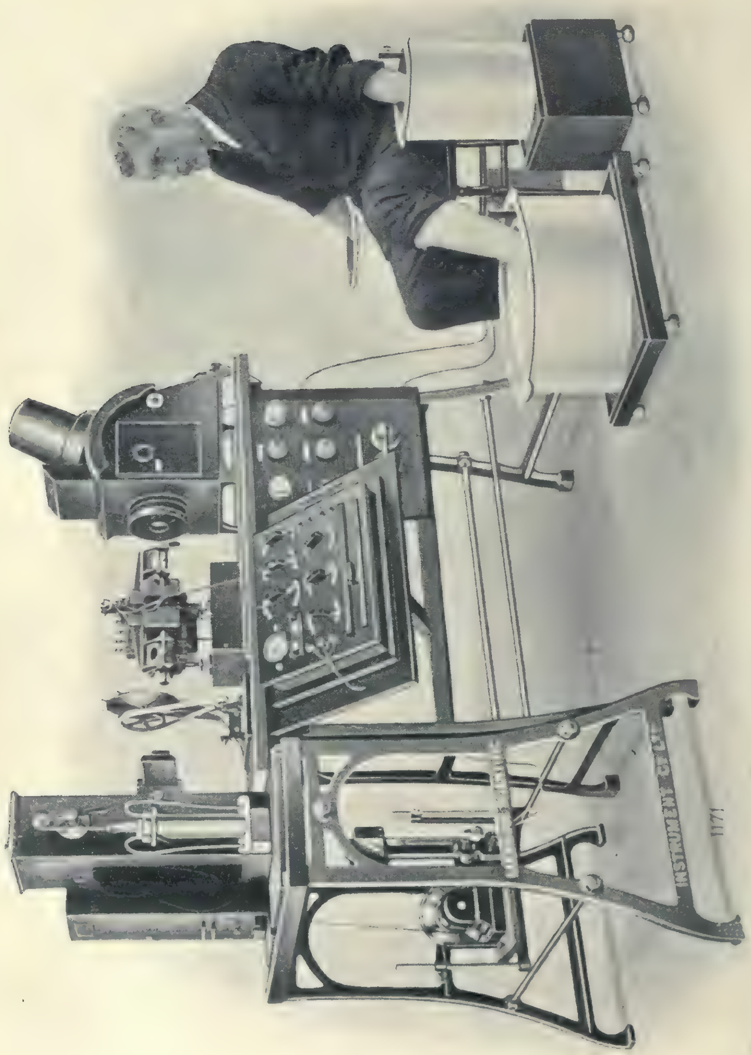


FIG. 7. Diagrammatic representation of the electrocardiograph.



.FIG. 8. A diagrammatic electrocardiogram of a normal rhythm. The auricular impulse is shown by the upright curve *P*, and the ventricular impulse by the complicated curve or "complex" *QRST*, the beginning and end of which mark the beginning and end of systole.

when the curve is taken separately can be identified as being of ventricular origin. It is only by analyzing the venous tracing in relation to the known sphygmographic curve that the origin of the waves in the venous curve can be ascertained, and even these auricular waves are determined by a process of exclusion. In the electrocar-



Photograph of a Complete Electrocardiograph, Showing the Manner in which the Electrodes are Attached to the Patient, In this Case the Hands and One Foot Being Immersed in Jars of diogram the auricular and ventricular complexes can be picked out at once by their characteristic shapes, and when the curves are well taken it is very simple to interpret them, as for example that of figure 9, where it is evident to anyone that the auricle beats twice to each beat of the ventricle. (Of course all curves are not as simple as this diagrammatic one, as some auricular beats may fall in some

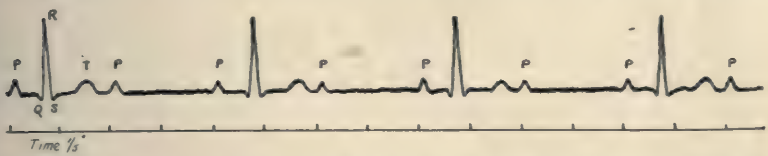


FIG. 9. A curve showing the simplicity of electrocardiograms compared with the polygraphic tracings. Here it is very evident that the auricle beats twice to each beat of the ventricle.

part of the ventricular complex and be lost, but there are ways of getting out of these difficulties which will be taken up later.)

This short review of the instruments in use will make it evident why it is simpler to begin our study of the heart rhythms with electrocardiographic curves, rather than with those of the supposedly simpler, because smaller, instruments, the sphygmograph and the polygraph.

CHAPTER II

Five Important Elements of the Heart Beat

The clinician's training is so closely connected with heart conditions of an entirely different nature from those dealt with in this book that it is hard at first for him to disregard his old ways of thinking, and to think of the heart abstractly, and not as it actually appears with its valves, its blood flow, etc. In the study of rhythms our interest is in the time relation only of the contractions of the four chambers of the heart and for our purposes the heart may be represented by four circles as in figure 10 and everything else disregarded. It will be found a great help if attention is paid to this heart diagram as we develop it, and to think of the time relation of beats of these circles to each other, rather than of the auricles and ventricles themselves.

If now we expose an animal's heart to view under an anesthetic, five important points can be made out by simple observation of the beating heart. These are

1. The Simultaneous Contraction of Both Auricles and Both Ventricles

In the first place it will be noticed that both auricles contract simultaneously, and this contraction of both auricles is followed after a short pause, by a contraction of both ventricles. One never sees first one auricle contract, and then the other, or the contraction of first one ventricle and then the other, but the two auricles beat as one and the two ventricles as one also. The two auricles are really one large muscle whose cavity is divided by a thin septum, and the same may be said of the ventricles, but the auricles are distinctly separated from the ventricles by a band of tissue, the auricular-ventricular septum. As both auricles beat as one, and both ventricles beat simultaneously, we may represent the heart as in figure 11, hereafter speaking of it as having one auricle and one ventricle, and our problem is reduced to the study of the time relation of contraction

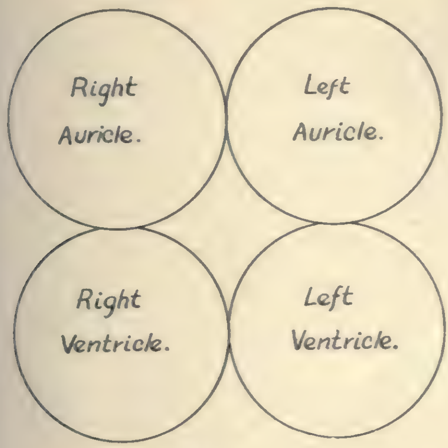


FIG. 10

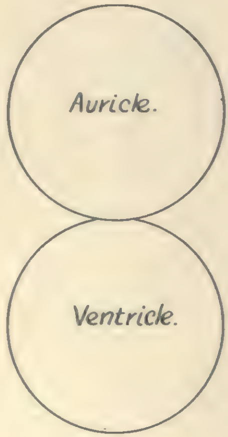


FIG. 11

FIG. 10. Diagrammatic representation of the four heart chambers, the time relations of contraction of which we are dealing with in the study of the heart rhythms.

FIG. 11. Reduction of the heart diagram to one auricle and one ventricle as both auricles beat as one, and both ventricles as one also.

of these two chambers to each other. If there were no factors governing the beating of these heart chambers, the number of rhythms would be infinite, but fortunately for us there are a few limiting factors which reduce the number of rhythms to a comparatively small number, and these can all be observed in the beating heart.

2. THE RHYTHMICITY OF BEAT OF CARDIAC MUSCLE

The exposed heart will be seen to beat rhythmically and regularly. When a strip of muscle is cut out of the heart and suspended in the proper solution to nourish it, or if the whole heart is removed and supplied by an artificial circulation, the heart which was for a time quiet will begin to beat, and this beat will occur at *regular* intervals. If the rate is increased or decreased by various methods, the rhythm will still be regular.

3. THE IMPULSE FOR CONTRACTION OCCURS AT THE POINT OF GREATEST IRRITABILITY

It will also be noticed that the auricle beats first and is followed by a ventricular beat, then there is a pause, and another auricular beat occurs, followed again after a short pause by a beat of the ventricle. One always speaks of the ventricle following the auricle, but it is possible for this order to be reversed. For instance if we cool the auricle of a beating turtle's heart, without cooling the ventricle, the auricle will beat more and more slowly, and finally the ventricle will beat first, and be followed by an auricular beat. That is, the auricle has been made relatively less sensitive, or as we say "irritable," than the ventricle, so much so that the ventricle contracts before the more sluggish auricle. And if we touch either the auricle or the ventricle with a stimulating electrode, or any stimulating substance, we may by increasing the irritant cause a contraction to occur before the normal time, while in pathological cases conditions occur in which areas in the auricular or ventricular muscle become abnormally irritable, and premature beats arise from them. From these experiments and others which will be taken up later, it appears that the beat arises from the point of greatest irritability in the heart, that normally the auricle becomes more irritable than the ventricle, and consequently beats first, but that artificially the ventricle can be made more irritable than the auricle, in which case the beat will arise in the ventricle. Also that the beat may occur out of time in either the auricle or ventricle, if these chambers are irritated by some means.

4. THE REFRACTORY PERIOD OF THE VENTRICLES

We have seen that when the beating heart is touched by a stimulating electrode, a contraction of the chamber stimulated takes place at once. This is true of the auricle, but if one repeatedly touches the ventricle with such an electrode, it will be found that there are periods in which the ventricle will not respond to stimulation. These periods occur during a ventricular contraction and shortly after. It seems as if the ventricle were like a gun, taking a certain length of time to reload and while reloading cannot be fired. The auricle on the other hand loads so quickly that one cannot get ahead of it, and it will fire as fast as the trigger is pulled. This period in which the ventricle will not respond to stimulation is called the "refractory period," and is of importance because in abnormal cases in which the auricle is beating very rapidly some of the auricular impulses reach the ventricle when it is in this refractory state, and no ventricular contraction will take place.

5. THE CONDUCTION OF IMPULSES FROM AURICLE TO VENTRICLE

We have noticed in the beating heart that the auricular beat is followed after a short pause by a beat of the ventricle. This pause is normally about one-fifth of a second.

It is due to the time taken for the auricular impulse to pass from the auricle to the ventricle. That such an impulse is transmitted from one of these heart chambers to the other can be easily shown in the turtle's or frog's heart by means of a specially devised screw clamp. This is so made that any desired pressure may be brought to bear on the septum connecting the auricles with the ventricles. If only slight pressure is exerted, the time taken for passage of the auric-

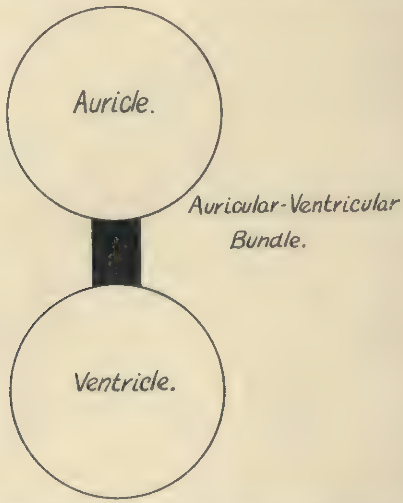


FIG. 12. The addition of the auricular-ventricular bundle to the heart diagram, in order to deal with the conduction of impulses from auricle to ventricle.

ular impulse from auricle to ventricle is increased from one-fifth of a second to two- or three-fifths or more. Eventually the time taken for the passage of one impulse becomes so great that the auricle may beat twice or even three or four times to one beat of the ventricle, and finally, if the clamp is completely closed, shutting off the auricles from the ventricles entirely, these two chambers beat absolutely independently of each other. It has been found that these impulses are transmitted through a band of specialized muscle tissue, running from auricle to ventricle, and called the "auricular ventricular bundle" or "bundle of His." In the human heart this bundle is easily seen with the naked eye. When this bundle is cut, no impulses pass from auricle to ventricle, and in man cases are observed in which the ventricles beat independently of the auricles and autopsy shows a gumma or arteriosclerotic changes which have destroyed the bundle. This conduction bundle is then of importance to us in the study of heart rhythms and we must add it to our heart diagram (figure 12).

SUMMARY

From simple observation we have learned that the heart beats at regular intervals. That the beat arises at the point of greatest irritability. That as the auricle normally beats first, it may be supposed to be more irritable than the ventricle, but that this condition may be experimentally or pathologically changed, and the auricle or ventricle, made more irritable by some agent, will beat out of time. That the auricle recovers quickly from a beat, and is always ready for the next one, but that the ventricle is relatively sluggish, and cannot be made to beat again until a certain amount of time has elapsed, which time we call the "refractory period." That impulses for ventricular contraction arise in the auricle, and are transmitted to the ventricle by means of the auricular ventricular bundle. That when this bundle is impaired by any means a greater length of time is needed for the passage of auricular impulses, and when the bundle is destroyed no impulses pass from auricle to ventricle, and each beats quite independently of the other.

CHAPTER III

The Division of the Heart Into Functional Areas by Means of the Electrocardiograph

By simple observation we have been able to make out the chief factors which control the heart rhythm, but we have a far better method of studying these in the electrocardiograph. If we anesthetize an animal which is suitably connected with this instrument, and expose the heart to view, the electrical disturbance set up by the beating heart will be recorded in a curve similar to that of figure (13). We have already said that the complexes *P* are caused by auricular impulses and the complexes *QRST* by impulses for ventricular contraction, but no mention was made of how this was known. In the first place when an electrocardiogram is taken, and recorded on the same plate as curves made mechanically by levers attached to the auricle and ventricle, it will be found that the *P* waves occur an instant before the mechanical auricular waves, and that the complexes *QRST* also occur a moment before the mechanical contraction of the ventricle, from which we may conclude that the *P* wave represents the auricular, and the complex *QRST* the ventricular impulse. When very careful measurements are made it is found that the curves recorded in the electrocardiogram always preceded by an instant the corresponding beat of the heart. Although we do not know just what the electrical phenomenon is, which goes on at this time, it seems that the difference of potential is not caused by muscular contraction, as it is recorded just before contraction takes place. Also in an excised heart which has ceased to beat, very good electrocardiograms may be recorded. We believe then that the electrocardiograph records *impulses for contraction and not a disturbance set up by contraction.* This is important, because the size and shape of the curve is in no way dependent upon the size and force of the beat. A good

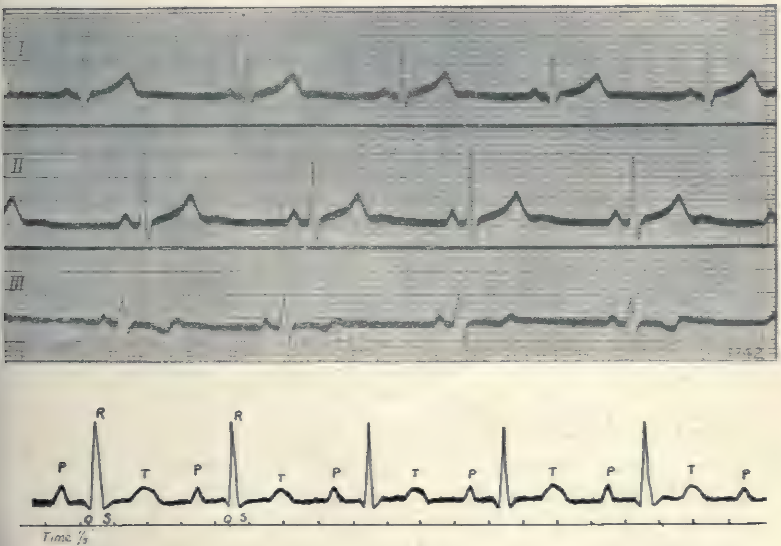


FIG. 13. The upper figure gives normal electrocardiograms from a human subject, showing the so called three "leads" described on page (60). This is done by placing the electrodes on different parts of the body, which emphasizes different portions of the curve as seen in these three electrocardiograms of the same subject. The lower curve gives a diagrammatic one which will be used entirely throughout this book for the sake of simplicity. Lower curve same as figure 8.

example of this is that of premature beats of the ventricle which give such a small pulse wave that they are often not felt at the wrist, and are spoken of as skipped beats. The electrocardiogram gives an abnormally large complex for these small beats, and a normal complex for the large pulse wave which follows these. This relationship can be seen in figure 14. Although the size of the electrocardiographic complex is of no importance to us as an index of the size of the beat, the shape of the complex is of the greatest importance, because by it we are able to locate the origin of the impulse, whether in the auricle or the ventricle, and whether it arises in a normal or abnormal position in these heart chambers. That the shape of the electrocardiographic impulse is characteristic of the point of origin of the impulse

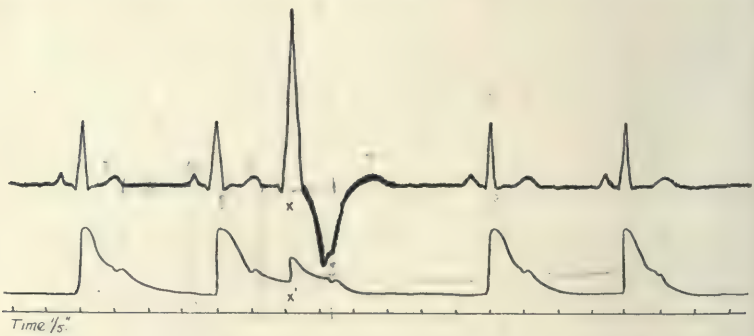


FIG. 14. The upper curve gives an electrocardiogram of an ectopic ventricular beat, the complex of which is much larger than that accompanying a normal beat, while the radial pulse shows a small pulse wave for the ectopic beat. The curve is given to show that the size of the wave in the electrocardiogram is in no way proportional to the actual size of the heart beat.

was discovered by stimulating the exposed heart in many places with single induction shocks, which caused the auricle or ventricle to contract, and recording the impulses for these contractions with the electrocardiograph. In this way the heart was functionally mapped out into the following areas.

1. The sino-auricular node. A small node of specialized muscle tissue located at the junction of the great veins of the neck with the auricles.

2. The auricular-ventricular node and bundle. Situated at the base of the auricle at the beginning of, and really a part of, the auricular-ventricular bundle. This is also made of the same tissue, and runs from the auricular-ventricular node to the ventricle, where it divides into two branches, one going to each ventricle.

3. *The auricular musculature.* That is, the mass of cardiac muscle making up the auricle, and which we cannot differentiate into any particular areas.

4. *The ventricular musculature.* Which is the general musculature of the ventricle.

Beats may arise from any of these four areas, and each beat will give its characteristic complex and thus be located at once. These areas and their characteristic complexes are shown in figure 15. It will be seen that the only difference in the impulses arising at the sino-auricular node, and those from the general musculature of the auricle is that one gives upright complexes, while the others are inverted. If we consult the electrocardiogram of a normal heart (fig 13) it will be seen that the auricular impulse normally arises at the sino-auricular node, and the normal ventricular impulse at the auricular-ventricular node. If for any reason an impulse arises outside these normal areas, we speak of it as an "ectopic" impulse of auricular or ventricular origin.

The ectopic ventricular complexes are not always of a very distinguishing shape, but, when one takes an electrocardiogram in which normal ventricular complexes are present, it is usually simple to differentiate an ectopic complex from a normal one. As a rule they are higher and broader, and the *T* wave may be inverted. On the other hand impulses may arise in one of the branches of the auricular-ventricular bundle which are very hard to tell from the normal. But these are minor details and will be taken up later; the point of interest here is that in the electrocardiograph we have an instrument with which we can record the time relation of contraction of the auricle to the ventricle with great accuracy, and with which it is possible to tell whether the impulse for contraction arises at the normal or

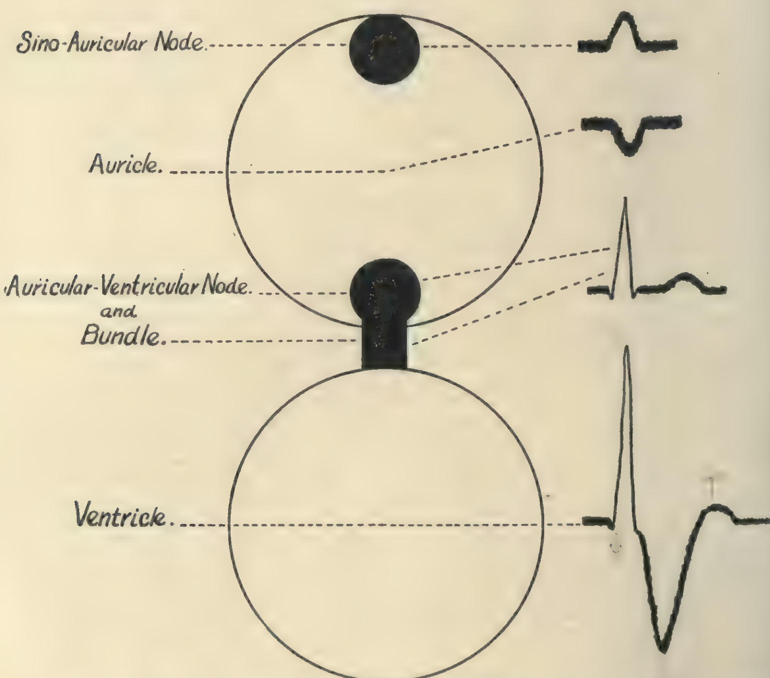


FIG. 15. Diagram showing the division of the heart into four functional areas by means of the electrocardiograph, and giving the characteristic complexes for each of these four areas.

at an abnormal place or "focus." It is also interesting to note that it has been possible to differentiate these areas in the heart functionally as well as anatomically. This instrument gives then a method by which we can make a complete study of the heart rhythms, and allows us to classify them on the basis of point of origin of impulses.

CHAPTER IV

The Classification of Cardiac Rhythms on the Basis of Point of Origin of Impulses

As we are able to differentiate the heart into four areas only, from which impulses may arise, we can have only four classes of cardiac rhythms based on the point of origin of impulses. These four classes are as follows: (1) Sino-auricular rhythms, (2) ectopic auricular rhythms, (3) auricular-ventricular nodal rhythms, (4) ectopic ventricular rhythms.

Let us take up each of these rhythms from a theoretical point of view, calculating from our knowledge of certain functions of cardiac muscle which we have already taken up, and our knowledge of the normal electrocardiogram, what rhythms are likely to occur when impulses arise in these four different heart areas.

1. SINO-AURICULAR RHYTHMS

By simple observation of the beating heart we found that the two auricles beat as one, and the two ventricles as one also, and that we could consider the heart for our purposes as consisting of one auricle and one ventricle. We saw that the auricle beat first, and the ventricle one-fifth of a second later. We concluded that the ventricular contraction was dependent upon impulses received from the auricle by way of the auricular-ventricular bundle because if this bundle were injured the ventricle would wait for the delayed auricular impulse. And if the bundle were destroyed no further relationship between the auricles and ventricles could be made out. When we took an electrocardiogram of such a heart, we found that the auricular complexes were characteristic of impulses arising from the sino-auricular node, and the ventricular impulses characteristic of others arising from the auricular-ventricular node started by impulse waves coming from the auricle. Why these impulses arise we do not know, but we do know that the rate at which they arise varies from time to time, that we can influence this rate by various means, and that the rate is under nervous control. This is shown by the fact that stimulation of the accelerator nerve causes an increase in rate, while stimulation of the vagus nerve causes a decrease in the heart rate. Certain chemicals, as calcium, will increase the rate and others, as potassium, will decrease it. And then there are complicated factors which influence the heart rate that cannot be so easily analyzed, as for instance the changes in exercise, the increased flow of blood, the increase in respiratory rate, the various chemical changes in the blood, etc., all of these things are liable to vary the heart rate and although we do not know just what occurs in the sino-auricular node at the time of impulse formation, the important points to be noted are that the impulses arise at *regular intervals*, no matter what variation in rate occurs, and any variation in rate of rhythms arising at the sino-auricular node is a *gradual variation*. There is never any sudden break in the rhythms as that which occurs in other conditions.

We have four uncomplicated sino-auricular rhythms which are:

1. *The normal heart beat*

a. Simple tachycardia. That is, a normal but fast rhythm.

b. Simple bradycardia. A normal but slow rhythm.

c. Sinus arrhythmia. This term is applied to *gradual* variations in rate as those occurring with exercise, etc., but chiefly to the variation in rate which comes with each respiration. This may be quite marked in some nervous young people, and is always very marked in children. It is an entirely normal condition and simply shows an active respiratory center.

We have seen that an electrical or chemical stimulus applied to the auricle or the ventricle would cause these chambers of the heart to contract. It is thus easy for us to conceive of some point in either the auricle or the ventricle becoming stimulated in the human heart by some pathological condition. Such conditions do occur as in posioning by chemicals, from changes brought about by infections, and cellular changes in the cardiac musculature. They give rise to beats which are recognized by their characteristic complexes in the electrocardiogram as being of ectopic origin. As normally the impulse for a cardiac cycle arises at the sino-auricular node, we may have ectopic impulses from any of the other three areas of the heart, that is, from the auricle, the auricular-ventricular node and bundle, and from the musculature of the ventricle, and clinically all such abnormalities of rhythm occur. Let us take up each of these three types of rhythm separately, beginning with

2. *Ectopic beats interrupting the normal heart beat*

a. Ectopic auricular beats. We have observed that one of the functions of cardiac muscle is the rhythmicity of beat. If a normal rhythm is interrupted by an ectopic auricular beat which will be followed in the normal time by a normal ventricular beat, it will interrupt that one cardiac cycle, but the auricle will begin to beat again normally at once, because if a second ectopic impulse does not occur, an impulse will arise from the sino-auricular node and the heart will go on beating normally. The ectopic beat must occur *prematurely* or otherwise it will be time for a normal sino-auricular impulse. That is why these are often called "premature" beats, but the term "extra systole" is wrong as there is no extra beat, merely a premature one.

If we examine the electrocardiogram of such a case, we find a curve similar to that in figure 16. The regularly occurring *P* waves followed in the normal time by normal ventricular complexes are interrupted at *X* by an auricular complex occurring prematurely. It will be noted that the complex is inverted, which at once tells us that the impulse

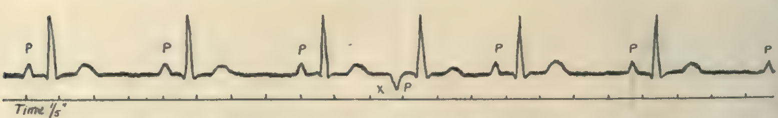


FIG. 16. Curve of an ectopic auricular beat, showing the inverted auricular complex, and the beat arising prematurely. It is followed by a normal ventricular beat in the usual conduction time.

arose from an ectopic focus in the auricle, and it will also be noticed that this ectopic auricular wave is followed by a normal ventricular complex. The reason for this is of course evident, *because auricular impulses, no matter of what origin, can reach the ventricle by way of the auricular-ventricular bundle only, and in so doing must set up a normal impulse for ventricular contraction.* The conduction time from auricle to ventricle will be normal as there is no abnormality of the conduction bundle. Following the ectopic beat, the heart goes back to its normal rhythm. The next auricular impulse is seen to be of sino-auricular origin and may occur at the normal time after the ectopic beat, sooner or later than normal, depending entirely upon the state of the sino-auricular node. Attention is called to this point in contradistinction to ectopic ventricular beats, which are always followed by a pause of the ventricle of a definite length. This pause is due to the ventricle waiting for the next auricular impulse, and is of importance in polygraphic tracings as a means of distinguishing between auricular and ventricular ectopic beats, but it has no significance here in electrocardiograms because the shape of the complex tells us at once whether we are dealing with an auricular or a ventricular beat.

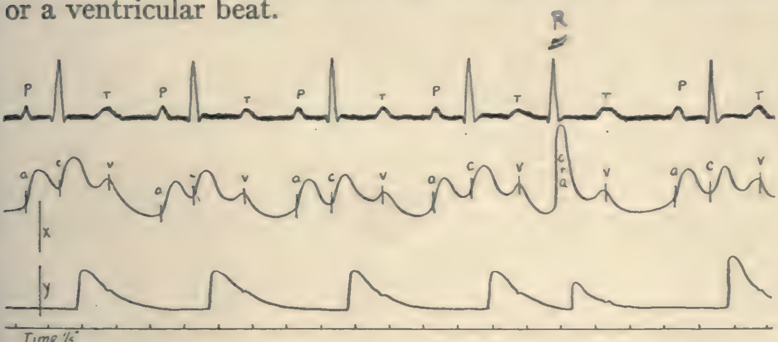


FIG. 17. Curves of a premature beat arising at the auricular-ventricular node. It will be noticed that the electrocardiogram shows simply an absence of an auricular impulse. The polygraphic curve on the other hand shows a small arterial pulse wave at the time of the premature beat, but an abnormally high *c* or arterial wave in the venous curve at this time, which leads one to believe that the auricle and ventricle contract simultaneously.

b. Ectopic auricular-ventricular nodal beats. In the same way an ectopic beat may arise from the auricular-ventricular node, and interrupt the normal rhythm. It is recognized by a normal ventricular complex occurring prematurely, and the absence of an auricular complex. This is due to the impulse arising at a point about equidistant from the auricle and the ventricle and being transmitted to each of these heart chambers in the same length of time and thus stimulating them to contract at once.

Such a beat is shown in fig. 17. There is no proof from such an electrocardiographic curve that the auricle does beat, but if one takes a simultaneous tracing with the polygraph it will be seen that the ventricular curve for the premature auricular-ventricular nodal beat, in the radial tracing, is if anything smaller than normal, while the corresponding ventricular curve in the venous tracing is much larger than normal. As no auricular wave is seen, it is supposed that the reason for this abnormally large ventricular wave in the venous curve is the simultaneous contrac-

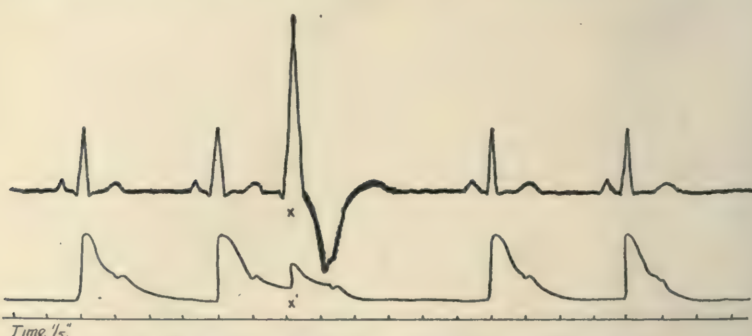


FIG. 18. Same as figure 14. Premature ventricular beat.

tion of the auricle and the ventricle sending a large wave up the vein.

c. *Ectopic ventricular beats*. Similarly the normal rhythm may be interrupted by an ectopic beat of ventricular origin. This is recognized at once by a *premature* ectopic ventricular complex occurring in the curve, as shown in figure 18. It gives a curve which is of interest because it shows that the auricle is not upset in its rhythm by the abnormal ventricular beat, but continues beating regularly in its usual manner. The ectopic beat occurred prematurely and when the next beat came down the auricular-ventricular bundle it found the ventricle in the "refractory" state (see p. 27) in which it could not respond to stimulation. The ventricle thus did not contract, and paused until the next auricular impulse arrived. Considerable emphasis is laid on this pause in polygraphic curves as it gives a method of distinguishing auricular from ventricular ectopic beats. It is however of no significance in our study here, but it is interesting to note that there really is no pause in the ventricular rhythm, but that every beat is on time except the ectopic beat which occurs prematurely.

These ectopic beats of auricular, auricular-ventricular nodal, or ventricular origin, may occur singly at rare intervals, or frequently, giving a regular pulse broken occasionally by a single beat, or a pulse which is so irregular that it is impossible to distinguish it from the absolute irregularity of auricular fibrillation.

II. ECTOPIC AURICULAR RHYTHMS

We have seen that it is possible for some ectopic focus in the auricle to become irritated, and for a single ectopic beat to arise from this focus. It is also possible for this irritation to become so constant that all the auricular beats arise from this point and none from the sino-auricular node, in which case we have a condition of an ectopic auricular rhythm. An electrocardiogram of such a rhythm is shown in figure 19.

During the establishment of the ectopic rhythm one may see runs of ectopic beats, then a return to the normal, then ectopic beats, etc., but when the ectopic rhythm is once established no sino-auricular impulses can be made out until the rhythm suddenly stops and returns to normal, when all of the auricular complexes are again of the sino-auricular type.

Auricular impulses of ectopic origin, as shown by the inverted complexes, arise at regular intervals and are followed in the normal time by normal ventricular complexes. Although all ectopic auricular rhythms are fundamentally of this same type, they fall into quite sharply defined clinical groups for two chief reasons: these are, the rate at which they occur, and the mechanical effect on the circulation. The first of these groups is that of

1. Paroxysmal tachycardia

In certain cases we find patients with the heart beating regularly and at the normal rate when suddenly they are conscious of a very fast throbbing circulation. They

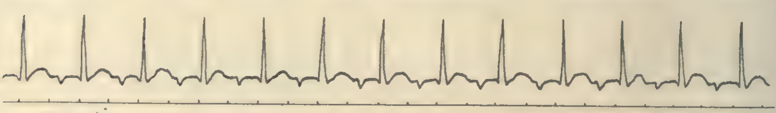


FIG. 19. Curve of an ectopic auricular rhythm in which all the auricular complexes are of the inverted type and followed in the normal time by normal ventricular complexes.

become nervous, frightened, short of breath, are conscious of palpitation, and the veins of the neck are usually swollen. The pulse is found to have increased enormously in rate, being often twice what it was before. It is regular and an electrocardiogram shows a regular rhythm in which all the auricular impulses are of ectopic origin, and each auricular beat is followed by a normal ventricular complex. Such a curve is shown in figure 19.

The attack may last for five or ten beats, several minutes, or many hours, and leave as suddenly as it came on. The cause of this condition is unknown, and nothing has been found which will shorten an attack although many substances are believed to, but the electrocardiogram shows us definitely that the pathology of the condition is the ectopic origin of all auricular impulses. There are several points of interest here. In the first place it will be noticed that the rate is much above the normal, roughly 180 to 220 per minute. A possible reason for this is that if impulses arose from this ectopic focus at a slower rate than that of the normal heart, the sino-auricular node would break in and reëstablish itself. Very often cases are found in which this occurs. There will be a run of three or four ectopic beats and then a few normal ones, then a short run of ectopic beats and finally the ectopic rhythm will be established with all the impulses of ectopic origin. There is however no gradual variation in rate. An ectopic rhythm assumes a rate of its own, and beats with great constancy, perhaps because it is not under any nervous control. The actual rate at which these impulses arise has a marked clinical significance. The ventricle is able to follow the auricle up to rates of about 220 per minute, and these cases in which each auricular beat is followed by a ventricular one are classified as *paroxysmal tachycardia*, the name, paroxysms of rapid heart beat, being well suited to the condition. With such a rapid *ventricular* rate there is necessarily a considerable circulatory disturbance of which the patient is aware. When however the auricular rate goes above 220 or thereabouts, the ventricle is unable to follow the auricle and we have an entirely different clinical picture, which has been given the name of

2. *Auricular flutter*

The pathology of this condition is exactly similar to that of paroxysmal tachycardia, namely, an ectopic auricular rhythm, but when the auricle is beating at a rate of 220 to

450 per minute the ventricle can no longer follow it, and we have two or three auricular beats to one of the ventricle. In such a case although the auricular rate is very great, the ventricular rate may be about normal, one hundred or so, and if the ventricle happens to follow an even number of auricular beats, the pulse may be perfectly regular. As the ventricle is pumping about the normal amount of blood through the body, there is none of the circulatory disturbance which is seen in paroxysmal tachycardia, and the patient complains only of a curious sensa-

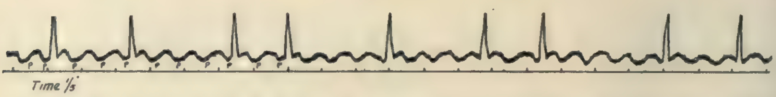


FIG. 20. Curve of auricular flutter in which the ventricular rhythm is irregular on account of the ventricle following an irregular number of auricular beats.

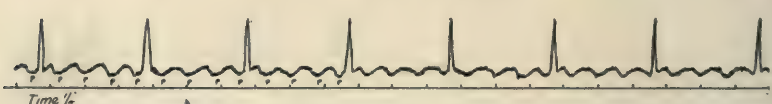


FIG. 21. Another curve of auricular flutter in which the ventricle follows every fourth beat of the auricle and gives a regular ventricular rhythm.

tion of "fluttering" about the heart, and a sense of weakness. These cases are often missed on account of the slow and regular pulse. When however an electrocardiogram is taken, the condition is seen at once. Figure 20 gives a diagrammatic curve of such a case. Here we have ectopic auricular complexes occurring at a very rapid and regular rate, and sometimes two, three, or four auricular beats followed by a beat of the ventricle. In figure 21 we have the same condition, in which however the ventricle follows every fourth auricular beat and gives a slow and regular pulse.

3. *Auricular fibrillation*

If the auricular rate goes above 450 or thereabouts, it is impossible for the auricle to contract coördinately, and it goes into a state of so called "fibrillation." This condition is often seen in laboratory work when one tries to perfuse a heart through the coronary arteries. The auricle may beat a few times and then it fills passively with blood and twitches in many minute contractions in different parts of its surface at once, but there is no coördinate

FIG. 22. Three curves of auricular fibrillation. It will be seen that in all of them the ventricle beats absolutely irregularly. There are no distinct auricular complexes seen, but in curve 1 rapid nearly regular oscillations of the curve can be made out. In curve 2 fewer and more irregular oscillations are seen while in curve 3 the curve is practically a straight line between ventricular beats.

contraction of the whole auricle. If one looks at it carefully it will be seen that innumerable contractions are taking place in small groups of muscle fibers. When an electrocardiogram is taken of such a case it is found that the impulses are arising from ectopic foci in the auricle at a very great rate, 500 per minute and faster. These may occur regularly as minute auricular complexes, or irregularly, and in old cases which have fibrillated for some time no definite auricular impulses can be made out. Curves of all three such conditions are shown in figure 22. It seems best not to be too certain in trying to decide just which is a case of flutter, and which is fibrillation. If auricular complexes occur at regular intervals, and polygraphic tracings show regular auricular waves, it is probable that the auricle is really beating, and we are dealing with a case of flutter. If however, we happen to find regular complexes at a rate of 600 per minute, and no well marked auricular waves in the polygraphic tracings it is probable that the auricle is not contracting coördinately. In all cases of fibrillation the auricular impulses are arising at such a very rapid rate that it is impossible for the ventricle to follow and it beats in an absolutely irregular manner. The irregularity is so marked and so persistent that these cases have been recognized for many years before any means of taking tracings were found.

Our knowledge of impulse formation still is very incomplete but more is being rapidly found out. The normal auricular impulse apparently arises at the sino auricular node and spreads in a wave over the auricle in all directions reaching the auricular ventricular node and starting there another impulse for ventricular contraction. When an ectopic auricular impulse arises the impulse spreads from this point in waves to all parts of the auricle, and again reaches the auricular-ventricular node and sets up a ventricular impulse. If however we have an ectopic auricular rhythm as for instance paroxysmal tachycardia once established it is interesting that the sino-auricular node which may be supposed to be quite normal, does not break in on the ectopic auricular rhythm and interrupt it. In seeking for some explanation for this one might imagine, with no proof of it, that the ectopic impulse wave travelling over the auricle reaches the sino-auricular node and discharges the impulse which is building up there before it has become of sufficient magnitude to discharge of its own accord and break in on the ectopic rhythm. When for any reason the ectopic rhythm fails for a beat, the sino-auricular node is then ready to discharge and again assumes command of the rhythm.

In auricular flutter, it is now believed that the cause of the very rapid (roughly 450 per minute) rate of auricular contractions is not due to impulses arising at some one ectopic focus in the auricle but that there are so called "circus contractions" taking place in the auricle. It was found some years ago in certain types of medusa, or contracting "jelly fish" that strips cut from them would show a wave of contraction starting at one end and passing off at the other. That after the passage of a contraction wave this point would become refractive and refuse to respond to stimuli for some little time. By cutting out a circular piece or ring strip of tissue it was possible to start a wave travelling around the ring. If the ring were of sufficient length when the wave of contraction had made a complete circle and reached the starting point again the refractory stage had passed off and the strip was ready to contract once more. In this way it was possible to keep up a wave of contraction travelling around the ring for days. This same phenomenon has been observed in strips cut from the hearts of the dog fish, the turtle, and the dog, and lately it has been experimentally shown in flutter produced in dogs that there is such a wave of contraction travelling around a ring at the junction of the great veins with the auricle. Such a wave in its rapid circular movement sends off waves of impulses over the auricle which cause it to beat, and stimulate in turn the auricular ventricular node. As long as this vicious circle of impulse around the veins occurs the flutter continues, but if a change in the conduction of this strip of tissue can be brought about which will break up the ring wave of contraction the sino-auricular node will then have a chance to send out its impulses to the auricle, and the normal rhythm will be again established. Such treatment has already been successful in certain cases but does not lie within the scope of this book.

In auricular fibrillation it is still undetermined whether the enormous number of impulses which are shown in the electrocardiogram arise from multiple foci of stimulation or whether they are complicated irregular "circus movements" similar to those of auricular flutter. For our purpose of studying the heart rhythms however this may be disregarded, and three types of auricular ectopic rhythms considered, simply from the different clinical pictures which they present. In the first, paroxysmal tachycardia, the ventricle follows each beat of the auricle, and gives a picture of a rapid circulation, in flutter the ventricle cannot follow the fast auricular rate and the pulse may be of about normal rate and the circulation apparently normal, while in fibrillation the auricular rate is too great for coördinated auricular contractions. Although all types are simply due to ectopic auricular impulses they cause quite different clinical pictures, which justifies this classification.

III. AURICULAR VENTRICULAR NODAL RHYTHMS

In exactly the same way that a point in the auricle may become irritated and give rise to an ectopic auricular

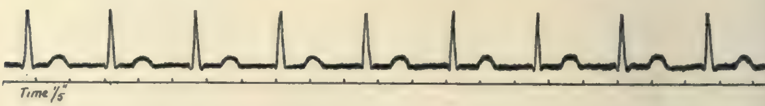


FIG. 23. Curve of an auricular-ventricular nodal rhythm. In this condition, which is very rare, the impulse for contraction arises in the auricular-ventricular node, and the auricles and ventricles contract simultaneously. No auricular complexes are visible.

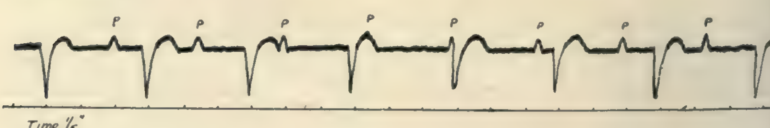


FIG. 24. Curve of a rare case of ectopic-ventricular rhythm in which the ventricular beats are of ectopic origin, and a fairly normal rate, and the ventricle is beating entirely independently of the auricle.

rhythm, the auricular-ventricular node may become the point of greatest irritability, and a rhythm may be set up in which all impulses originate from this node. As shown in figure 23, the rhythm will be regular, on account of the tendency of cardiac muscle to beat regularly, and the rate will be very limited. In fact it is a very rare condition and the reason for this will be seen if we think of just what the rhythm means. When an impulse arises at the auricular ventricular node, the auricle and ventricle both beat at once. If the rate is fast the ventricle must follow each impulse, it will not have time to fill properly with blood, and the circulation will not be properly maintained. If the rate is very slow, the sino-auricular node will break in and start the normal rhythm again. Thus there is a comparatively narrow range of rates in which it would be possible for such a rhythm to be established. As has been said, the condition is extremely rare.

IV. ECTOPIC-VENTRICULAR RHYTHMS

In the same way that a point in the auricle may become irritated and give rise to an ectopic auricular rhythm, it is conceivable that a point in the ventricle might also become irritated and give rise to an ectopic ventricular rhythm. But such a rhythm would have to be rapid or else the sino-auricular node would break in and upset the rhythm. We see many instances of this in which there are runs of ectopic ventricular beats, and then a return of the normal rhythm. If the runs are of fairly long duration they are very upsetting to the patient, as the rapidly beating ventricle cannot pump sufficient blood to maintain the circulation. Certain very rare cases of temporary ventricular paroxysmal tachycardia, flutter and fibrillation have been reported, which are of theoretical interest as it shows us that all the possible rhythms which we can calculate from our classification of rhythms do occur, but for all practical purposes we may say that ectopic-ventricular rhythms are incompatible with life. The one case of ventricular fibrillation which I have seen reported was one in which an electrocardiogram was being taken from a patient with a very bad heart. Suddenly the patient became pulseless, stopped breathing and was considered dead. The electrodes were removed, when suddenly the patient began to breathe, recovered and lived for twenty hours longer. On development of the film it was found that during the time of unconsciousness the ventricle went into a state of fibrillation, but was unable to maintain the circulation and the patient became unconscious and pulseless. It is probable that the establishment of an ectopic-ventricular rhythm is often the cause of sudden death.

It has been shown that we have rhythms arising from each of the four heart areas. We have shown that each of these rhythms could be broken in on by impulses from any of the other areas. We have pointed out that there is a limit to the rate at which the ventricle can contract and still maintain an efficient circulation, and that even the auricle can not contract coördinately above a certain rate. We have considered all rhythms arising from the four areas into which we have divided the heart, and seen that their number is limited by certain functions of cardiac muscle.

Theoretically it is possible for impulses to arise from all four areas at once, from points near the auricular ventricular bundle giving curves slightly differing from nodal rhythms, etc. These are of interest theoretically, but are so extremely rare that they can be disregarded here. It is however important to remember that one may sometime take an electrocardiogram of such a case, and then it is simply necessary to plot out diagrammatically the time relations of auricles to ventricles, the origin of the beats, and see where this rhythm falls in the above classification in which it must find its place.

There is a condition in which an independent ventricular rhythm may occur however, and that is in complete heart block which will be taken up directly. If for some reason the auricular ventricular bundle is functionally destroyed so that no impulses pass from auricle to ventricle, the ventricle is left to take on a rhythm of its own, quite independent of, and uninterrupted by the auricle. In an uncomplicated case of heart block, these ventricular impulses are of the normal type, but in old diseased hearts cases have been reported in which there is a regular ectopic ventricular rhythm, of a fairly normal rate, about one hundred per minute, which is absolutely independent of the auricle, which beats at its own rate. Such a condition is shown in figure 24.

SUMMARY OF ECTOPIC RHYTHMS

We see from this review of the different rhythms that they are fundamentally the same, although giving very different clinical results. That an ectopic rhythm, apparently must occur at a faster rate than normal, to prevent the sino-auricular node breaking in and reëstablishing the normal rhythm. That when the rhythm is once set up it is of constant rate, perhaps as it is not under nervous control. That in the ectopic auricular rhythms we have first a group, *paroxysmal tachycardia*, in which the ventricle follows the auricle. Then a group in which the ventricle is no longer able to keep pace with the auricle, *auricular flutter*, and finally a group in which the rate of impulse formation is so great that the auricle itself cannot contract coördinately, and goes into a state of *fibrillation*. In all of these auricular rhythms, these great variations of rate are not extremely dangerous, as the ventricle can continue to beat at such a rate that it can deliver enough blood to keep up the circulation. When however the rhythm is one in which the new rate controls the ventricle as well as the auricle, the rate at which the rhythm can occur must be such that the ventricle is able to maintain the circulation, that is, a fairly slow rate, and this rate apparently cannot occur without the sino-auricular node breaking in, except in rare conditions, as for instance auricular-ventricular nodal rhythm, and of complete heart block in cases of ectopic ventricular rhythm.

CHAPTER V

Abnormalities of Conduction from Auricle to Ventricle

We have seen that normally the auricular impulse is transmitted from the auricle to the ventricle by the auricular-ventricular bundle in about one-fifth of a second. In cases of poisoning with chemicals, toxic conditions as pneumonia, typhoid, etc., this bundle may be functionally, partially or wholly destroyed. And in other conditions of pressure or destruction by new growths, syphilitic lesions, etc., it may be physically injured or destroyed. Such impairment of conduction delays the conduction of impulses and gives rise to three conditions all of which are different degrees of the condition known as "heart block."

1. Increased conduction time. In the first of these the conduction time is simply increased; instead of being the normal one-fifth of a second it may be increased to two- or three-fifths of a second, but the ventricle follows each auricular beat.

2. Dropped beats or partial block. If however the injury to the bundle is greater, the delay in conduction will be so great that the auricle will beat once or several times to one beat of the ventricle.

3. Complete block, idio-ventricular rhythm. And finally if the bundle is completely destroyed the auricle will beat at its own rate and the ventricle will take on an independent rhythm of its own. The first two of these conditions are self-explanatory. If the conduction time is simply increased the pulse will be of the same rate as the auricle and regular, and the abnormality will be shown by the use of some instrument only. If the ventricle follows each second or third beat of the auricle, the pulse will be slow and regular, while if it follows an irregular number of auricular beats it will be irregular.

When however we have complete block a very distinct clinical picture is found. During the establishment of the independent ventricular rhythm the patient goes through a very trying transition period. He will pass through the first two stages of heart block with no great difficulty, but will then come to a condition in which the ventricle must wait for a very long time before an auricular impulse will pass through the bundle and set it off. At first this may be for six or eight beats of the auricle. The ventricle will become greatly distended with blood and the patient will become conscious of the pause and the forcible beat which will follow. As the block to the passage of impulses becomes more complete, there will be a still longer pause and sometimes it will be as much as ten or fifteen seconds before the ventricle will beat again. During this time the patient will become unconscious but will regain consciousness as soon as the heart begins to beat once more. Such attacks may go on for a very long time before complete block is established, and the ventricle takes up a rhythm of its own. When this does happen the ventricle suddenly begins to beat with great regularity, and at a very slow and characteristic rate, about twenty-four to thirty times per minute. The patient is at once relieved and usually returns to very good health and may go about for many years with often little disturbance. This independent ventricular rhythm, usually called "idio-ventricular rhythm," gives normal ventricular complexes in the electrocardiogram, which means that impulses arise somewhere in the bundle above its bifurcation. Electrocardiograms of these different rhythms are given below.

We have now considered rhythms arising from each of the only areas into which the heart can be divided at present. We have considered the factors which limit their numbers, and it is hoped that from this description the reader will have a true understanding of the rhythms of the heart. This is the main object of this book. The rhythms are

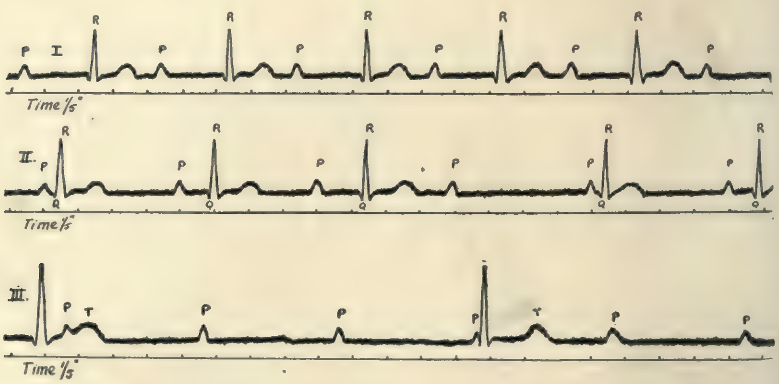


FIG. 25. Curves showing abnormalities of conduction from auricle to ventricle. I. Showing simple increase of conduction time in which each auricular beat is followed after an abnormally long interval by a beat of the ventricle. II. Showing a still greater disturbance of conduction in which one auricular impulse fails to get through to the ventricle and this ventricular beat is dropped. III. Finally a condition where the ventricle is completely cut off from the auricle and the two beat absolutely independently of each other.

extremely simple, and if one will practice constructing rhythms in which beats arise from the different areas, using the limiting factors of regularity of beat, conduction time, refractory period of the ventricle, and rate consistent with life, one can very soon satisfy oneself as to what rhythms can occur, and obtain a working knowledge of the subject, which will allow him to reason out any individual case, rather than to have a few rhythms learned by memory which one tries to apply to the case in hand. A diagrammatic summary of the rhythms is given below.

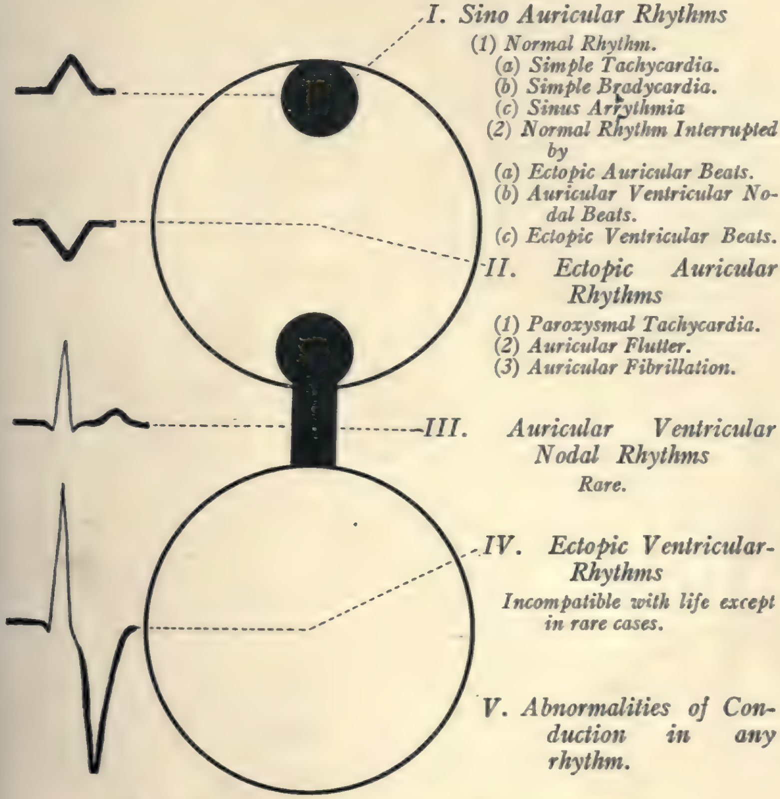


FIG. 26. A diagrammatic summary of the heart rhythms.

PART II

CHAPTER I

Interpretation of the Electrocardiogram

In the first part of this book it was hoped to give the reader a knowledge of the heart rhythms, uncomplicated by the details of diagnostic methods. In this second part the object is to tell him what to expect from the use of the different instruments for recording the heart rhythms. A detailed description of their use is however not attempted. It is assumed that the electrocardiograph gives complete information in each case. It is then merely necessary to point out the usual difficulties in obtaining a satisfactory record. There is however no necessity for a long description of the use of the electrocardiograph. The instrument is somewhat similar to an automobile. Almost anyone can run one, but to obtain a knowledge of its parts takes considerable study. The ordinary student or practitioner cannot afford one of his own but should be able to have an electrocardiogram taken, examine the record himself and confirm the diagnosis given. In order that he will know whether the record has been well taken or not the following few essential points are given.

As the electrocardiogram gives us characteristic complexes for impulses arising from each of the four differentiated areas above mentioned, and shown in figure 15, it is possible to determine at once from such a curve, the rate, regularity, source of impulse formation of both auricular and ventricular beats the length of conduction time, and the interrelation of auricular and ventricular beats. Thus we may obtain *complete* data from an electrocardiogram, and can at once locate the condition with which we are dealing in the above classification of cardiac rhythms.

There are however two conditions which at times offer considerable difficulties in the interpretation of these curves: those in which auricular impulses are not clearly indicated, and other conditions where auricular impulses are obscured by falling in the ventricular complex.

The first of these conditions is often remedied by taking the so-called three leads. If two electrodes are placed at the ends of a bundle of muscle fibers, and the muscle is then

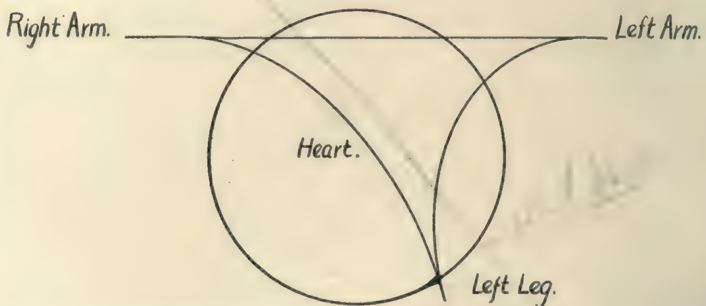


FIG. 27. Showing the different angles at which the lines of electromotive force cross the heart in the so-called "three leads," Lead I—R. A. and L. A. Lead II—R. A. and L. L. Lead III—L. A. and L. L.

made to contract, a much greater deflection of the string of the galvenometer occurs than when the electrodes are placed at the sides of the bundle. In taking an electrocardiogram it is customary to "lead off" the current from either or both hands, or from the right or left hand, and the left leg. It will be seen from figure 27 that in these different leads the lines of electromotive force will cross the heart at different angles. One of the leads may cross the heart at a more advantageous angle than another, so that in case auricular complexes are not clearly seen in one, it is well to try another until a satisfactory result is obtained.

In case the auricular waves are thought to be hidden in the ventricular complexes, these three leads may be used in hopes of depressing a portion of the ventricular curve and bringing out the auricular complexes. If this is not possible a change in rate may be attempted by cautious means (making certain of course that it will not be injurious to the patient). If these means also fail it is well to take a long strip of curve to see if any irregularities occur, in which case the auricular complex may show up between the beats. If the heart remains perfectly regular the chances are very great that the auricle is beating and controlling the rhythm. Whether the auricular impulses are of sinus or ectopic origin can however not be ascertained in that condition. One is then left to judge whether this is the case or not by other means, as the history, symptoms, change from day to day, which of course does not come directly under the heading of interpretation of curves.

The beginner may adopt some such routine examination of curves as the following in order not to overlook anything.

1. Examine the time curve. See if the intervals are equal, in other words whether the paper runs at an even rate. This is important.

2. Locate auricular complexes if possible.

3. Locate ventricular complexes.

4. If auricular complexes are present (they are absent in auricular fibrillation and auricular-ventricular nodal rhythm only) see if they are of normal or ectopic origin, equidistant, or irregular. Note the rate.

5. See if a ventricular complex follows each auricular complex and note the length of conduction time. (The distance between auricular and ventricular complexes.) See if this is normal (about one-fifth second) and if it is constant throughout the curve.

With these data we can determine the rate and rhythm of the auricle and of the ventricle, and the time relation of contraction of one to the other. That is, whether we have a regular auricular rhythm, a gradual variation in rate of auricular rhythm (sinus irregularity) or whether the regular rhythm is suddenly broken. We can tell the same of the ventricle. From the conduction time we can determine the condition of the conduction system. Finally we note the form of complexes, whether of normal or ectopic origin. We then decide which of the five general types of rhythm we are dealing with (sino-auricular, ectopic auricular, auricular-ventricular nodal, ectopic ventricular, or heart block).

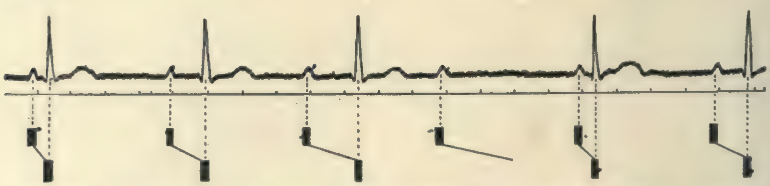


FIG. 28. Diagrammatic scheme for showing auricular and ventricular beats and the conduction time. The upper heavy line represent auricular contraction and the lower ventricular, while the slanting line gives the conduction time.

In complicated cases it may help the beginner to represent the curve diagrammatically. A strip of paper may be laid along the curve as in figure 28 and the time of auricular and ventricular complexes marked off on it in vertical lines. Connect the auricular to ventricular lines by slanting lines as in the figure, and let these represent the conduction time. In this case it is evident that the auricle is beating regularly, that the conduction time gradually increases until one ventricular beat is dropped. This method of diagrammatically representing the beats is much used, and the construction of such a curve may make it more simple to see just what condition we are dealing with in complicated curves.

One other point remains to be spoken of, and that is the form of ventricular complexes. One needs to look at very few electrocardiograms to see that the form of the complexes, especially those of ventricular origin, vary greatly. It is usually simple to tell whether they are of normal or of ectopic origin, but it is not simple to tell just where they arise. By a careful study of these complexes, taken with the different leads, information may be obtained as regards right and left cardiac hypertrophy, lesions of the right and left bundle, the position of the heart, etc. This information although valuable, has nothing to do with cardiac rhythm, and the reader is referred to more advanced books for the study of these problems.

CHAPTER II

The Polygraph, Sphygmograph, and Pulse

Instruments. In studying tracings taken with these instruments we are dealing with curves made by recording the mechanical filling of the vessels by blood pumped from the different heart chambers. It is at once evident that these curves will give only the time of contraction of auricle and ventricle, and not the point of impulse formation as shown in the electrocardiogram (as both a normal and ectopic beat will give an equally good pulse wave). Furthermore the shape of the curves is not characteristic, so that by glancing at a tracing we cannot pick out auricular and ventricular waves. Finally the recording and shape of these curves depends upon the sensitiveness of the apparatus, the skill of the operator in adjusting it, and extraneous factors such as movements of the patient, the apparatus, etc., all of which may cause extra waves in the curves or absence of expected waves. The recording and interpretation of polygraphic tracings will be found to be much more difficult and inexact than the making and interpretation of electrocardiograms.

The most important and helpful point in the interpretation of these curves is to know exactly how many points in the curve can be fixed with certainty, how many more by one's knowledge of heart physiology, and how much must be left to one's judgment. The interpretation of polygraphic tracings is not a complete and exact science. Certain facts can be established, often enough for a complete interpretation, more often however the facts of the curve are not enough to make a diagnosis certain but can be used as a diagnostic aid only.

The instruments in use are of several types but all are based on two principles. In one the radial pulse is taken by means of a small spring which rests on the radial artery. The pulse wave raises the spring, compresses the air in a tambour connected to it, and transmits this wave to a second tambour to which is attached the writing lever.

In the other type an arm cuff is used, which is placed about the arm over the radial artery. This cuff is attached

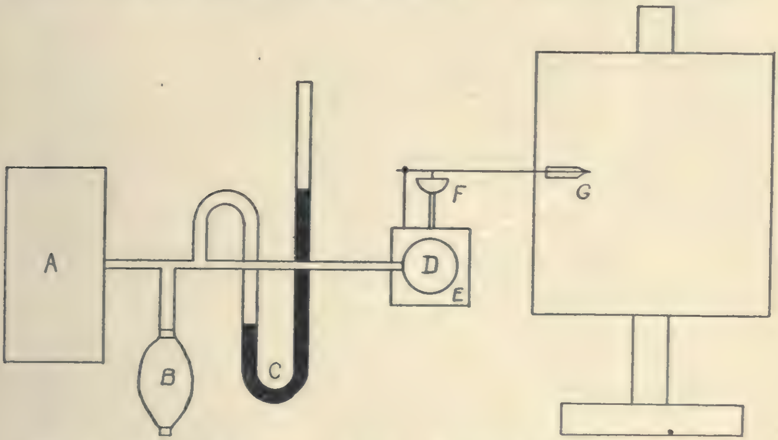


Fig. 29. Diagrammatic scheme of arm cuff method of recording the arterial pulse curve. The letter *a* represents the arm cuff; *b* the bulb to fill it with air; *c* the manometer with which to take the arterial pressure; *d* a rubber ball to take up this heavy pressure; *e* a glass container in which the pulse waves reaching *d* are transmitted to the air at low pressure to the tambour *f*, which records them by means of the lever *g* on the revolving drum.

by a rubber tube, to a recording tambour. On account of the high arterial pressure a bulb is interposed between the cuff and the tambour to take this pressure off the recording tambour as shown in figure 29. In this figure *a* is the arm cuff, *b* the bulb to fill it with air, *c*, the manometer to record the pressure, and *d*, the bulb to take up this pressure. When the cuff is blown up to the proper pressure (somewhere between the diastolic and systolic pressures), each pulse wave causes *d* to expand, compresses the air in *e*, a closed glass chamber connected with the tambour *f* and the writing lever *g*, which records each pulse wave. A mercury manometer is also attached to the instrument, which is useful in taking the blood pressure, but also is of help because the cuff may be blown up until the best arterial pulse is obtained, the pressure recorded, and then the venous tambour arranged. When the time comes to

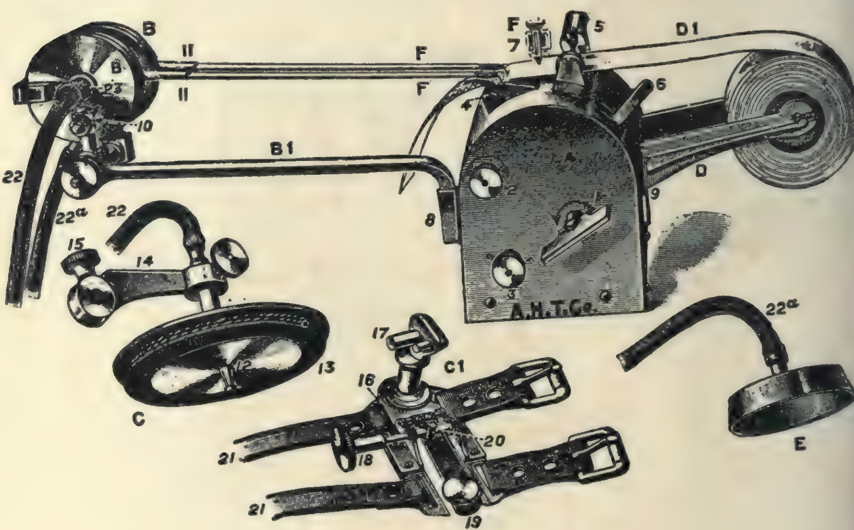


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FIG. 30. The Mackenzie polygraph, with horizontal pens.

make the arterial tracing it is only necessary to blow up the cuff to the pressure noted before, turn on the tambour, and one is sure of obtaining a good radial curve.

The first of these methods requires more time and trouble in adjusting the spring to the pulse. This is often annoying when trying to take a tracing quickly after exercise, etc. The latter method requires no skill in adjustment as the cuff is merely slipped over the arm and blown up. It can be attached at once and gives beautiful records.

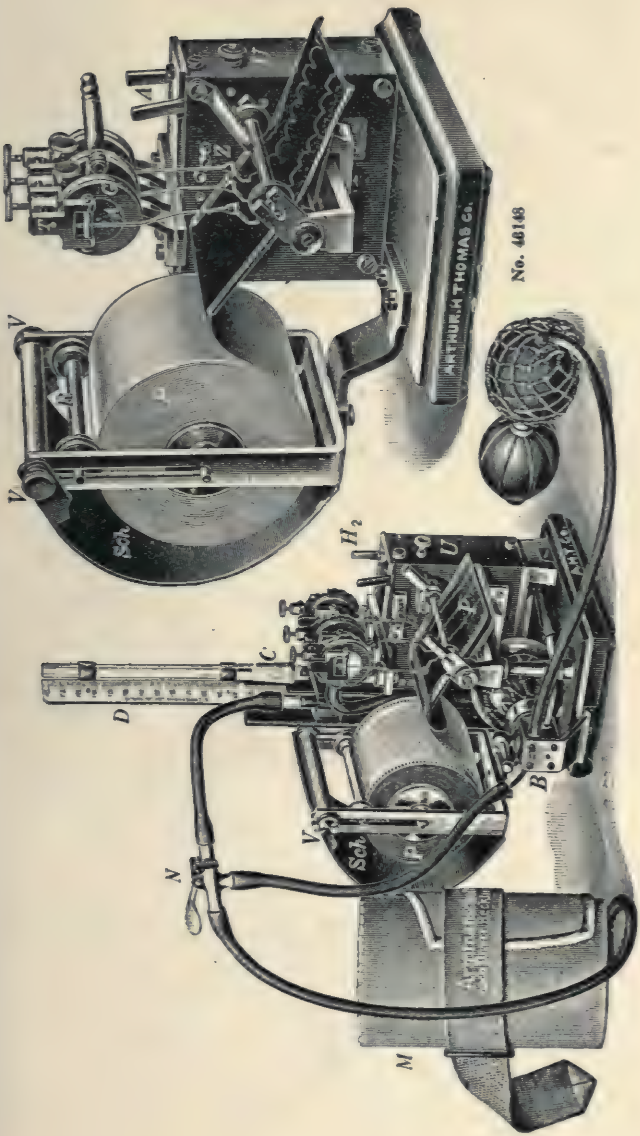


FIG. 31. The Zimmermann polygraph with vertical pens, arm cuff and blood pressure attachment, capable of writing on either smoked paper or with ink. The simplest type of instrument to use, and one giving perfect curves.

The venous pulse is recorded by placing a small glass funnel or other cup receiver, over the veins of the neck. The air is transmitted to a tambour, and writing lever similar to that used with the radial pulse, and described on page 65.

The tambours are all of the same general type, but some use a horizontal, others a vertical pen. The horizontal

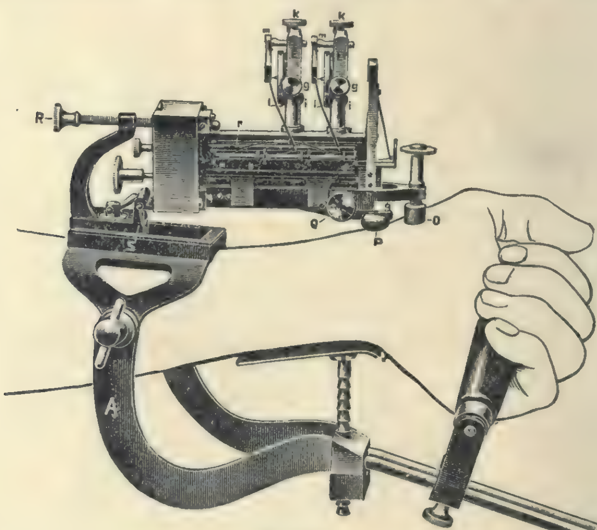


FIG. 32. The Jaquet polygraph, a very beautiful instrument, which is attached to the wrist.

pen is good when one is accustomed to it, but with the beginner it is constantly coming off the paper. With the vertical levers the pens hang on the paper and cannot come off, and when in good condition give excellent curves.

The two types of instrument most often used are the Mackenzie with horizontal pens, which is a beautiful machine and compact, and a newer type the Zimmermann (fig. 31), with arm cuff attachment, vertical pens, and blood pressure attachment. This is by all means the simplest machine as no difficulty is found in obtaining a good radial tracing. The pens cannot come off the paper, and the instrument is so constructed that tracings may be made on rolls of smoked paper, or on plain paper with ink.

Another very beautiful instrument is the Jaquet (fig. 32) which is a delicate little affair which is attached to the wrist. One has to use small strips of smoked paper, and although it is as beautifully built as a watch it is not as convenient for ordinary use.

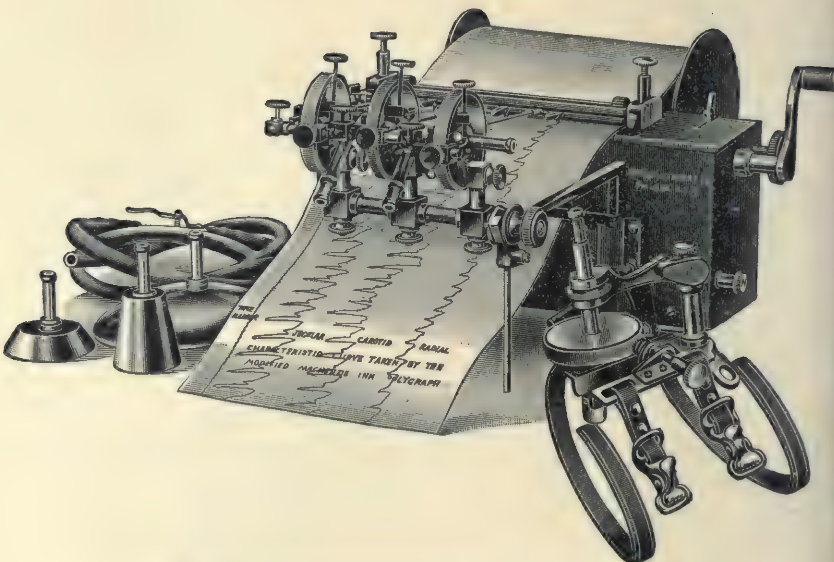
THE RADIAL PULSE

Let us return once more to our original diagram of the heart (fig. 33).

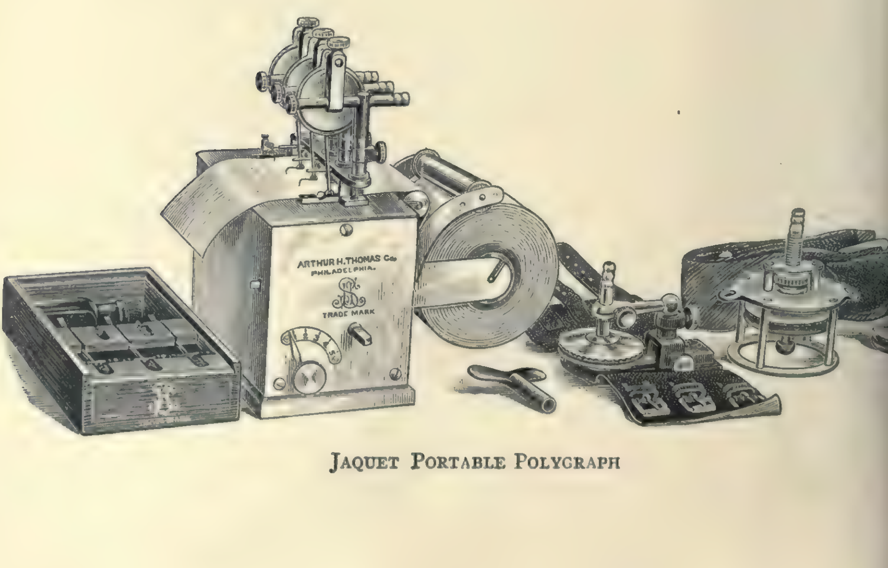
We see that the left ventricle is the only heart chamber which sends blood into the aorta, and consequently all arterial pulses are indices of *left ventricular contraction only.* Any arterial pulse curve (that is radial, brachial, temporal, etc.) will show the following points (fig. 34).

An upstroke (*1*), a sharp apex (*2*), a plateau broken by a notch (*3*), a downstroke reaching normal at (*4*), Let us now see to what causes these various parts of the curve are due.

The upstroke (*1*) is due to ventricular systole, sending a wave of blood down the artery. The end of this upstroke is seen in a sharp point (*2*), which will vary in shape and size with the weight of the lever, the sensitiveness of the tambour used etc. It is not then a constant, *and is of no importance.* The notch (*3*) is the so called dicrotic notch. It occurs at the end of systole at the time when the ventricle relaxes. Various explanations have been given for its origin but we may think of it unscientifically



MACKENZIE INK POLYGRAPH, NEW AMERICAN MODEL



JAQUET PORTABLE POLYGRAPH

as a back kick of the blood when the ventricle stops forcing it into the aorta, and relaxes, the arterial pressure becomes then relatively higher than in the ventricle, and slaps back

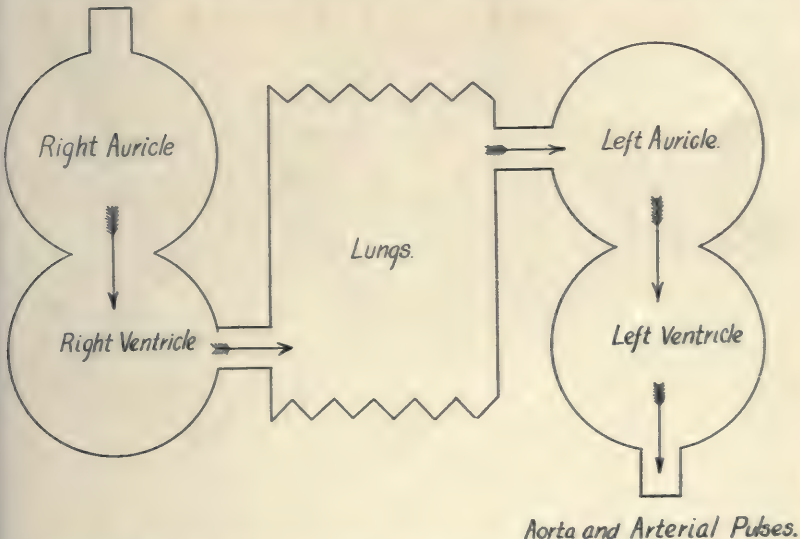


FIG. 33. Same as figure 1. Diagrammatic representation of the origin of the arterial pulse.

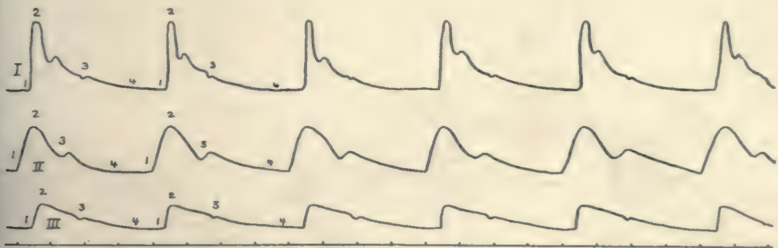


FIG. 34. Same as figure 3. Three types of arterial pulse curves showing the different forms of the curve which are unimportant as long as the beginning of systole (*1*) and the dicrotic notch (*3*), the end of systole, are to be seen.

on the aortic valves. In any case it occurs at the end of systole. The point (*4*) where the curve returns to normal, is a variable, it depends upon how full the arteries are when the pulse wave comes down it, etc. It is of no use to us and should be entirely disregarded.

In the radial pulse curve we have then two points of importance only, everything else may be disregarded. These two points are:

1. The upstroke marking the beginning of ventricular systole.

2. The dicrotic notch, marking the end of ventricular systole.

Curves should be so taken that these two points come out clearly. If they do not the curve is of no use. Whether the rest of the curve is large or small is merely a matter of beauty, but is of no consequence.

THE VENOUS PULSE

In taking a venous curve the patient should lie flat (if possible), with a small pillow under the head in such a position that the sterno-cleido mastoid muscle is relaxed. The receiver is best placed over the lower end of this muscle on the right side, just above and at the inner end of the clavicle. One is tempted to place the receiver higher up where the veins are more prominent, but in most cases this will not give as good a curve. No fixed rule can however be given for this, and the best position will have to be found for each patient.

Having obtained a venous tracing we find a curve in the normal individual, similar to that shown diagrammatically in figure 35. An actual polygraphic tracing is shown in figure 4. The shape of the curve is of no importance, and it varies in each case, and in the same case depending entirely upon the adjustment of the instruments. It is however necessary to know what to look for in these curves, and to take them with the object of bringing out the essential points instead of making a beautiful appearing tracing which may lack the few points necessary for a diagnosis. Nothing very definite can be made out of such a curve. The waves are not of characteristic shape or size, we cannot, therefore, identify any one of them as being due to some particular portion of the cardiac cycle. It is then evident that the venous curve alone is of little

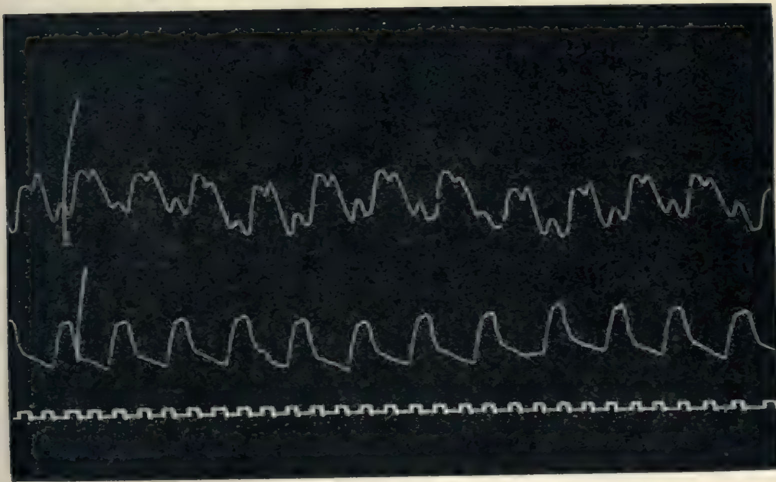


FIG. 35. Same as figure 4. A normal polygraphic tracing showing that the venous curve gives no waves of characteristic shape by which the auricular beats could be distinguished from those of the auricle.

value to us, and before taking up the analysis of such curves let us represent diagrammatically (fig. 36) a cardiac cycle, the heart being shown as having but one auricle and one ventricle, and the great veins as a tube entering the auricle from above.

If one uses the imagination a trifle it may be possible to make out from this series of figures the sequence of events taking place in the auricle and ventricle, and the cause of the different venous and radial pulses.

At (*1*) both auricle and ventricle are partially filled with blood. At (*2*) the auricle contracts, as indicated by the heavy outline, and forces its blood into the ventricle, distending the latter. This contraction of the auricle is accompanied by a back wave up the vein, and a rise in the

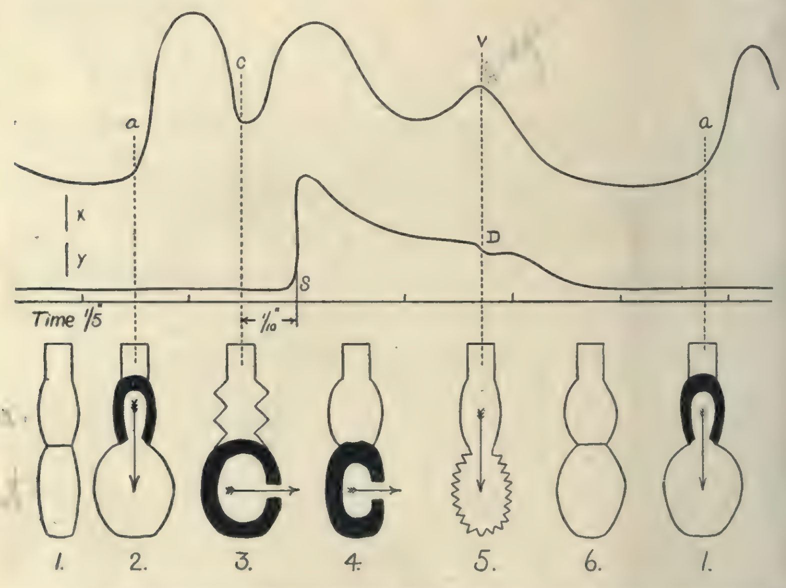


Fig. 36. Diagrammatic scheme showing the cause of the venous and arterial pulse waves. At (*1*) both auricle and ventricle are partially filled with blood. At (*2*) the auricle contracts as shown by its heavy outline, and forces blood into the ventricle, distending it. At the same time it sends a wave up the veins to the neck and causes a rise in the venous curve, the *a* wave. At (*3*) the auricle relaxes as shown by the irregular outline and the ventricle contracts and drives the blood out into the aorta. This contraction causes a wave in the venous curve, the *c* wave at the beinning of systole. The ventricular pulse wave does not reach the wrist until one-tenth of a second after the corresponding wave in the neck, due to the time taken to travel there. At (*4*) the ventricle is still contracting and the auricle filling with blood. This causes backing up of blood in the veins and a rise in the venous curve. At (*5*) the ventricle relaxes, end of systole, and the blood falls from the auricle into the ventricle causing a sharp drop in the venous curve, the *v* wave (really a drop in the curve). At the same time the dicrotic notch occurs in the arterial pulse. At (*6*) both the auricle and ventricle are passively filling with blood, and at (*1*) the cycle is begun again by contraction of the auricle.

venous curve at (*a*). The letter (*a*) is used in these curves to denote auricular waves. It is placed at the ***upstroke*** of the waves as are all polygraphic measurements, as the end of the upswing depends, as before stated upon the sensitiveness of the writing lever, etc., and is not constant. The auricle immediately relaxes as indicated by the irregular outline in (*3*), and blood runs into it from the great veins causing a fall in the venous curve. At (*3*) the ventricle contracts and forces blood out into the aorta as indicated by the arrow. Simultaneously with this contraction there is an upstroke in the venous curve (*c*). The letter *c* was first used to denote carotid pulse. It was formerly thought that the curve *c* was due to the receiver being held over the carotid artery, but experiments in dogs with no carotid artery give this same wave, so that it may be due to a back wave up through the auricle to the vein.

One-tenth of a second later the upstroke at *s* occurs in the radial tracing, this delay being due to the time taken by the pulse wave to travel from the heart to the radial artery. The reference (*4*) shows another stage in the middle of ventricular systole. It will be noticed here that during systole no blood can pass from auricle to ventricle, therefore the auricle fills up, and as it fills blood gradually backs up in the veins above it depending upon conditions in the general circulation. On this account the venous curve after the quick up and down wave due to systole of the ventricle, will gradually rise to the point *v*. This rise may be small or if the veins are very full it may be a sharped peaked curve. It is important to remember this as one is otherwise often puzzled by the variations in this wave.

At (*5*) the ventricle relaxes (end of ventricular systole) as shown by the irregular line. As it does so the pressure within it falls, and the accumulated blood in the auricle rushes down into the empty ventricle, not from a contraction of the auricle, but merely on account of the blood there being at a higher pressure than in the empty ventricle. This is accompanied by a sudden drop in the venous curve denoted by *v* (ventricular wave). One often speaks of the *a*, *c*, and *v waves.* At *v* we really have a drop in the venous curve, not an up wave. On account of the filling of the veins during ventricular contraction the venous curve may rise giving a sharp peak just before *v*, but at this point the curve should show a sudden fall. At the same time (not one-tenth of a second later) the dicrotic notch occurs in the radial tracing.

The ventricle and auricle then both gradually fill, and the cycle is repeated.

One should practice drawing a complete set of diagrams for oneself until he is familiar with the course of events in a cardiac cycle as there is no use in attempting to interpret polygraphic curves without understanding this completely.

From a study of the above curves it will be seen that we can fix four points with certainty. These are,

1. Beginning of ventricular systole in the radial curve (upstroke *S*).

2. End of systole in the radial curve (dicrotic notch *d*).

3. The beginning of systole may be plotted onto the venous curve by marking a point one tenth of a second earlier in the venous curve (upstroke *c*).

4. The end of systole may be plotted on the venous curve by measuring up directly from the dicrotic notch. This gives (*v*) at the beginning of the downstroke of the wave.

In this figure the pens for both curves are writing directly over each other, as shown by the ordinates *x* and *y*, lines made by moving each pen on the paper to record their relative positions. In all curves these ordinates are necessary and all measurements are made from them. For example in this curve with the pens directly over each other, the point *v* is over *d*. If however the pen for the venous curve were not directly over the arterial pen, *v* would not come over *d*. In order to plot *d* onto the venous curve, its distance from *y* would be measured, this distance would then be laid off from *x* along the venous curve and *v* fixed. These ordinates must be given with each tracing or it is of no use.

No other points can be fixed. With polygraphic tracings we are then able to fix the beginning and end of systole in the radial curve, and have an exact method for determining the rate and rhythm of the left ventricle if all the beats are transmitted to the wrist. In many cases however of weak and irregular hearts the small premature beats send too small a pulse wave to be felt or recorded at the wrist, and one of the first things which must be done in polygraphic tracings is to compare the radial pulse with the cardiac impulse or heart sounds to determine if any beats fail to reach the wrist.

In the normal venous pulse curve there are three waves in each cycle, and we are able to fix two of these from plotting them from the radial curve, namely the beginning and end of systole. The third wave in the cycle should be due to contraction of the auricle, *but we have no way of fixing it.* From our knowledge of heart physiology however we have two points which help us to decide about these auricular waves, one is that:

1. Auricular waves occur at *regular* intervals. The two exceptions being a gradual variation in rate due to sinus arrhythmia, or to a sudden break in the rhythm due to premature ectopic beats.

2. Auricular waves occur normally about one-fifth of a second before the carotid waves.

If then we are given a polygraphic curve to interpret we first fix the beginning and end of systole on the radial curve, plot these points onto the venous curve with exactness marking each of them regardless of where they fall, mark them *c*, and *v*, and then plot points one fifth of a second before the *c* points and mark these with a ? mark. These are the only possible points which one can *fix*, and the interpretation must be made from them.

Next one should see if waves occur at the points where the *a* waves are to be expected. If they do, mark them with *a* if no other waves are left unaccounted for one is then in possession of sufficient data to make a diagnosis. If however other waves occur in the venous pulse which cannot be accounted for by the fixing of the above points, the only things which other waves can be are auricular waves or artefacts, or if the *a* waves occur slightly out of place, or some or all of them are absent the only way to make a diagnosis is to plot out just what we really have, and then see with which one of our known cardiac rhythms this best agrees. It is self evident that without a complete knowledge of *all* cardiac rhythms it is useless to try and make a diagnosis by exclusion.

Let us take one or two curves as examples.

Before taking a tracing each pen should be swung back and forth to give the ordinates *x* and *y*, their relative positions on the paper, as described above. If they are so arranged that they are just over each other, then the points on the radial curve can be plotted vertically onto the venous curve, if however they are not over each other as is usually the case, the points on the radial curve may be transferred to the venous curve by taking a strip of paper laying it along the radial curve, marking the ordinate *x* and the points *s* and *d* of each pulse curve. Then by laying this paper on the venous curve with the ordinate *x* on the ordinate *y* the points *s* and *d* may be marked off onto the venous curve and given their proper lettering *c* and *v*. *The c points will however all be moved back (towards the ordinate) one-tenth of a second to allow for the time taken for the pulse wave to reach the wrist as already described.*

One should then measure the time intervals as recorded by the time marker and notice if they are all equidistant,

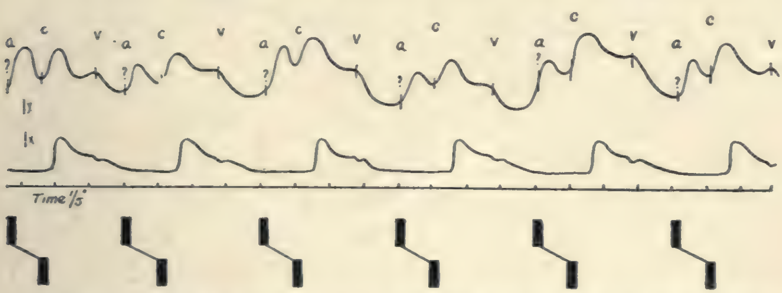


FIG. 37. A normal polygraphic curve, showing the plotting of the beginning and end of systole onto the venous curve, the *c* and *v* points, and the probable location of the auricular waves at points one fifth of a second before the *c* waves. These are the only points which we can fix in the polygraphic curves.

in order to tell if the paper is running evenly. Slight variations in the rate of movement of the paper often give very confusing curves if this is not checked up.

Next we mark off points one-fifth of a second before the *c* points, which is easily done as the time intervals in most polygraphs is one-fifth of a second. These points are marked with a ? mark. We have now fixed all the points which we can and we are ready to interpret the curve.

At the points *c* we should have an up wave in the curve, due to the carotid beat, and at the points *v*, there should be a decided fall in the curve, for the reasons described above.

At the points marked with the ? we should expect to find upward curves which are the auricular beats. In the curve under examination we find that all these factors occur as we expect and that *there are no other waves which are unaccounted for*, the *a-c* interval or conduction time is normal and we may then feel quite certain that we are dealing with a normally beating heart.

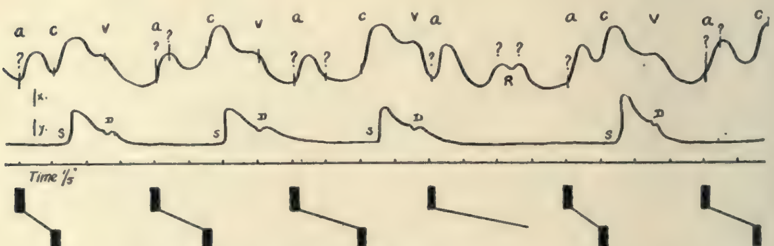


FIG. 38. Another illustrative curve showing the location of the *c* and *v* waves and the marking of the points where the *a* waves should normally come, one-fifth of a second before the *c* waves. It is found that waves occur in the venous tracing near the normal points for the *a* waves but not exactly at these points. These waves are however equidistant from one another, and all but one are followed by a ventricular beat. The curve would show a gradual increase of conduction time with a dropped ventricular beat after the fourth auricular beat if it were not for the two waves at *r*. It has already been found that all ventricular beats are transmitted to the wrist, so that these cannot be ventricular beats, they are out of time for auricular beats and they are not followed in the radial curve by ventricular beats, so that they are neither auricular or ventricular beats and must be due to some mechanical movement of either the patient or the instrument.

If however we have a curve as shown in figure 38, complications will arise.

Here again we examine the time marker, measure off the points *s* and *d* on the radial curve, plot these from the ordinates onto the venous curve, remembering that the point *c* will come one tenth of a second before *s*. Mark points one fifth of a second before the *c* points on the venous curve with ? marks, and then examine the curve.

In the first place we find that the ventricular radial beats are not regular. We know that there are several causes of ventricular irregularity but the one which it is important to think of at once is whether there is absolute irregularity, that is auricular fibrillation. If this condition is present there will be no auricular waves. Examining the curve for auricular waves which should fall in a normal heart at the points marked with a ?, we find that there is a wave at the first mark, and a small wave near each of the others except next to the last one where the curve is very irregular. If one now starts with the first of these waves which are thought to be auricular waves and tests their *regularity* by measuring the distance between them it will be found that they are all equidistant and that there is one wave falling in the right interval which is not followed by a ventricular wave. If one measures the distance from the beginning of each of these waves to the point *c* (the *a-c* distance) representing conduction time from auricle to ventricle, it will be found that it gradually increases up to the one which is not followed by a ventricular beat, and that the next auricular wave which is followed by a ventricular beat is of the original *a-c* distance. We have then a gradually increasing *a-c* distance, or a lengthened time of conduction, and in one instance a dropped ventricular beat, in other words we are dealing with a case of partial heart block.

We now examine the curve and see if anything remains unaccounted for, and we find a double curve in the venous tracing at *r*, which we have not yet accounted for. This must be either an auricular or ventricular beat or an artefact. The wave at *r*, is not followed or accompanied by a ventricular beat, each apex beat is transmitted to the wrist, it does not come at the regular auricular time; it is therefore neither a ventricular or auricular beat but must be due to some mechanical disturbance of the levers, as coughing, moving, etc.

Each curve must be worked out in some such systematic way as this. The important points to remember are to first see that the time marker is running evenly, then fix the beginning and end of systole in both the radial and venous curve, and lay off the points where the auricular beats should arise; having done this next look for auricular waves which should be equidistant except where there is a gradual variation in their rate due to sinus arrhythmia, or a decided and abrupt change due to premature beats.

A review of these different methods of recording the heart rhythms shows us that the electrocardiograph gives us complete information. It is merely necessary to take a curve, plot out the auricular and ventricular beats, their time relations to each other, and the points of origin of the impulses and one will be able to locate the rhythm in its proper place in our classification. With the polygraph our information is always incomplete. We may be able to tell the time relations of the auricular and ventricular beats, but we cannot tell the point of origin of impulses directly. For instance it is impossible by the tracing alone to distinguish between the ectopic-auricular beats of paroxysmal tachycardia, and the normal auricular beats of a rapidly beating heart. It is on this account that it is essential to have a complete knowledge of the heart rhythms to interpret a polygraphic or sphygmographic curve. In order to aid one in getting a clear picture of all these different rhythms the following diagrammatic curves of each type of heart rhythm are given. The polygraphic curve is given and below it the auricular and ventricular beats plotted out in a diagrammatic scheme. As such curves give also the sphygmographic tracings one can use the same curves in discussing this instrument, and the arterial pulse.

CHAPTER III

Polygraphic Curves

I. SINO-AURICULAR RHYTHMS

a. Normal heart beat. This has been taken up so often before that it is unnecessary to repeat the curve, it is important to remember however that the auricular beats occur at regular intervals, that they are followed in one-fifth of a second by the ventricular beats, and that in plotting the beginning of ventricular systole onto the venous curve the point *c* will come one-tenth of a second earlier in the venous curve, while the point *v* is plotted up directly from the dicrotic notch, finally to remember to plot all points from the ordinates *x* and *y*.

b. Simple tachycardia. Here there is an increased auricular rate, the conduction time will remain normal, the increase in rate will be found to be due to shortening of the diastolic interval. The rhythm will be regular.

c. Simple bradycardia. The slow heart rate is here arrived at by a lengthened diastolic period, but the conduction time will be found to be normal. The rhythm is regular.

d. Sinus-arrhythmia. Here the rate of auricular beats undergoes a gradual variation due to direct chemical or nervous stimulation of the sino-auricular node. The change in rate will always be found to occur gradually, no sudden break ever occurring. Such a rhythm is shown in figure 39 and it is seen that the gradual variation in rate is due to changes in rate of the auricular beats. The conduction time is normal and the pulse curve shows a gradual change in rate.

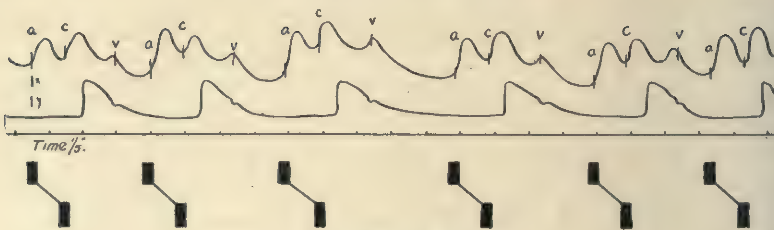


FIG. 39. Sinus arrhythmia.

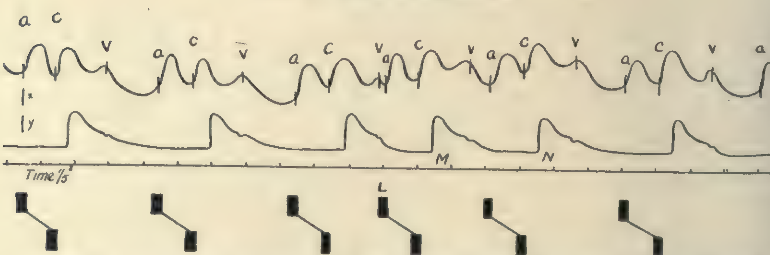


FIG. 40. Ectopic-auricular beat. This occurs prematurely and is followed by a normal auricular beat which occurs also in a shorter interval than normal. The normal rhythm is then interrupted by *two* beats.

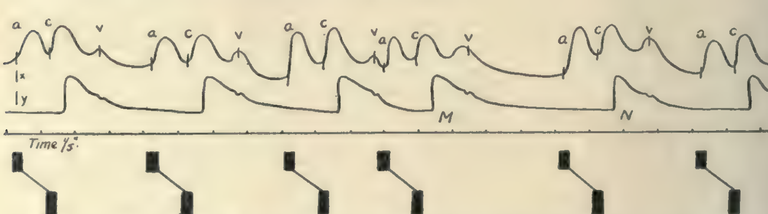


FIG. 41. This is another curve of a premature ectopic-auricular beat which is followed by the normal auricular beat in such a time that the regular rhythm is broken only by the one premature beat.

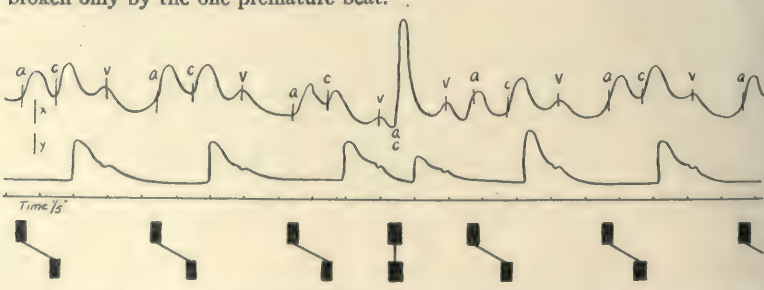


FIG. 42. Curve of an ectopic auricular-ventricular nodal beat, which occurs prematurely and is followed in such time by the normal auricular beat that the normal rhythm is interrupted by two beats.

II. ECTOPIC BEATS INTERRUPTING NORMAL RHYTHMS

a. Ectopic-auricular beats. In all of these ectopic beats we have a normal regular rhythm interrupted by single or multiple beats of ectopic origin. It will be noticed that there are never any *extra* beats but that a beat occurs *prematurely*. Such a beat is shown in figure 40 and 42.

The normal point of origin of impulses is the sino-auricular node the auricle beating first and the ventricle following it, we therefore always *look at the auricular beat first*, and work out the rhythm from it. Here we see that we have a regularly beating auricle interrupted at *L* by an auricular beat coming prematurely, this is followed in a shorter time than the regular auricular rhythm by another auricular beat and then the regular auricular rhythm is again established at the original rate.

Each auricular beat is followed in the normal time by a ventricular beat so that the radial curve shows the same irregularity as the auricular rhythm. *Two beats are out of time.* This is due to the premature beat and to the normal auricular beat following, occurring also prematurely. All of this is easily seen in the polygraphic curve but it is important to compare the two radial beats which are out of time with the one beat which we will find out of time in the radial tracing, when we have an ectopic beat of other origin.

In figure 41, however a curve is given in which we have an ectopic-auricular beat the same as in the above curve, in which the auricular beat following the premature one comes in the normal auricular interval. In this case only one auricular and one ventricular beat is out of time and it cannot be distinguished from the ectopic beats of other origin.

b. Ectopic auricular-ventricular nodal beats. An ectopic beat of auricular-ventricular nodal origin is shown in figure 42. Here the regular rhythm is interrupted by a premature beat arising from the auricular-ventricular node. Both the auricle and ventricle beat at once. This is shown by the abnormally large venous wave occurring at the time of ventricular contraction while the radial pulse wave is if anything smaller than normal. The next auricular beat from the sino-auricular node may occur as in the case of the ectopic-auricular beat, either slightly earlier than normal or in the normal time, in which case there may be either one or two beats out of time in the radial curve.

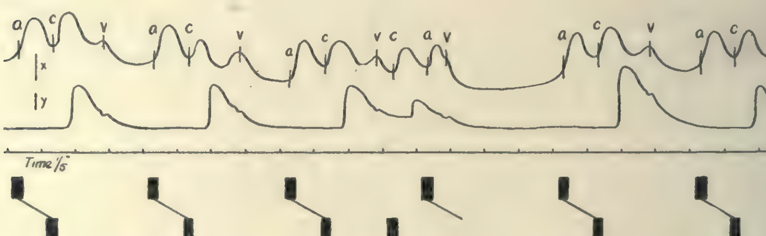


FIG. 43. Ectopic-ventricular beat. Here the rhythm is interrupted by the premature ectopic-ventricular beat only. The next auricular beat falls in the refractory period of the ventricle and this fails to respond but does so to the next auricular beat.

c. *Ectopic-ventricular beats.* In this condition there is no abnormality of the sino-auricular node therefore we will find a regularly beating auricle. Each auricular beat will be followed by a ventricular beat in the normal time until we have one ventricular beat occurring prematurely as shown in figure 43. When the next auricular impulse comes to the ventricle it finds it in the refractory state and it cannot contract, so that this auricular beat will not be followed by a ventricular beat, but the next auricular impulse finds the ventricle again ready for contraction, and it is followed by a ventricular beat. We have then *only one* interruption to the normal rhythm, and that is the single premature ventricular beat.

This rather lengthy description is given to enable one to differentiate by means of the sphygmograph alone an ectopic-auricular from an ectopic-ventricular beat. It will however be seen that the auricular and auricular-ventricular nodal beats may both give a single interruption to the regular rhythm which is exactly similar to the interruption caused by a premature ventricular beat. The only diagnostic point of any value is then, that if the regular rhythm is interrupted by two beats in succession the ectopic beat is not of ventricular origin but of either ectopic-auricular or auricular-ventricular nodal origin. The origin of any ectopic beat may however be determined by the use of the electrocardiograph.

III. ECTOPIC-AURICULAR RHYTHMS

a. Paroxysmal tachycardia. Here we have a very fast regular rhythm of ectopic origin, all of the auricular beats arising from an ectopic focus in the auricle. They are followed in the normal or slightly reduced conduction time by normal ventricular beats. The polygraphic curves can in no way be distinguished from a fast beating normal heart, as the auricular beats arise at regular intervals, and each is followed by a ventricular beat. Such a curve is shown in figure 44.

b. Auricular flutter. In this condition the auricle is contracting at regular intervals and at such a fast rate that it is impossible for the ventricle to follow it. Two conditions may then result as shown in figures 45 and 46. In the first the ventricle may follow a regular number of auricular beats giving a regular pulse which may be of fairly normal

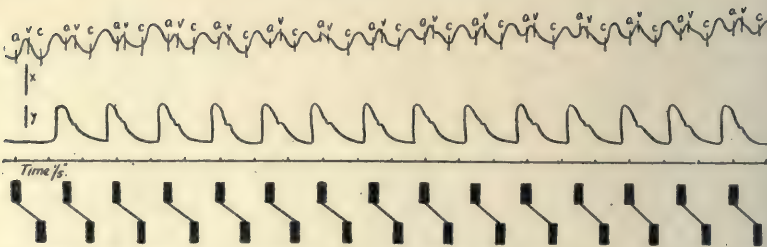


FIG. 44. Curve of paroxysmal tachycardia which will be seen to be indistinguishable from a rapid normal rhythm.

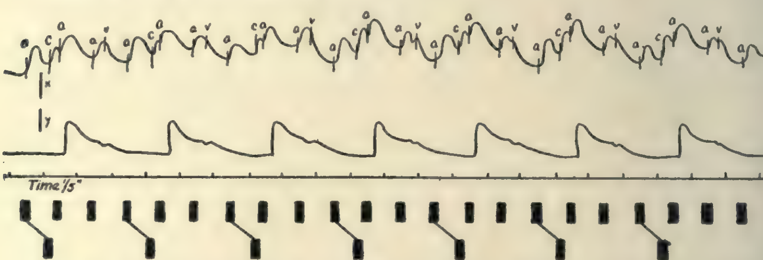


FIG. 45. Curve of auricular flutter. The ventricle follows a regular number of auricular beats and gives a regular slow ventricular pulse.

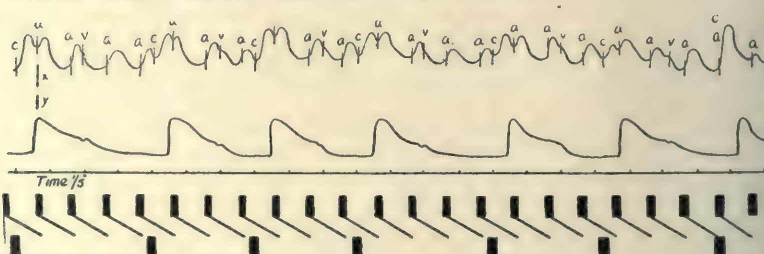


FIG. 46. Auricular flutter in which the ventricle follows an irregular number of auricular beats and is very irregular.

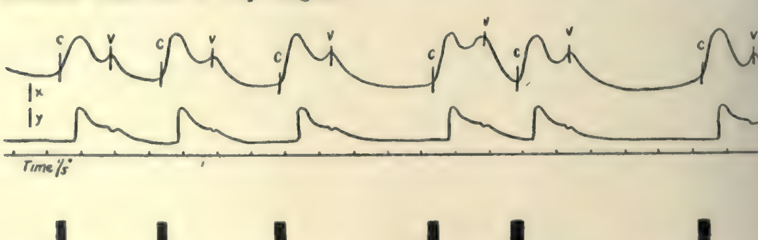


FIG. 47. Curve of auricular fibrillation in which no auricular waves are seen, and the ventricle beats absolutely irregularly.

rate. In the second condition the ventricle follows an irregular number of auricular beats and will then show all manners of irregularity. Sometimes pulses can be made out in which the ventricular beats occur in groups following first three, then four auricular beats. If such *regular* groupings occur in the radial pulse one feels that there must be a controlling factor; that there must be a beating auricle, and that the ventricular rhythm must be due either to a condition of auricular flutter, or to heart block, which will be taken up later, the principle being the same however, the ventricle following first one number and then another of auricular beats. In flutter this irregular beat of the ventricle is due to its being unable to maintain the auricular rate, while in the case of heart block the conduction is so poor that all auricular impulses do not reach the ventricle.

c. Auricular fibrillation. In this condition there is no coördinate contraction of the auricle, no auricular waves can therefore be made out. The venous curve will show simply *c* and *v* waves due to the beginning and end of ventricular systole. As there is no regular auricular rhythm but a very irregular auricular impulse formation the ventricle will respond to only those irregular impulses which reach it and its rhythm will be one of *absolute irregularity*. Such a curve is shown in figure 47.

IV. AURICULAR-VENTRICULAR NODAL RHYTHM

This is an exceedingly rare condition. The impulse for contraction arises at the auricular-ventricular node and is transmitted to the auricle and ventricle in the same length of time so that the auricle and ventricle beat simultaneously. In such a case the *a* and *c* waves would occur at the same time and make one wave, no separate *a* waves would appear, and the venous curve would consist only of the combined *a* and *c* wave and the *v* wave. The rhythm would be regular as all uninterrupted rhythms are, and therefore we would have a regular arterial pulse. The simultaneous beat of the auricle and ventricle give an abnormally high and sharp wave occurring at the beginning of ventricular systole, while the arterial pulse wave is of the normal size as shown in figure 48. The diagnosis of this condition has to be made with caution, if the polygraph alone is used. It is based on having a regular rhythm, no auricular com-

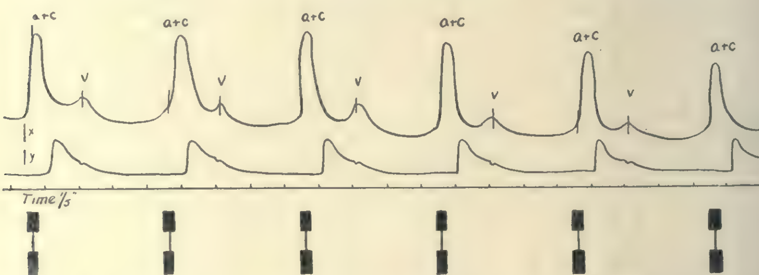


FIG. 48. Curve of auricular-ventricular nodal rhythm, in which the ventricle beats regularly and gives an abnormally high *c* wave in the venous curve. No auricular waves are visible. Care should be taken in making a diagnosis of auricular-ventricular nodal rhythm from such a curve alone, as a very similar curve may be obtained by placing the venous receiver over the carotid artery and missing the venous curve altogether in a normally beating heart.

plexes, and an unusually high *c* wave. But one can see that it is perfectly possible to place the venous receiver on the neck in such a way that one will be able to record carotid beats and not record the venous pulse at all, in which case of course no auricular beats could be seen. The condition is so rare that one will hardly ever see it, and most all cases in which a regular ventricular venous pulse is found with no signs of auricular waves, will be found, if an electrocardiogram is taken, to be due to the manner in which the venous curve was taken. In fact in the hands of the beginner more than half of the tracings taken will be found to consist of nothing but the carotid pulse instead of the venous curve.

V. ECTOPIC-VENTRICULAR RHYTHMS

We have seen that if runs of ectopic beats arise in the ventricle they must be rapid or the auricle breaks in and the normal rhythm is set up again. On the other hand if the run of ectopic beats is rapid and prolonged the circulation fails and the patient becomes unconscious and dies. There is then a very narrow limit of rates within which it is possible to have ventricular rhythms compatible with life, and we may from a practical point of view consider that they do not occur. They are theoretically possible however.

VI. ABNORMALITIES OF CONDUCTION FROM AURICLE TO VENTRICLE

a. Prolonged conduction time. In certain conditions of toxic poisoning, or pressure, the conduction from auricle to ventricle is impaired and it takes the impulse more than the customary one-fifth of a second to pass from auricle to ventricle. If this lengthened conduction time is not too great the ventricle will still follow each auricular beat, and the curve will show no changes from the normal except an increased *a–c* interval. Such a curve is given in figure 49. The arterial pulse will be perfectly regular and no abnormality can be made out without the venous tracing being taken.

b. Dropped beats or partial block. If the impairment of conduction increases so that all auricular impulses are not transmitted to the ventricle it will be found that every once in awhile one ventricular impulse will be dropped, as shown in figure 50.

Polygraphic tracings give us complete information in such cases as the auricular and ventricular waves are both shown, and the conduction time may be measured. The arterial pulse may however be very deceptive. The gradual increase in conduction time makes a slight lengthening of time between the arterial beats, and an interval where the beat is dropped. Single beats are easily recognized by

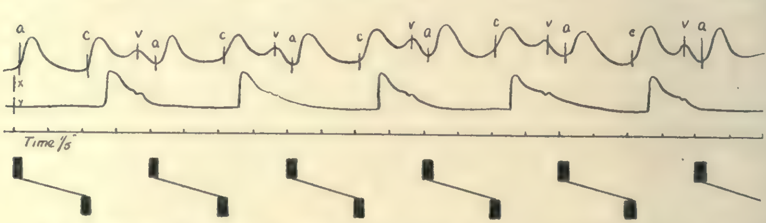


FIG. 49. This shows a simple prolongation of the conduction time but each auricular beat being followed by a ventricular beat.

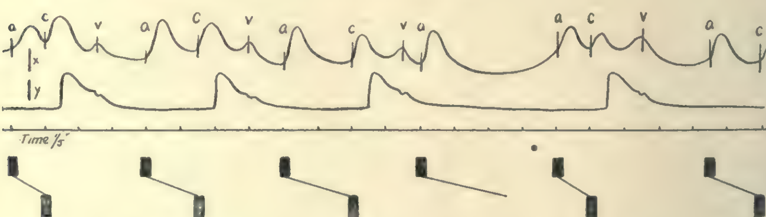


FIG. 50. In this curve the conduction time is prolonged after each of the first three beats until the fourth, where the auricular impulse does not reach the ventricle and one ventricular beat is dropped. The next auricular beat passes to the ventricle and the cycle is repeated.

these factors. Where beats are dropped at regular or recurrent intervals the condition may be made out from the radial pulse alone. For instance if each fourth beat is dropped, one will find a gradual lengthening of the interval between beats, and then a dropped beat, the sequence of events being repeated regularly. Or one may find a gradual increasing distance between the radial beats, and then a dropped beat occurring after first three and then four auricular beats alternately. But when the ventricle follows no regular number of auricular beats, the pulse curve loses all signs of regularity and the condition cannot be told by the arterial pulse alone from the absolute irregularity of auricular fibrillation or of multiple ectopic beats.

c. Complete block. Finally we have a condition of complete block, which has been described above in which no auricular beat can reach the ventricle and the ventricle takes on a rhythm of its own, known as an idio-ventricular rhythm. This rhythm is characteristic, as no other condition (except in cases of poisoning) gives such a slow ven-

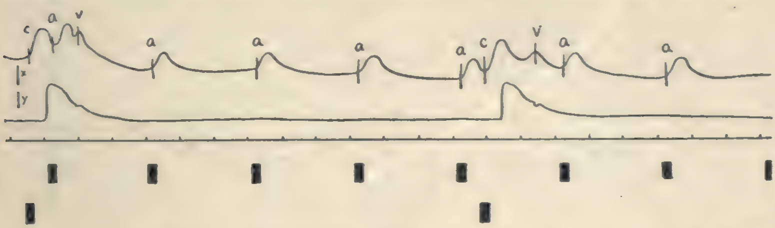


FIG. 51. This curve shows a condition of complete block in which the auricle and ventricle beat absolutely independently of each other. The ventricular rate is characteristic of this condition being a little over twenty per minute.

tricular rate. It is usually between twenty-four and thirty beats per minute, but may be higher. A curve of such a condition is shown in figure 51. Auricular waves are shown occurring at regular intervals, and bearing no relation to the ventricular beats which occur at long and perfectly regular intervals.

SUMMARY OF POLYGRAPHIC RHYTHMS

If we summarize this review of the polygraphic tracings we find that it is possible to make the following diagnoses with this instrument.

Sino-auricular rhythms. Complete information can be obtained of all these rhythms but a simple tachycardia cannot be distinguished from paroxysmal tachycardia by the tracing alone.

Ectopic beats. These may all be recognized, and the origin of the ectopic beat located, that is whether it is auricular, auricular-ventricular nodal, or ventricular.

Auricular-ventricular nodal rhythms. These cannot be proven to occur as the diagnosis is based on the absence of auricular waves, and abnormally large *c* waves, both of which factors may be obtained in a poorly taken normal rhythm in which the venous receiver is placed over the carotid artery and no venous pulse is recorded. The condition is extremely rare.

ECTOPIC-AURICULAR RHYTHMS

Paroxysmal tachycardia. This cannot be differentiated from simple tachycardia by this instrument alone.

Auricular flutter. This may give very beautiful auricular waves, and an even better picture than the electrocardiogram. Sometimes however the waves are very hard to obtain.

Auricular fibrillation. In this condition no auricular waves occur and the ventricle beats with absolute irregularity. One is never certain that the absence of auricular waves in the curve is not due to the technique of taking the tracing. The other two possibilities are multiple ectopic beats, and irregular heart block. These of course would be shown in the venous curve if one were sure that the venous curve were being taken, but it is surprising in how many cases the beginner is unable to obtain anything but a carotid tracing instead of the venous curve.

HEART BLOCK

All stages of heart block may be shown perfectly by polygraphic tracings.

SUMMARY OF SPHYGMOGRAPHIC TRACINGS

Sphygmographic tracings give us graphically the same information which we can obtain by feeling the pulse. Our information is very limited, and unless it is combined with other clinical signs and symptoms is of limited use, but with a good knowledge of the heart rhythms, and a clear picture of the clinical conditions associated with each, which one can obtain by experience only, the pulse will be found to be of great diagnostic aid. It gives of course only ventricular beats.

All regular rhythms cannot be differentiated except by their rate. Such rhythms are the normal beat, simple tachycardia, simple bradycardia, paroxysmal tachycardia, auricular flutter, in which the ventricle follows a regular number of auricular beats, auricular-ventricular nodal rhythm, and heart block in which the ventricle follows a regular number of auricular beats.

Sinus arrhythmia may be easily recognized by the gradual variation in distance between the individual beats.

Ectopic beats if occurring singly may be recognized as such. The normal rhythm is interrupted by *one* beat occurring prematurely, and sometimes a second one, the only break in the regular rhythm any of the three types of ectopic beats, namely ectopic-auricular, auricular-ventricular nodal, or ectopic-ventricular, may give the same picture. If however the premature beat is followed by a second beat at an interval shorter than the normal period, and the regular rhythm then restored, we know that the ectopic beat is *not* of ventricular origin. It may be an ectopic-auricular or an auricular-ventricular nodal beat, but the two cannot be differentiated.

Absolute arrhythmia is always associated with fibrillation but it may occur in multiple ectopic beats, or irregular heart block.

Periods of regular beats may occur in partial heart block, but also in runs of ectopic beats.

CONSTRUCTION OF DIAGRAMMATIC CURVES

In conclusion a method of construction of these diagrammatic curves is given as a help to those who wish to plot out the rhythms for themselves. Such a scheme is given in figure 52.

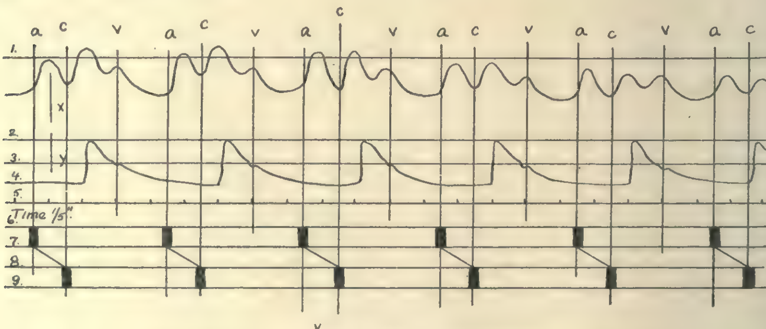


FIG. 52. Diagrammatic method of constructing polygraphic curves which will be found described in the text.

One saves a great deal of time by using a drawing board and T-square. First the nine parallel construction lines are ruled off in pencil. The first one for the plotting of the venous curve, the second for the top of the arterial pulse curve, the third for the dicrotic notch in this curve, the fourth as a base line for the same curve, the fifth for the time marker, the sixth and seventh for the top and bottom of the auricular diagram, and the eighth and ninth for the top and bottom for the ventricular diagram.

Time intervals are laid off along the time marker line at regular intervals. One-half inch for each fifth of a second will give a convenient working scale. One can calculate quickly the intervals at which to put the auricular beats for any given rate by deciding how many to put in a three second interval, this number multiplied by twenty will give the rate per minute. For instance three, a rate of sixty, four, one of eighty, etc. Having decided on the rate, let us suppose the auricular beats will fall at two-inch intervals. The ruler is then laid along the venous line (1), and marks made at two-inch intervals and marked (a). One-fifth of a second after each of these will come the ventricular waves which should be marked by points, in this case one-half inch after the (a) points. The duration of ventricular systole is a little more than the conduction time or the *a-c* interval, and so points are made, let us say three-quarters of an inch after the *c* points and lettered *v* marking the end of systole. We now have all the beats plotted out. Construction lines are now drawn down from each of these points across all the horizontal lines. Points one-tenth of a second after each *c* line are marked on the base line of the radial pulse curve. The ventricular beats are now drawn in, starting each upstroke at these points, and putting in the dicrotic notch at the proper place, shown by the construction line from "*v.*" The venous curve can then be drawn making upstrokes at the *a*, and *c* points, and down strokes at the *v* points. Finally the diagrammatic lines for the auricular and ventricular beats may be drawn in.

From such a construction it will be seen that the venous curve gives us the true relation of the beats to each other. That all our rhythms are based on the *auricular* beats, the normal controlling pacemaker of the heart, and the time relations of ventricular beats to these auricular beats plotted. The method which we must adopt in reading a tracing is however the reverse, on account of the absence of characteristic venous curves. In a tracing we must first start with the ventricular beat as shown in the arterial curve, because it gives us our only two fixed points, the beginning and end of systole, and from these plot backwards so to speak onto the venous curve in order to distinguish there, auricular from ventricular waves.

INDEX