

ATRIO-VENTRICULAR NODAL RHYTHM,

ATRIO-VENTRICULAR DISSOCIATION
(With and Without Interference)

and

RECIPROCAL RHYTHM

by

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November 1940.



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The subject of this thesis is the result of a study of that group of conditions which is associated with certain changes in the origin of the normal impulse leading to contraction of the heart muscle.

The subject being a complicated one is divided into three parts, the first being a general description of the Conducting Systems and the production of the normal electrocardiogram, the second a consideration of those abnormalities referred to in the title, and the third being a description and discussion of illustrative cases.

PART I.

It has long been known that in health, the impulse resulting in contraction of the heart originates in the sino-auricular node. In certain conditions, however, the sino-auricular node ceases to be the dominant factor, its function being taken over wholly or in part by one of the lower centres of impulse formation such as the atrio-ventricular node.

Such activity of the Atrio-ventricular Node may result in the following conditions:-

1. Extrasystoles.
2. Paroxysmal Tachycardia.
3. Atrio-ventricular Nodal Rhythm.
4. Atrio-ventricular Dissociation.

It is not my intention to deal with the two former conditions in detail, but chiefly with the two latter - Atrio-ventricular Nodal Rhythm and Atrio-ventricular Dissociation which will form the central theme of this thesis.

Briefly atrio-ventricular nodal extrasystoles are uncommon varieties of premature contractions in

response to ectopic impulses arising in the atrio-ventricular node, and paroxysmal atrio-ventricular nodal tachycardia consists of a series of such extrasystoles.

In Atrio-ventricular Nodal Rhythm* there is a reversal of the normal cardiac mechanism in that the auricles contract in response to a stimulus passing BACKWARDS to them from the atrio-ventricular node, the impulse at the same time passing ONWARDS to the ventricles.

Atrio-ventricular Dissociation is a condition where the auricles contract in response to impulses arising in the sino-auricular node (S-A node) and the ventricles to impulses arising in the atrio-ventricular node (A-V node). In this condition, in contra-distinction to complete heart block, the rate of the ventricular contraction is greater than that of the auricles.

Both Atrio-ventricular Nodal Rhythm and Atrio-ventricular Dissociation are rare conditions, although there is evidence that the latter may be more common than is generally supposed.

Both depend on graphic methods for their demonstration and both may produce few or no symptoms; consequently they may easily be overlooked. Furthermore, they may occur purely temporarily in cases presenting no cardiac symptoms and in whom no electrocardiographic examination is indicated. My investigations on the dying human heart (as demonstrated by records shown later on) tend to show that they very commonly occur either immediately preceding or following clinical death.

In order to consider the nature of these conditions in detail it is essential to have a clear understanding of the normal course of the impulse in the heart, and I therefore propose to give a brief description of the conducting systems and the production of the normal electrocardiogram. It will then be comparatively easy to recognise from electrocardiograms these abnormalities later described.

The Conducting System (Fig.1).

Extensive research in recent years has firmly established the presence of a specialised system of tissue, known as the conducting system, by which impulses are normally transmitted from auricle to

* This condition is commonly described as "nodal rhythm", but as this is a loose term it should be avoided. The normal sequential rhythm is also a nodal rhythm but originates in the sino-auricular node i.e., a sinus nodal rhythm. Mackenzie also used this term for Auricular Fibrillation, a totally different condition as is now known.

ventricle..This system comprises two collections of specific fibres in the heart. This first is the sino-auricular, which in lower animals connects the sinus to the auricle but in man has become a small remnant of the primitive cardiac tube situated in the right auricle; the second is the atrio-ventricular system.

A. The Sino-auricular System.

This system consists of the sinus node (Node of Keith and Flack) and its junctional fibres.

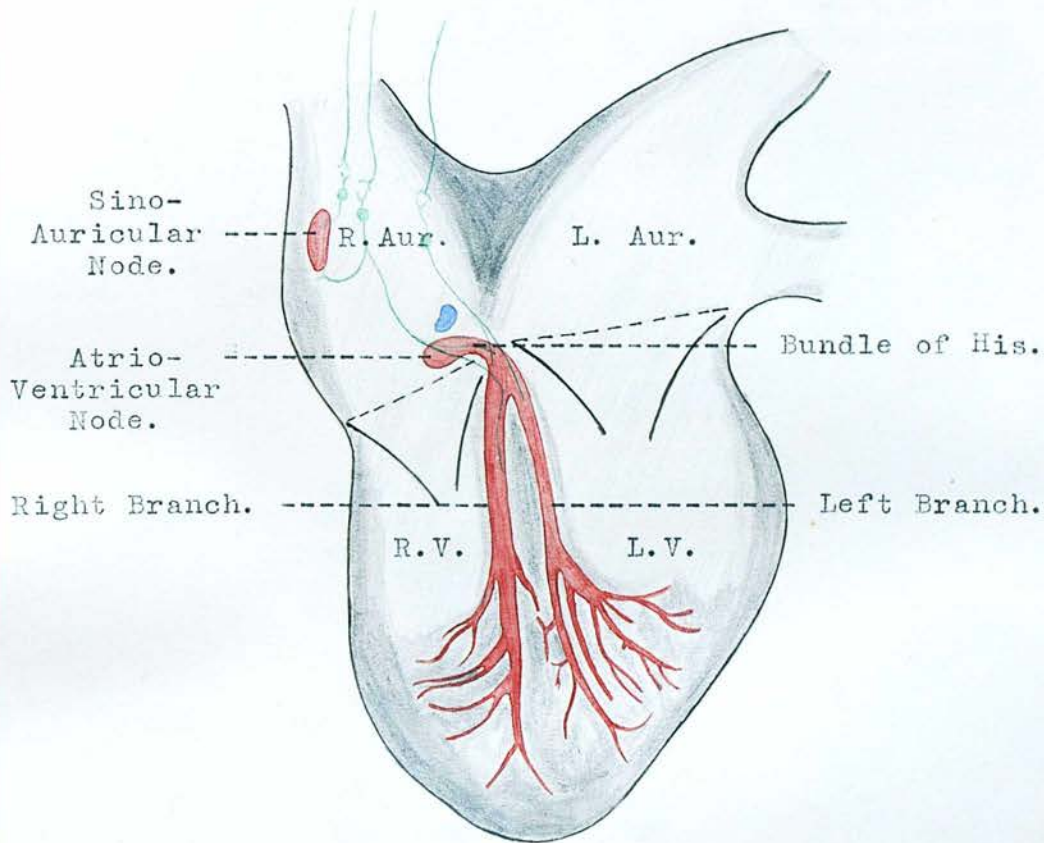


Fig. 1.

Diagram of the Bundle of His emanating from the Auriculo-ventricular Node and innervating both ventricles through the right and left branches.

(After British Encyclopaedia of Medical Practice.)

The upper end of the sinus node is broad and is situated in the angle formed by the junction of the superior vena cava and the right auricle. The remainder of the node is long and tapering and extends along the sulcus terminalis to the region of the opening of the inferior vena cava near the atrio-ventricular junction.

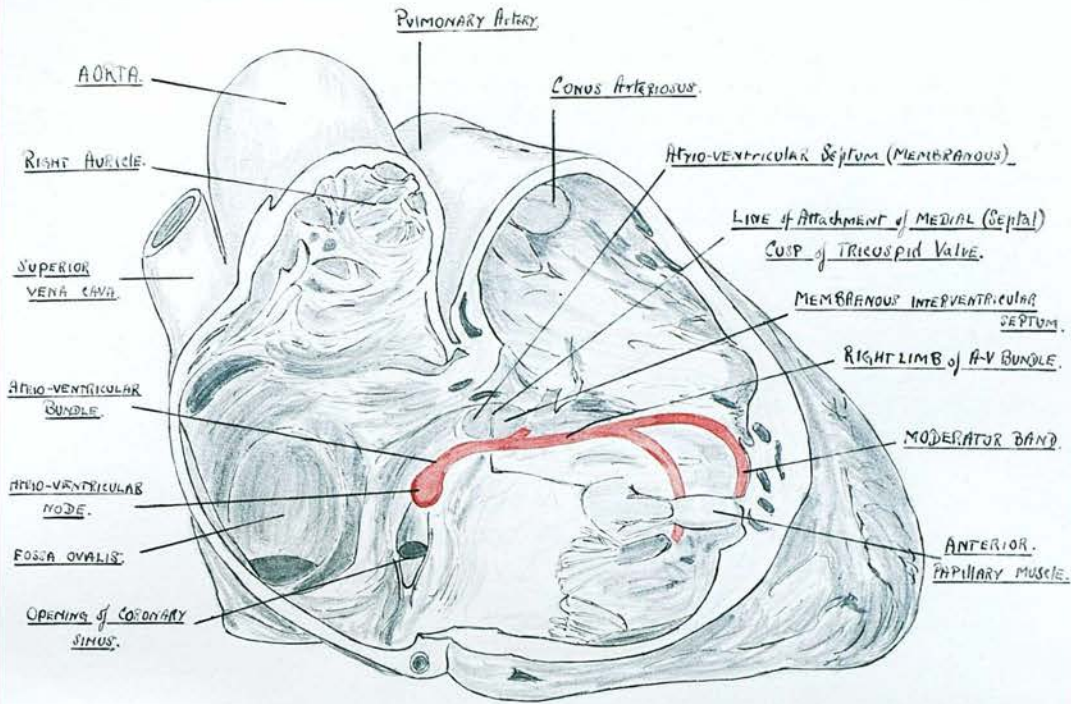


Fig. 2.--A schematic representation of the Atrio-ventricular Bundle. The course of the Bundle is represented in red.
(From Gray's Anatomy.)

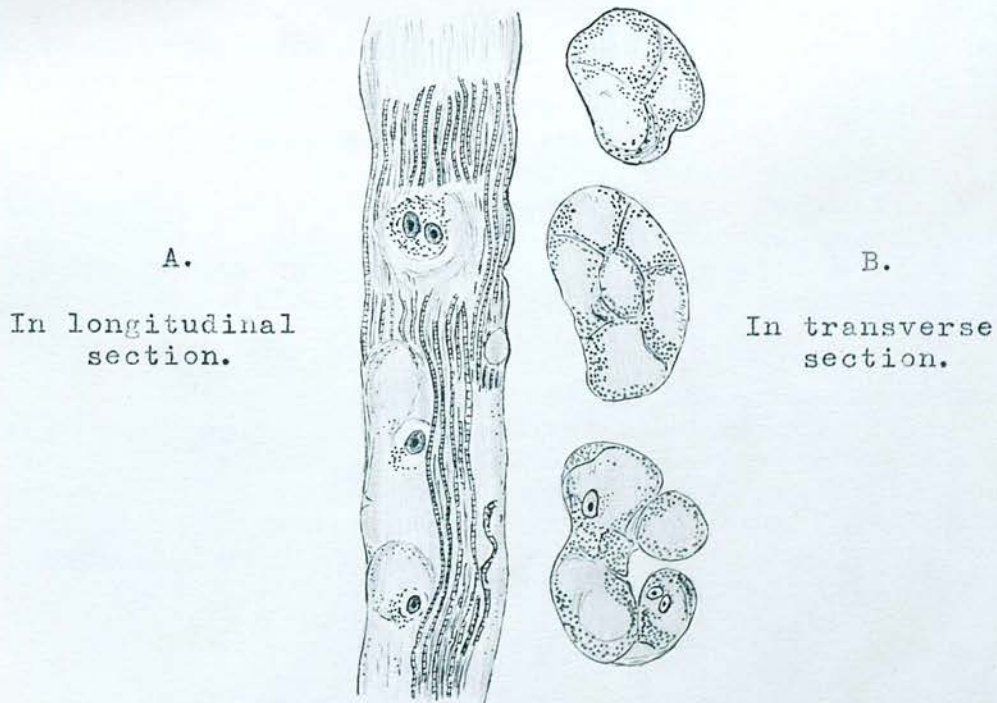


Fig. 3.--Purkinje's fibres from the sheep's heart.
x 250. (From Gray's Anatomy.)

In the adult human heart this node is about 3 centimetres long and about 2 millimetres in width.

Junctional or connecting fibres radiate from the sinus node in all directions and soon merge imperceptibly with the auricular muscle. There are no definite conduction pathways in the auricle itself.

B. The Atrio-ventricular System.

This system commences with the Atrio-ventricular node (Node of Aschoff and Tawara) which is situated in the right side of the postero-inferior portion of the inter-auricular septum just in front of the mouth of the coronary sinus in the right auricle (Fig. 2).

The A-V node can be divided into a small auricular portion lying above the atrio-ventricular septum and a larger ventricular portion lying below this septum. Junctional fibres spread out in all directions from the node and pass particularly to the musculature of the right auricle, auricular septum and also to the left auricle.

From the A-V node passes the section of the conducting system known as the Bundle of His. This is a short bundle which runs forwards horizontally and to the left, passing along the posterior and lower border of the upper end of the membranous septum where it reaches the upper part of the muscular septum and divides into a right and a left branch.

The right branch runs to the right ventricle via the moderator band where it divides into finer branches.

The left branch pierces the intermuscular septum and then divides into numerous smaller branches supplying the left ventricular musculature.

These main limbs subdivide into progressively smaller branches which become interwoven and finally pass into a microscopical network of particularly large fibres (Purkinje's fibres - Fig. 3), which invest the inside of the ventricles penetrating the muscle wall to reach the muscle cells.

No proof exists of a direct connection in the auricle between these two systems. There is no experimental evidence of the existence of other specific tissue in the auricle other than that of the sinus and auricular portions of the A-V node and their junctional fibres.

The specific tissue of the sino-auricular and atrio-ventricular nodes has a remarkably rich blood supply derived from the coronary arteries in addition to that of the muscular tissue, - so much so that despite severe coronary disease, the specific tissue may remain intact. (Fig. 4).

Similarly the innervation of the specific

tissue is very extensive, each element of it being surrounded by a net of nerve fibres belonging to the autonomic nervous system. (Fig. 5).

The vagal portion of the autonomic nervous system carries cardiac inhibitory fibres, whilst the sympathetic portion carries the accelerator fibres. Sympathetic fibres can be demonstrated everywhere in the heart and are very numerous in the S-A node, but less numerous in the A-V node. Parasympathetic fibres, on the other hand, can only be demonstrated with certainty as far down as the A-V node and direct vagal effects have never been proved to occur in the ventricle.

Fig. 5 is a diagrammatic illustration of the cardiac nerve supply.

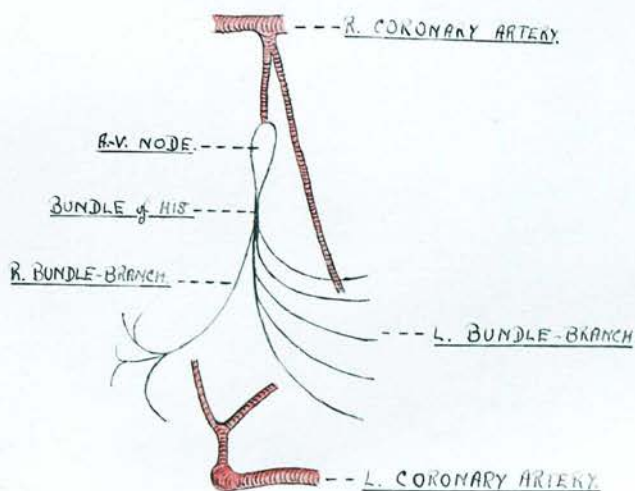


Fig. 4.

Schematic Drawing of the Arterial Blood Supply
of the Auriculo-ventricular Conduction System.
 (After Mahaim.)

The specific tissue differs from the common cardiac muscle in that it possesses in itself the power of stimulus formation - i.e., automatism. When placed under suitable conditions every specific fibre possesses this property. Lewis named the sino-auricular node "the pacemaker of the heart" for normally the excitation process arises in the head of that node. Any of the numerous fibres in the node can give rise to this stimulus, but under normal conditions only one does so, the remainder being silent. The fact that only one among thousands of fibres gives rise to the excitation wave is an example of the numerous safety devices in the heart. The excitation wave on leaving the sinus node,

spreads over the auricle in all directions, but also tends to follow certain well-defined paths simply because they form the shortest routes to the left auricle or to the A-V system. After excitation of the auricles the stimulus passes down the junctional tissues and so reaches the ventricular muscle via the Purkinje system. Thus it follows that the structure of the conducting system permits the excitation wave to reach approximately all parts of the ventricles simultaneously so that the two ventricles contract together.

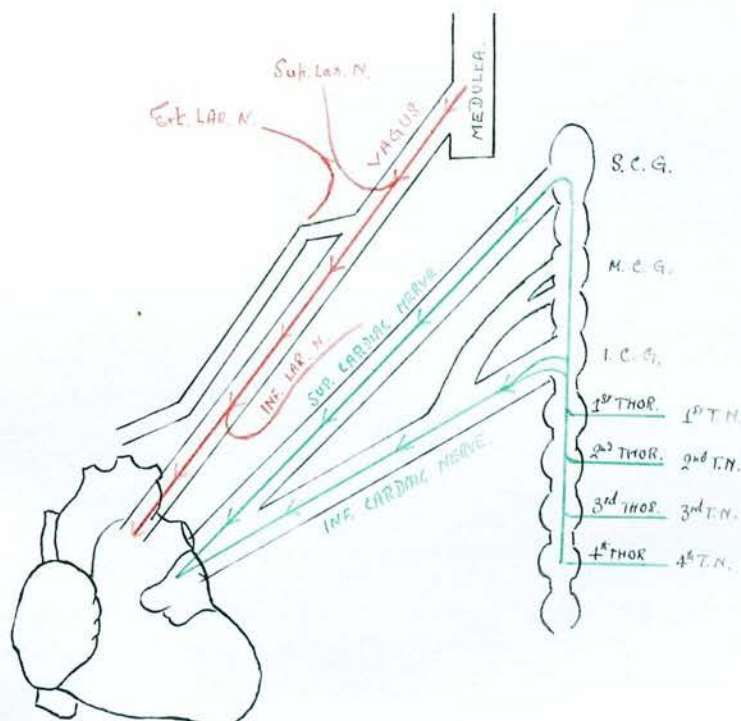


Fig. 5.

Diagram to Show the Cardiac Motor Nerves.
(After Lambert. (41).)

An interesting experiment by Demoor tends to show that a chemical agent may be produced normally in the nodes or junctional tissues which has the power of forming rhythmic discharges. The isolated right auricle suspended in warm oxygenated Ringer-Locke Solution can beat rhythmically and regularly for hours, but the isolated left auricle will not do so, but remains quiescent or possibly gives occasional irregular beats. If an extract be made from the S-A or A-V node or from the junctional tissues and added to the Ringer-Locke solution, the left auricle will commence to beat regularly, sometimes for hours.

Experimentally also rhythmic contractions can be demonstrated macroscopically in the smallest visible portions into which the sinus node can be

divided. They "form stimuli" (v. Skramlik). Even the smallest fragments removed from the A-V conducting system exhibit movements when placed in appropriate nutrient solutions at the body temperature with an oxygen supply. A strip of ventricular muscle will also show contractions if it remain in contact with specific fibres. According to Pick, the fibres of the specific tissue form the "ultimum moriens" in the heart for small parts of the ramifications of the Purkinje system removed two or three days after death may still be shown microscopically to exhibit movement (Isihara and Pick).

Thus every specific fibre of the heart can form stimuli without any external influence. "From itself alone" it can become automatically active. If every specific fibre can initiate impulses, one must explain why they normally remain quiescent and why the normal cardiac stimulus only develops in the S-A node. Two fundamental laws of the heart explain these facts.

1. The nearer the specific fibres to the apex of the heart, the less is their automatism developed and the slower they work. The fibres of the sinus node (the primary centres) possess the most actively developed automatism; the fibres of the A-V node (secondary centres) possess a less rapid automatism, and the peripheral fibres of the Purkinje system (tertiary centres) are the least active.

2. If a stimulus produced in the head of the sinus node spreads normally over the heart, it breaks through all the less active centres and destroys the stimulus material accumulating there. Thus the formation of new stimulus material must recommence everywhere. Since stimuli are produced most rapidly in the head of the sinus node, they always appear earlier than stimuli arising in other centres and prevent the latter from emerging. Under normal conditions, that centre controls the heart which forms stimuli at the most rapid rate.

If for some reason, as will be discussed later, the head of the sinus node becomes depressed, a lower centre of that node, which has remained intact, will assume control. If the whole of the sinus node can no longer form impulses, the A-V node (or "secondary centres") assumes control; if these secondary centres also fail, the tertiary centres will take over. All the deeper centres are ready and able to assume control of the heart beat should the higher centres cease to function or act too slowly or when impaired or interrupted conduction of the pathway of the impulse occurs. This mechanism is very clearly demonstrated in electrocardiograms of the dying heart, but as the final changes in the ventricular complex has little to do with the subjects to be considered, only a few electrocardiograms showing this are reproduced.

Heart muscle is excitable and responds to stimuli by contracting in accord with the "All or none law". If the stimulus be too weak contraction does not occur, but if sufficiently strong, the heart responds to the best of its ability as a single unit, so that

normally the whole heart will contract. During contraction the heart is absolutely refractory and will not respond in any way to extra stimuli. Each contraction must be completed and recovered from before a second contraction can occur. It is relatively refractory shortly after a contraction is over, i.e., although minimal stimuli produce no result, stronger stimuli may be effective in producing a contraction.

Conductivity though especially developed in the specific tissue of the conducting systems is a property of the whole heart muscle. According to Lewis, the rate of conduction of the wave of excitation in different tissues is given as follows:-

- (i) 200 mm. per second in the A-V node.
- (ii) 400 mm. per second in ventricular muscle.
- (iii) 1000 mm. per second in the auricular

muscle.
(iv) 4000 mm. per second in the Bundle of His and Purkinje system.

Thus conductivity is slowest in the A-V node. Recent experiments, however, tend to show that conduction may be less rapid than given in these figures.

The Normal Electrocardiogram (Fig. 6).

Although the specific tissue forms and conducts stimuli, no electrical response is directly recorded in the electrocardiogram. Only when the wave of excitation has left the system and entered the common muscle does one find a wave recorded, i.e., only the results of the stimulus are rendered visible. The waves of the electrocardiogram develop with the excitation of the common muscle and not with that of the specific fibres.

When the excitation wave leaves the sinus node and radiates in all directions over the auricle, the auricular or P wave appears in the electrocardiogram. This wave is small, rounded, upright (positive) deflection and develops from potentials following the activation of the auricles. The excitation of the auricles is completed when the apex of the P wave appears in the electrocardiogram. The potentials are mainly short-circuited in the heart; consequently an iso-electric line appears following the P wave.

When the stimulus leaves the A-V system and enters the ventricular muscle, one obtains the ventricular electrocardiogram comprising the initial QRS complex and the terminal T wave. The QRS complex is developed from the summation of the potentials formed by the excitation of the ventricles and consists of a small downward wave Q followed by a tall upright wave R, which is followed by a small downward deflection S. As soon as both ventricles have been activated an iso-electric line occurs (S-T or should the S wave not be present R-T interval) since no difference in potential occurs at that moment, but as soon as recovery from the excitation commences (de-activation), differences in potential again appear and the terminal deflection or T wave is formed. This is normally a low positive wave which evolves slowly. Not infrequently a small lower wave appears after the T wave at the beginning of

diastole, and has been called the U wave; the cause of this wave is uncertain and its presence or absence has no known pathological significance. Many records illustrated in the following cases show U waves.

Certain time relations are important in the reading of the electrocardiogram. Firstly, there is the time interval between activation of the auricles and of the ventricles. In the electrocardiogram this is obtained by measuring the distance between the beginning of the P wave and the beginning of the Q wave, or in the absence of a Q wave, the R wave. This gives the P-Q or P-R interval which is a measurement of the time transit of the excitation wave through the auricle and through the A-V conducting system. Normally it lasts 0.15 and 0.20 second, and all values above or below these may be considered abnormal. The width of the QRS complex is the second important time measurement as it indicates the duration of the ventricular excitation. It has a normal range of 0.05 to 0.10 of a second. The length of the S-T interval normally varies greatly and may be as short as 0.03 of a second or as long as 0.15 of a second or even more. Its length depends largely upon the heart rate and in general it becomes shorter as the rate becomes more rapid.

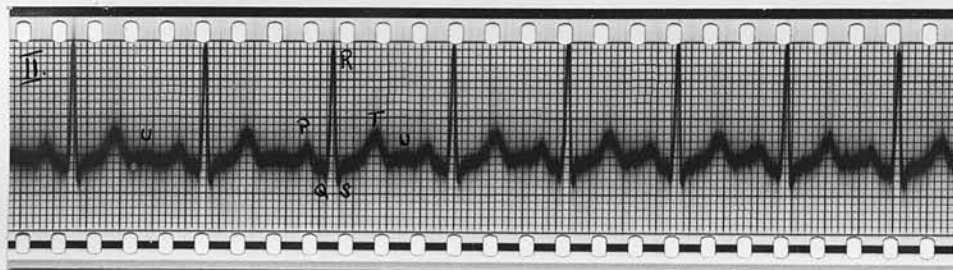


Fig. 6. Normal Electrocardiogram.

Nervous Control of the Heart.

The rate of the heart depends to a considerable extent on the blood pressure but it is not intended to discuss this subject beyond drawing attention to the nervous mechanism of the heart.

The vagus nerve exercises a continuous restraining action on the heart and the degree of vagus activity is probably the chief factor in controlling the heart rate at rest. The sympathetic, on the other hand, exerts an accelerator action and can increase both the rate and force of the heart.

If the vagus be paralysed (e.g. by the administration of atropine) the heart rate may rise to 150 per minute. A further increase in rate will take place by subjecting the patient to violent exercise - probably due to sympathetic stimulation.

Stimulation of the peripheral end of the sectioned vagus proves that the nerve can depress every part of the heart. In the S-A node the rate at which impulses are elaborated is diminished and consequently the whole heart is slowed. Vagal stimulation acting on

the bundle of His impairs conductivity to varying degrees; the P-R interval may become prolonged; occasional impulses may fail to pass through, resulting in blocked beats and a 2 : 1 or other form of heart block may occur, or conductivity may be entirely suppressed with dissociation of auricle and ventricle: the customary sequences of cardiac rhythm may cease with temporary ventricular standstill until the ventricle resumes beating at its own slower idio-ventricular rate. Finally bundle-branch block may be produced. But there is no proof of a direct vagal action on the ventricle causing depression of contraction, conduction, or stimulus formation.

In some experiments later described, stimulation of the vagus has been made by pressure on the carotid sinus; so a description of the method used is here given, together with the effects of exercise and anoxia.

The carotid sinus is an enlargement of the internal carotid artery just above the bifurcation of the common carotid artery, and is richly supplied with nerve endings, stimulation of which tends to slow the heart through a vagal reflex. Similarly an increase in the blood pressure in the carotid sinus initiates a depressor mechanism which through vagal stimulation checks the rise and slows the heart.

Clinically, stimulation of the vagus through the sinus can be obtained by pressing the thumb over the pulsating artery towards the vertebral column. Slowing of the heart results. This reflex is obtained more easily in elderly subjects with arteriosclerosis or in subjects of hypertension when very marked slowing of the heart may result. By such means various grades of heart block may be obtained or sometimes complete cardiac arrest may result and syncopal attacks follow. Changes may be observed in the P wave of the electrocardiogram due to migration of the pacemaker. Pressure on the left carotid sinus is said particularly to be concerned with the production of the A-V block, whilst pressure on the right is more likely to depress the S-A node.

Vagal stimulation may be obtained in other ways, e.g., by means of ocular pressure or even by deep inspiration.

The effect of exercise is to produce acceleration of the heart through reflex stimulation of the sympathetic accelerator fibres (Bainbridge's reflex).

Lack of oxygen (anoxia) also causes acceleration of the heart rate, the pulse becoming quicker and weaker with oxygen insufficiency. Excess of carbon dioxide also causes cardiac acceleration and in large amounts poisons the bundle of His, producing heart block, and a slow pulse rate; this occurs in the terminal phases of asphyxia and its effects may be seen in electrocardiograms of the dying heart.

The Victor Electrocardiograph.

Except in a few instances, I have taken all the electrocardiograms reproduced here with the Victor Portable Amplifying Electrocardiograph, the instrument at present in use at the Leicester Royal Infirmary. With this instrument a continuous film of 50 feet in length is used from which sections are cut when a record has been taken. The film is a sensitive bromide paper having a recording surface of 25 mm. in width. It is developed in the usual way and the result is a positive print. There being no negative, only one record is obtained. For this reason I have had these records photographed.

The Leads used in the electrocardiogram are standard:-

Lead I - between right and left arms.

Lead II - between right arm and left leg.

Lead III - between left arm and left leg.

A few examples of CHEST Leads are also shown and have been marked:-

Lead IVR - between right arm and the outer border of the apex beat.

Lead V - between right arm and the fourth left intercostal space at the border of the sternum.

In all these records the time intervals are measured in $\frac{1}{3}$ th. and $\frac{1}{15}$ th. of a second.

All records before being taken have been carefully standardized to give a deflection of one centimetre when a current of one millivolt is inserted into the circuit (Fig. 6A).

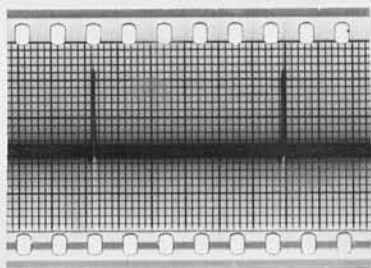


Fig. 6A. Standardization Mark

A few records I have taken with the Cambridge String Galvanometer Electrocardiograph, the timing and standardization being the same as with the Victor Apparatus.

*

PART II.

This section is intended to elaborate the definition of the subject matter and form a pre-ample to the consideration of the cases which will be described in the third part of this thesis. This will avoid the necessity for elaborate description and discussion of each of the electrocardiograms reproduced.

Atrio-ventricular Nodal Rhythm.

As has been mentioned previously there are several centres of impulse formation in the heart which are potentially active and would control the heart's rhythm, were it not for the fact that it is that centre which has the greatest or most rapid rate of impulse formation which governs the heart rate. Normally this is the S-A node. In atrio-ventricular nodal rhythm, however, the sinus node has ceased to be the pacemaker and the A-V node initiates impulses to which the whole heart, auricles and ventricles, responds. Such a situation may arise under either or both of two conditions:-

1. When the activity of the sinus node is depressed or destroyed and no subsidiary part of it is able to take over the function.

2. When the activity of the A-V node is enhanced and its rate of impulse formation reaches a higher level than that of the sinus node. Naturally there must be no obstruction to the backward passage of the impulse to the auricular muscle.

1. Depression of the S-A Node.

A-V nodal rhythm characteristic of the former condition differs considerably from that of the latter. Here the heart is controlled by the "secondary centre" which, not being irritated, produces impulses at its own inherent rate. The heart rate is then about 40 per minute (or less) with a range of from 30 to 50 per minute; usually the rhythm is perfectly regular, but slight variations may occur due to vagal and sympathetic effects on the junctional tissues.

It has already been pointed out that only by graphic methods (such as the electrocardiogram) can this condition be diagnosed. The characteristic electrocardiographic feature is a change in the P wave (auricular contraction). As the impulse arises in the A-V node, and travels in a retrograde direction to the auricles, the P wave becomes inverted. Further, its relation to the initial ventricular deflection becomes changed, being deflected nearer to, simultaneous with (and therefore not apparent in the electrocardiogram) or following after the QRS complex - giving a shorter P-R interval, zero, or an R-P interval as the case may be. Three varieties of electrocardiograms are thus somewhat arbitrarily differentiated on the assumption that the impulse arises high up, near the middle, or low down in the A-V node.

In the first of these three varieties the auricular contraction precedes the ventricular by an interval shorter than normal - i.e., less than 0.15 second. The impulse is then assumed to be arising in

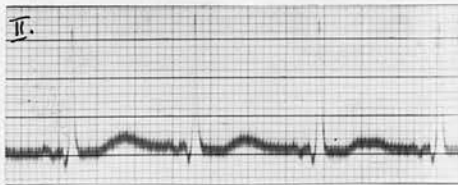


Fig. 7. (P-Q interval = 0.08 sec.)

the upper portion of the A-V node and whilst spreading in both retrograde and forward directions, reaches the auricle before it does the ventricle, thus producing the shortened P-R interval and inverted P wave. This has been termed "Superior Nodal Rhythm" by some French authors. Fig. 7. shows these electrocardiographic features.

In the second variety the impulse is assumed to arise in the middle of the A-V node and spreads both backwards and forwards reaching auricle and ventricle at the same time so that they contract simultaneously. Thus the P wave, coincident with the QRS complex, is

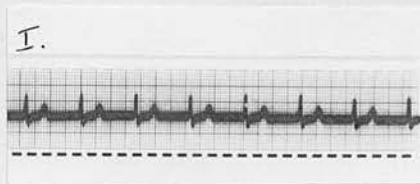


Fig. 8. (P-Q interval = zero).

concealed in it and hence is not apparent. Owing to the poor conduction in the A-V node it is very possible that the excitation will take just as long for the shorter passage to the auricle as for the longer journey to the ventricle. Fig. 8 is an example of this variety, no P waves being visible. Similar absence of the P waves occurs in chest leads so that their invisibility is not merely due to low amplitude. This is probably the commonest form of A-V nodal rhythm.

In the third variety the impulse is said to arise in the lower part of the A-V node (possibly in



Fig. 9. (Q-P interval = 0.18 sec.)

the bundle of His), and therefore rapidly reaches the

ventricle but there is a longer delay in its reaching the auricle. Thus the QRS complex appears first and is followed by an inverted P wave, this usually lying between the QRS and the T complexes. This is shown in Fig. 9, the deeply inverted P wave lying on the S-T interval.

This differentiation into three varieties is essentially artificial as no definite anatomical proof exists in its favour and according to Scherf (64) it is not justified by experimental observations. The anatomical position of the A-V node in the heart makes experimental studies very difficult and at present the knowledge of its physiology is limited.

Probably the most important exciting factor in the production of A-V rhythm is vagal inhibition which depresses the rate of impulse formation in the sinus node below that in the A-V node. The latter then assumes control of the heart beat. Thus A-V rhythm can occasionally be produced in the healthy subject by carotid sinus pressure. (Vide page 11.) By reflexly causing vagal stimulation and depressing the activity of the sinus node, the A-V node (which is less likely to be affected by vagal influence) assumes control. Other means of producing vagal inhibition may act similarly, e.g., ocular pressure, and for the same reason A-V rhythm is occasionally found associated with deep respiration (Wilson, 74); A-V nodal rhythm has also been shown to occur sometimes during partial asphyxia associated with Cheyne-Stokes respiration (Resnik and Lathrop, 57).

The following electrocardiogram (Fig. 10) is an example of A-V nodal rhythm produced by right sided carotid sinus pressure, which was applied between the two vertical lines on the second strip.

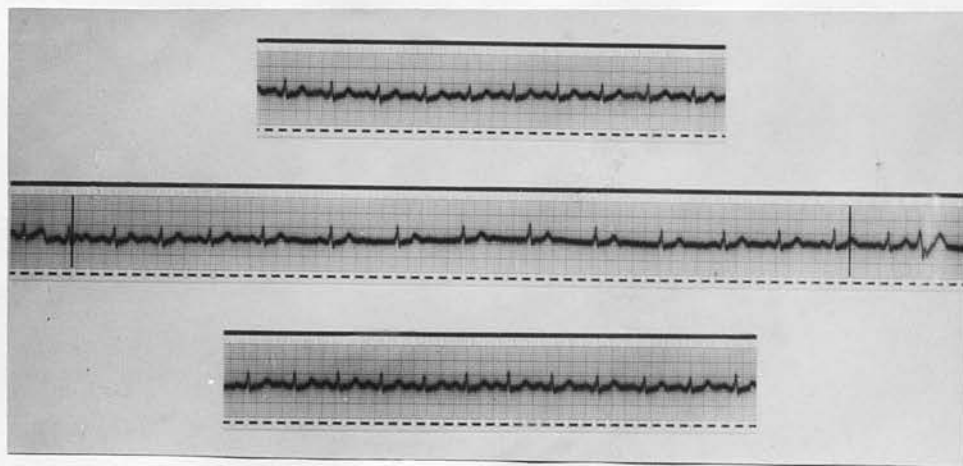


Fig. 10. (Lead II only). 13-9-40

The three strips shown in this figure are continuous and in the uppermost record one sees normal sequential rhythm, the P waves preceding the QRS complexes by an interval of 0.18 second. Shortly after the pressure was commenced the heart rate slows from its

previous value of 86 per minute to 60 per minute and the P waves disappear until shortly before the pressure was relaxed, the heart rate again returning to its previous value as seen in the third strip. This is therefore an example of the second variety of A-V nodal rhythm described above.

2. Increased Activity of the A-V Node.

On the other hand, instead of resulting from depression of the sinus node, A-V rhythm may be due entirely to stimulation of the A-V centre. Examples of enhanced activity of the A-V node are seen in those uncommon varieties of paroxysmal tachycardia when an exceptional irritability of the junctional tissues exists. Such an irritability also accounts for the premature beats of A-V nodal origin. In certain fevers, notably rheumatic fever (55), with myocarditis involving the node, the irritability enhances the rate of impulse formation of the A-V node beyond that of the S-A node and A-V nodal rhythm may occur. In these cases, in contra-distinction to S-A nodal depression, there is a rapid heart rate (see Case 2). Such lesions have been demonstrated pathologically in several cases dying from acute illness.

Enhanced activity of the A-V node can be induced temporarily in the healthy subject a few minutes after the administration of atropine (Wilson, 75). According to Eckl (13) about 80% of normal individuals show a transient A-V rhythm soon after a subcutaneous or intravenous injection of atropine has taken effect. Before the full paralytic stage is reached atropine does not paralyse all the vagal nerve endings in the heart simultaneously. Consequently the A-V centres may function more rapidly for a time than the S-A centres and therefore assume control; so a temporary A-V rhythm results. In such artificially produced A-V rhythms that variety in which auricle and ventricle contract simultaneously and in which the P waves are merged in the QRS complexes nearly always occurs, but the other varieties may also be obtained.

Figures 79 and 80 of Case 3 are examples of this mechanism in which I produced an artificial A-V rhythm by administering atropine according to the method employed by Wilson(75). This method is described in connection with these records, but as it is a particularly interesting subject I wish to draw attention to some of his observations. Wilson described the effect of administering 1 mgm. of atropine subcutaneously to eighteen young men and women between the ages of 20 and 28 years. In nine of these cases A-V rhythm was produced by forced respiration, in two by right ocular pressure and in one it appeared spontaneously; five cases were negative. In no case did the A-V rhythm appear on vagal stimulation before atropine was given, apart from occasional single idioventricular beats and some flattening of the P wave. The period during which A-V rhythm appeared varied greatly, but the rhythm most readily occurred between 8 and 15 minutes after the injection. A-V rhythm could

not be produced some 20 minutes after the injection and when the drug had reached its full physiological effect. All three types of A-V nodal rhythm occurred.

Wilson explained the production of this rhythm by postulating a selective action of the atropine upon the vagal nerve endings in the A-V node, so that this node is released from vagal inhibition, while the sinus node is still relatively under its control; the period of the lower node is then increased so as to approach or even exceed that of the sinus node and when it exceeds it A-V rhythm will naturally follow. When it approaches but does not exceed the period of the sinus node, A-V rhythm may be induced by some means of vagal stimulation which causes depression of the S-A node without producing a corresponding alteration in the A-V node. When the effect of the atropine is maximum the sinus node is also released from vagal control and its rate of impulse formation cannot be slowed by vagal stimulation; its inherent rhythm is also much increased so that A-V rhythm cannot be produced. Wilson also points out that vagal stimulation without atropine may not produce A-V rhythm because both nodes are depressed, the A-V node being kept below the period of the S-A node; ocular pressure or forced respiration may, however, cause an A-V rhythm in exceptional cases in which the period of the A-V node is pathologically rapid or less sensitive than normal to vagal stimulation (as in Fig. 10), and single idio-ventricular beats occur fairly frequently as a result of the first of these procedures.

In this resume of Wilson's observations the term "period" has been used. This term was introduced by Williams and James (73) to describe the latent inherent rhythm of the A-V node. When the auricle and ventricle are separated by interruption of the conducting tissue, as in complete heart block, the auricle continues to beat at the same rate as before, but the ventricle contracts at a much slower rate. This slow rate of the ventricles is their inherent rhythm at which they always would beat were they not under the control of another chamber having a more rapid inherent rhythm. That is, they tend to beat at their own "period" when the control of another chamber having a greater "period" is removed. Normally the ventricles are driven by the auricles as the latter possess the greater "period" and the usual ventricular rate is consequently a forced rate. The period of the auricles may be altered in various ways, especially by the action of the vagus, and changes in their period affect the whole heart rate. The period of the ventricles, on the other hand, may vary considerably without affecting the heart rate, but should it become greater than that of the auricles, then the ventricles would assume control with the production of an A-V rhythm provided the ventricular impulses could pass back to the auricles.

Animal Experimentation.

Atrio-ventricular nodal rhythm has been produced experimentally in animals by a large number of observers usually either by slowing the rate at which impulses are discharged from the S-A node or by preventing the impulses from leaving the node.

Amongst the experimental methods designed to eliminate or depress the activity of the sinus node the following may be mentioned:-

1. Cooling the region of the sinus node by means of an ice pencil, ice-cold water circulating in a lead tube, or ethyl chloride spray. (Lewis, 43; Ganter and Zahn, 21).
2. Scorching of the node (Hering, 29).
3. Excision of the node (Cohn, Kessel and Mason, 7) or crushing of the node.
4. Isolating the node by making surrounding incisions.
5. Injury to the node with formalin (Lohmann, 47).

Experimental stimulation of the A-V node in order to increase its automaticity and so as to usurp the pacemaker function of the S-A node has been performed by electrical stimulation of the A-V node by Lohmann (46) and also by Kraus and Nicolai (39).

A-V rhythm may, however, also be produced through the action of the cardiac nerves. Spontaneous beats recorded polygraphically and having the reduced As-Vs interval characteristic of ~~the~~ A-V nodal rhythm, were first observed experimentally by Lohmann (46) during vagal inhibition of the mammalian heart (rabbit) and he located the site of origin of impulse formation in the junctional tissues. Similar shortened As-Vs intervals were obtained by Hering (27) and by Rihl (59) during sympathetic stimulation. Later Rothberger and Winterburg (62) confirmed this latter result by producing A-V rhythm in 30 percent. of their experiments by means of stimulation of the left sympathetic nerve, and Meek and Eyster (51) also obtained it in two out of twenty-seven experiments by right vagal stimulation. Kure (40) obtained A-V rhythm in a similar manner by the effect of asphyxia upon the cardiac nerves, confirming the work of Rothberger and Winterburg.

Engelmann (16) in 1903 was the first to describe A-V nodal rhythm. He noticed that in certain experiments on the frog's heart, after tying the First Stannius Ligature the auricles and ventricles beat simultaneously or the ventricular contraction preceded that of the auricle, both beating independently of the sinus venosus. He worked out mathematically that the impulse must have arisen on the ventricular side of the A-V ring.

In 1908 Lohmann (47) re-affirmed his previous conclusion that the impulse arose in the musculature of the atrio-ventricular ring after killing the sinus node with formalin, thus producing synchronous contractions of the auricle and ventricle. Hering later repeated and confirmed these observations.

Hering (30) observed that delay in atrio-ventricular conduction took place only in the A-V node and he explained the different values of the polygraphic As-Vs intervals by assuming impulse formation in different parts of the node, following the explanation previously given by Lohmann.

Ganter and Zahn (21) found that during experimentally produced A-V rhythm heat or cold only affected the heart rate when applied to the region of the A-V node. Zahn (78) also studied the effect of temperature changes upon the different portions of the A-V node. He showed that during A-V rhythm the only part of the auricle in which cooling affected the heart rate was in the region where the A-V node extended towards the coronary sinus and that when the interval was zero it was the middle part of the node which was affected and in the case of negative intervals, it was the ventricular portion of the node which was influenced by the change in temperature.

Meek and Eyster (51), by means of electrodes placed in different regions in the right auricle and A-V node and connected to a galvanometer, proved that the initial negativity during A-V rhythm occurred in the A-V node. In a previous paper (50) these authors using the same method, confirmed experiments of Wybauw and of Lewis, Oppenheimer and Oppenheimer that the site of primary negativity in the dog's heart during normal sinus rhythm lay in the region of the S-A node. The work of Zahn was confirmed by this electrical method, two types of A-V nodal rhythm being distinguished according as the impulse arose in the auricular or ventricular parts of the A-V node.

Lewis (42) has shown that an alteration in the shape of the P wave of the electrocardiogram may indicate a change in the location of the pacemaker in the auricle. He found that for Lead II, if the impulse originates in the upper part of the auricle the P wave is upright; if the stimulus has its origin in the middle portions of the auricle, the P wave is flattened and approaches the iso-electric line; and if the stimulus originates in the lower portion of the auricle the P wave is inverted. The P wave of Lead I need not be so markedly altered in shape and direction even if the impulse originates in the A-V node (Hering, 31). Experimentally, a decrease in the size of the P wave has been reported in dogs by Einthoven (14) during vagal stimulation (Lead II); by Eyster and Meek (17) after poisonous doses of morphine (Lead II); by Ritchie (60) during vagal pressure (Lead II with an inverted P wave in Lead I); and by von Hoesslin (77) by vagal pressure (Leads I, II and III). Einthoven, Fahr and de Waart (15) have also noticed this change in all the standard Leads during forced respiration, the P wave becoming inverted in Lead III. Ritchie, von Hoesslin and Einthoven, Fahr and de Waart regarded these changes as due to a change in the location of the pacemaker or to a change in the conduction pathway over the auricles. Wilson (74) also noticed similar changes during forced

respiration and regarded them as due to a downward movement of the pacemaker. Eyster and Meek (52) and Lewis, Meakins and White (45) showed that experimental stimulation of the right vagus may cause downward migration of the pacemaker from the head to the lower portions of the S-A node. Stronger stimulation occasionally caused A-V rhythm (51, 43) and further vagal stimulation may dislocate the pacemaker to some lower portion of the A-V node (51). To explain this Meek and Eyster assumed that the number of vagal fibres supplying the conducting system diminished from the S-A node downwards.

The name A-V nodal rhythm is consequently given to that phenomenon produced under such experimental methods as are given above in which the impulse appears to arise in the A-V node and activate both auricle and ventricle, clinical electrocardiograms exhibiting corresponding characteristics being similarly designated. The P wave is usually but not invariably inverted (Scherf and Shookoff, 65). Different areas of the node may become new centres of impulse formation but the opinion generally held is that at a given moment the centre is limited to a single focus in the node.

Depression of the normal pacemaker leads to escape of another centre whose automaticity is second to that of the sinus node and further suppression may dislocate this new pacemaker to still another area. There is much evidence that these new pacemakers need not necessarily lie within the A-V node and Geraudel (23) holds that there are several auricular centres which are natural areas of impulse formation. Geraudel's conception offers an explanation of certain phenomena associated with A-V rhythm which are difficult to explain on the assumption that the A-V node is the site of stimulus production and also explains the varying shapes of the P waves which are encountered in both experimental and clinical cases of A-V rhythm. As an example, supra-ventricular extrasystoles may be considered where it is frequently difficult to decide whether the abnormal P waves are of auricular or A-V nodal origin. At present the recognition of an A-V nodal extrasystole rests upon the demonstration of an inverted P wave occurring at a shortened interval, e.g., 0.10 second, before the ventricular complex; in auricular extrasystoles the P-R interval is frequently lengthened owing to their prematurity.

To summarise, it may be stated that the centre of impulse formation in so-called A-V nodal rhythm need not be within the A-V node in every case but may lie low in the auricle. There is no definite experimental evidence against this view.

RETROGRADE HEART BLOCK

It will not be inappropriate at this stage to refer to the condition known as retrograde heart block, for it is of great importance not only in A-V nodal rhythm, but also in the production of other arrhythmias.

Retrograde block (or as it is sometimes called, unidirectional block) is analogous to the well known forward heart block in which there is interference to the passage of the wave of excitation from auricle to ventricle. In complete forward heart block the auricle continues to beat in response to the higher inherent rhythm of the S-A node, while the ventricle contracts at its slower idio-ventricular rhythm in response to impulses arising in the A-V node. Retrograde block implies a similar interference in the reverse direction; that is impulses arising in ventricular centres may or may not pass back to the auricle, depending upon the degree of interference with their passage in that retrograde direction. If this degree of interference with retrograde conduction is complete, then a ventricular stimulus, e.g., a premature contraction, will fail to excite any auricular response. If the A-V node is forming stimuli at a more rapid rate than the sinus node and there is no interference with the passage of its impulses to the auricle, A-V nodal rhythm will result; on the other hand, if there is complete blocking of these A-V nodal impulses to the auricle, this chamber will respond only to the slower sinus stimuli and the form of A-V dissociation results which will be described in detail shortly. In fact it is the degree of retrograde block which decides whether A-V nodal rhythm or A-V dissociation will occur in a given case when the A-V node elaborates stimuli more rapidly than the S-A node.

The name "retrograde block" was given to this condition by Lewis (43) in the experimental study of the effect of vagal stimulation during A-V rhythm. It has already been stated that vagal stimulation during normal sinus rhythm may produce varying degrees of heart block (page 11), generally appearing either as a prolongation of the P-R interval or as occasional dropped beats, the ventricle failing to respond to the auricular stimulus. During experimentally induced A-V rhythm Lewis found that vagal stimulation invariably produced a diminution in the value of the P-R interval so that it may become zero or even develop a negative value - i.e., an R-P interval.

Hering (28) showed moreover that delay in atrio-ventricular conduction normally takes place only in the A-V node and this portion of the junctional tissues permits the passage of impulses at their slowest rate (see page 9). It is now well recognised that conduction of stimuli in a reversed direction (from ventricle to auricle) is more difficult than in the normal forward direction.

Goodman (25) points out that complete unidirectional block is probably the normal state of

the conducting tissues. When a ventricular premature contraction arises it is extremely rare to see it followed by a retrograde auricular response; this cannot be due to the impulse meeting refractory auricular tissue for when a ventricular extrasystole occurs early in diastole (e.g., an interpolated extrasystole) it rarely causes auricular activity.

Retrograde heart block need not necessarily be complete, however, in a given case and in A-V nodal rhythm a degree of interference with conduction from ventricle to auricle may produce lengthening of the R-P interval analogous to the lengthening of the P-R interval of slighter degrees of forward heart block. Electrocardiograms will later be described showing this increase of the R-P interval in A-V rhythm and the relation of the degree of reversed block to the occurrence of reciprocal rhythm will also be described.

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ATRIO-VENTRICULAR DISSOCIATION

and

INTERFERENCE DISSOCIATION.

In complete heart block the auricles and ventricles are dissociated, each chamber contracting to impulses originating in the sinus and A-V nodes respectively, generally at different rates. There is interference with both forward and retrograde conduction of impulses.

In the form of atrio-ventricular dissociation now to be considered, however, there is a reversal of the rhythmicity of the two chambers, the ventricles beating at a faster rate than the auricles. The condition is similar to A-V nodal rhythm but in this case there is complete retrograde heart block, the auricle beating in response to sinus stimuli undisturbed by any retrograde conduction of ventricular impulses. The slow auricular rate is due to depression of the sinus node and the failure of a faster secondary auricular centre to assume control of the heart beat. Conversely unusual irritability of the A-V node may produce a ventricular rate faster than the auricular but owing to complete retrograde block none of these impulses pass to the auricle and an A-V rhythm consequently fails to develop.

Although the degree of retrograde block is complete there is no impairment of forward conduction. Thus it may happen that occasional impulses of sinus origin may pass through the junctional tissues and produce ventricular responses. The number of sinus impulses passing through to the ventricle will depend upon the relative rates of the two centres, upon the duration of the refractory period of the junctional tissues and upon the conduction time of the S-A impulses.

These transmitted auricular impulses interfere, therefore, with the rhythm of the ventricular pacemaker and the condition was named by Mobitz (54) in 1923 "Interferenzdissociation" and has been called Dissociation with Interference after the terminology of Wenckebach (Dissociation mit Interferenz).

In such a rhythm with interference the ventricles are responding to two pacemakers and the occasional ventricular contractions initiated by sinus impulses have been called "ventricular capture". The condition also forms one variety of Parasystole. The conducted sinus beats may also appear at fairly regular intervals producing what has been called an allorhythmia, i. e., a tendency for the arrhythmia to repeat itself. This allorhythmia is an interesting condition and has been produced experimentally by Kaufmann and Rothberger (36) who observed that if the regularly beating heart of an animal be exposed to regularly recurring shocks at a slower rate than the natural contraction, a simple allorhythmia consisting of regular premature beats

developed. It results from regular interference with the formation of natural impulses, the artificial shock liberating the stimulus material prematurely and the resulting beat is followed by a compensatory pause. In the case of allorhythmia due to interference dissociation the auricular impulses are analogous to the regular recurring shocks.

The descending auricular impulses which reach the ventricles interfere in two ways with the regular ventricular rhythm. The ventricular response is firstly premature and secondly the impulse whilst travelling through the junctional tissues will destroy impulse material being built up there. The formation of impulse material for the production of the next ventricular beat consequently has to start again at the moment when the interfering impulse has left the A-V node and the next ventricular beat follows at an interval corresponding to the time taken for the impulse material to mature. It occasionally happens, however, that this interval is shortened. This condition was first described by Scherf (63) who gives the following explanation to account for the shortened interval. He assumes a delay in the conduction of the wave of excitation through the bundle of His with a consequent long interval before the ventricles are activated. The impulse material for the next A-V nodal beat commences to be formed at the moment when the conducted impulse has left the region of the A-V centre and by the time it is released the junctional tissues have had sufficient time to recover from transmitting the auricular impulse. The inter-ventricular interval following the conducted beat is thus shortened because the impulse material is being formed before the auricular impulse has left the junctional tissue owing to the delay in its passage. Schott (68) describes a case showing shortening of this interval and cites further evidence in support of this theory to that put forward by Scherf. Several records illustrated in Case 1 exhibit this shortening of the inter-ventricular intervals during interference dissociation.

An A-V nodal beat may also fail to appear at the expected time because a sino-auricular impulse has discharged the stimulus material being built up in the A-V node but has itself failed to reach the ventricle owing to interference with its conduction in the junctional tissues below the level of the A-V centre (8, 67). A second explanation of this occurrence is the postulation of an A-V nodal block comparable to sino-auricular block but there is little evidence in favour of this theory (8).

On the other hand, it occasionally happens that the inter-ventricular interval following the conducted impulse is slightly prolonged. Schott (67) considers that this may be due to a temporary inhibition of the impulse formation in the A-V centre caused by the passing auricular impulse and he regards it as analogous to the inhibitory effect of auricular extrasystoles on experimental A-V nodal rhythm (Rothberger and Winterberg). Korth and Shrumpf (38) and Winternitz

(76) describe cases showing prolongation of the interval between two A-V nodal beats and explain this phenomenon in a similar manner to Schott.

Prolongation of the P-R interval of the conducted S-A beat may also occur and may be considerable. It is again due to interference with the conduction of the impulse through the junctional tissues which have not recovered completely from conveying the A-V impulse. The sooner the conducted beat occurs after the preceding A-V beat the longer will be its P-R interval.

These conducted auricular impulses may produce a coupling of the ventricular beats which has been called by Katz and Kaplan (35) "pseudo-reciprocal rhythm" in contradistinction to the reciprocal rhythm occurring during the A-V nodal rhythm. This bigeminal effect is considered further under reciprocal rhythm.

Depending on whether there is depression of the sinus node or excitation of the A-V node, two varieties of A-V dissociation may be differentiated. In the former the relative rates of the auricle and ventricle are slow and in the latter rapid. In 1930 Dressler (11) attempted to dissociate these two varieties and suggested the terminology "passive heterotopy of the A-V centre" for the former case and "active heterotopy of the A-V centre" for the latter instance due to a primary increase in the irritability of the A-V node. In practice, however, the difference is not always easy to distinguish. The two factors, depression of the S-A node and excitation of the A-V node may occur in a single case and it is often impossible to account for the increased irritability of the A-V node although reasons may be present to account for sinus bradycardia.

The causes of A-V dissociation appear to be similar to those of A-V nodal rhythm. They may be briefly tabulated as follows:-

A. Causes of Depression of the Sinus Node.

1. Vagal Inhibition is, as in A-V rhythm, the most important contributory cause and may arise in a variety of ways:-

(a). Associated with marked sinus arrhythmia (8) and forced inspiration may occasionally lead to dissociation of the auricle and ventricle, the latter chamber contracting at the more rapid rate (7). (see page 15). Wilson(74) has described such a case.

(b). Carotid sinus or ocular pressure.

(c). The administration of digitalis (32, 71) or quinidine (37).

(d). Asphyxia (57).

2. Disease of the Sinus Node The sinus node is relatively large in size and it is very rare for a pathological process in its neighbourhood to completely destroy or isolate the node from the auricular issue. An inflammatory condition involving the S-A node would be expected to irritate it, at least

at first, with consequent increased stimulus production, but later might lead to its destruction. A few cases have been published where disease of the branch of the coronary artery to the S-A node has been demonstrated pathologically (22) and Jones and White (34) report a case of A-V nodal rhythm with bigeminy in a case of coronary occlusion.

3. Unknown causes.

B. Causes of Increased Irritability of A-V Node

1. The result of infection. This appears to be the commonest cause both of A-V rhythm and A-V dissociation and in some cases inflammatory reaction of the A-V node has been demonstrated at autopsy. Rheumatic infection (8, 55) is probably the commonest cause, but acute tonsillitis (8), diphtheria (33), scarlet fever (3), typhoid fever (24) and pneumonia (54) have also been held responsible.

2. During the first few minutes after the administration of atropine (19, 32, 75). (See page 16.)

3. From unknown causes.

C. A Combination of the Two Effects - depression of the S-A node and excitation of the A-V node (71).

Digitalis as a Causative Factor

Considerable aetiological significance has been given to the rôle played by digitalis in the production of both A-V rhythm and A-V dissociation. Cases have been reported in which the administration of digitalis had undoubtedly been the causative factor (71, 79) and I have produced interference dissociation by giving toxic doses of this drug (Case 3). On the other hand very many of the reported cases of these arrhythmias did not have any digitalis at all (8, 55). Other cases which had received digitalis developed the arrhythmia without there being any evidence of overdosage; at times the quantity given was very small. Probably the drug was contributory to the production of the condition rather than the actual cause.

The occurrence of interference dissociation during digitalis therapy is of some importance. Clinical examination alone during this arrhythmia may reveal bradycardia and give the impression of ventricular extrasystoles, resulting in the assumption that digitalis intoxication is present. The electrocardiogram furnishes the only means of accurate diagnosis. It is well to remember the tendency of these arrhythmias to occur during digitalis therapy.

A further curious effect occasionally observed with digitalis is that small doses of the drug may lead to a symptomatic cure (67, 68). The patient commonly complains of "palpitation" which is due to the premature ventricular contractions resulting from the conducted auricular impulses. The effect of digitalis probably lies in depression of the impulse formation centre in the A-V node so that its rhythmicity becomes less than that of the S-A node which assumes control

of the whole heart with ensuing sinus bradycardia.

Rheumatic Fever as a Causative Factor

Cutts (8) emphasises the importance of Rheumatic Fever as a predisposing factor in the production of both A-V rhythm and interference dissociation. He reports twelve cases showing one or other of these arrhythmias, six of whom suffered from Rheumatic Fever and a seventh had acute tonsillitis. Oettinger and Neslin (55) reported seven cases of interference dissociation in patients suffering from Acute Rheumatic Fever and they subsequently noted its occurrence in 14 out of 200 cases of that disease. Cutts therefore regarded these arrhythmias, especially in young persons, as being suggestive of a rheumatic process. On the other hand, as he points out, all these cases were clinically recognisable as Rheumatic Fever. He also accentuates the frequency of pyrexia during these arrhythmias.

The rheumatic or infectious process involving the S-A or A-V node is probably responsible for the high incidence of these arrhythmias by producing depression of the former or irritation of the latter node. That the arrhythmias do not occur more frequently still in these conditions is explained by the disease generally causing irritation of the S-A node resulting in increased rate of its stimulus formation.

Both A-V rhythm and interference dissociation are generally transitory phenomena and may occur for only a few beats during the course of normal sinus rhythm. Occasionally frequent variation in the control of the heart beat between the S-A and A-V nodes may be seen in one case. For these transitions to occur the two nodes must have approximately the same rate of impulse formation, so that a relatively slight change in the rhythmicity of one or other of the nodes due to variation in vagal or sympathetic tone or to some other cause, may initiate a change from one type of rhythm to the other. An example of this change was shown in one of Jones and Whites' cases (34) in which rising from the recumbent to the sitting position was sufficient to produce a change from S-A to A-V rhythm. Similar alteration from S-A to A-V nodal rhythm or A-V dissociation and vice versa repeatedly occurred in the first case I describe in Part III.

The transition from S-A rhythm to A-V rhythm is generally gradual and the P wave gradually changes its shape from the upright form of sinus origin to the inverted form found in A-V rhythm. Two explanations have been advanced to account for this (43, 51, 74).

1. That there is a gradual migration of the pacemaker from the sinus node downwards to the A-V node. (See page 19).

2. That the altered shape of the P wave is due to the meeting of two impulses, one from the sinus node and the other from the A-V node. Lewis (43) favoured this explanation since the P summit is of

transitional form; it is found where one would anticipate the occurrence of both a normal and invert P; such transition forms are only seen when the P-R interval is considerably reduced, the less the reduction the nearer the P wave being to the S-A type, and the greater the reduction the more nearly it conforms to the A-V type.

Occasionally the transition to and from sinus and A-V rhythm is abrupt (74).

When the S-A node regains control of the entire heart it frequently initiates impulses at a faster rate. The reason for this is not clear. It may be due to its "rhythm of development" whereby once its activity is awakened it is enhanced. Zeisler (79) suggests that the coronary blood supply may be improved with better nutrition of the S-A node when the auricle and ventricle regain their proper sequence.

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RECIPROCAL RHYTHM.

This is a very uncommon condition occurring during A-V nodal rhythm in which there is a coupling of the ventricular complexes, an inverted auricular wave being sandwiched between them.

The name "Reciprocal Rhythm" was given to this condition by Drury (12) in 1924. He recognised a similarity between this condition and a curious rhythm described by Mines (53) in 1913 as "Reciprocating Rhythm" and occurring in the heart of the electric ray and of the frog; Mines showed that a single stimulus applied to suitable heart preparations from such animals may provide a continuous excitation wave travelling in a circulating manner over the same path so that auricular contraction produced a ventricular response and ventricular contraction evoked an auricular response, the whole mechanism continuing indefinitely unless interrupted by a second stimulus applied either to the auricle or to the ventricle.

Wenchebach in 1906 was the first to describe this condition in polygrams taken in a case of chronic rheumatic heart disease and he interpreted the tracings as showing a dissociation between the rhythms of the right and left auricle, the left auricle producing a regular contraction of the ventricle and the right auricle beating at a slower rate and occasionally initiating a ventricular response when the ventricles were no longer refractory.

In 1914 Gallavardin (19) described the electrocardiograms of two cases showing this bigeminy and regarded the auricular and second ventricular contractions as due to normal supra-ventricular beats. Peters (56) regarded the second beat as a sinus extrasystole.

White (70) in 1915 described a case where during A-V rhythm a bigeminy in which the first ventricular complex was followed by an inverted P wave, the R-P interval being longer than that occurring with single A-V nodal beats, and in turn this P complex was followed by the second ventricular deflection. Thus the bigeminy occurred when the R-P interval of the A-V impulse became increased to a certain critical level. White advanced two explanations to account for this bigeminy.

1. The more reasonable explanation appeared to be that the impulse liberated from the A-V node, having activated the auricle, re-entered at some other supra-ventricular point, passed again to the ventricle and caused it to respond a second time. The R-P interval following the initial ventricular complex had, in the instances where bigeminy occurred, been noticed to be unusually prolonged and this delay in the passage of the impulse to the auricle may permit of recovery of the junctional tissues and ventricle from their refractory period in time for the ventricle to respond again to the re-entered and returning impulse.

2. His second explanation of the ventricular

bigeminy was that abnormal auricular beats were mechanically excited by the idio-ventricular contraction, and were in turn followed by ventricular responses.

In recent years numerous writers have employed two theories, the one of "re-entry" and the other of Parasystole, to account for this ventricular bigeminy, and so I propose to discuss them in more detail.

Those advocating the theory of "re-entry" regard all auricular activity as due to impulses originating in the A-V node but differing from other instances of A-V rhythm in that there is increasing interference with the backward conduction of the impulse to the auricle. Thus the R-P interval of the electrocardiogram becomes progressively lengthened, auricular systole occurring at longer and longer intervals after the ventricular systole. Forward or downward conduction to the ventricle, on the other hand, is unimpeded and there is no delay in the response of the ventricle. Forward conduction in the junctional tissues is always easier than retrograde conduction. When the degree of retrograde interference with conduction reaches a certain critical value a premature ventricular response to an impulse from the auricle occurs. Some observers regard the auricular contraction initiated by the A-V nodal impulse as itself constituting the stimulus to the second ventricular contraction, while others believe the A-V nodal impulse in some manner returns from the auricle and passes again to the ventricle.

The possible point of re-entry of the impulse is of speculative interest. There is no evidence of a macroscopic circus movement in the auricular muscle since the auricular complex of the electrocardiogram does not generally alter its shape during reciprocal rhythm. If such a circus movement were present one would expect evidence of its existence in a change in the shape of the P wave. Consequently one has to explain the point of re-entry and such a circus movement, if it exists at all, as occurring in such a small area as to give no electrocardiographic alteration. Drury (12) suggested that the point of re-entry may be in the auricular portion of the A-V node itself and Cutts (9) reports an interesting case in which reciprocal rhythm occurred, but at times the auricular complex was entirely absent between the two ventricular complexes. He therefore comes to the conclusion that an impulse travelling up the junctional tissues may return and initiate a ventricular response without having entered and activated the auricle and he cites his case as evidence that auricular systole is not necessary for the production of the second ventricular response.

In order for the impulse to re-enter the conducting system and again initiate a ventricular contraction, the junctional tissues must be capable of transmitting the impulse very shortly after they have conducted it to the auricle. Mines in his consideration of reciprocating rhythm suggested that different fibres

of the conducting tissues may recover at slightly different rates, this difference enabling a stimulus to pass in one direction in one series of fibres and return by way of the remaining fibres which had by then recovered. A similar state of affairs can be postulated in reciprocal rhythm, the impulse travelling in a retrograde manner by a certain number of fibres only and returning by way of other fibres which had had time to recover from their refractory period. A point in favour of this explanation is found in the fact that a reciprocal contraction only occurs when conduction through the junctional tissues is considerably delayed as is indicated by the prolonged R-P interval of the electrocardiogram.

It occasionally happens that the second ventricular complex of reciprocal beating differs from the first ventricular complex in being widened, slurred or notched. Such a change in shape of this QRS complex indicates that the impulse has spread to the ventricles by different pathways than normally. Such abnormal complexes have been described by Dock (10), by Blumgart and Gargill (6) and by Cutts (9). The most probable explanation is that conduction pathways to the ventricle have not completely recovered from their refractory period following the initial ventricular response when called upon to convey the re-entered impulse to the ventricles. If the impulse be delayed longer in its passage to the auricle, the ventricle will have a longer time in which to recover from its refractory phase and the reciprocal ventricular complex will conform more nearly to its normal outline (Blumgart and Gargill (6) Case 4).

Prolongation of the R-P interval can be due to two possible causes - (i) a downward shift in the position of impulse formation in the node or (ii) variation in the degree of retrograde conduction. In many of the reported cases no variation is found to occur in the length of the ventricular cycles (R-R intervals) which would be expected were the former possibility the case. In the majority of cases, however, the second possibility appears to be the mechanism operating as (as has been previously stated) forward conduction through the A-V node takes place more readily than retrograde conduction; consequently it is highly probable that variation in retrograde conduction will occur more readily than in forward conduction. During the periods of reciprocal rhythm also, the P-R interval of the reciprocal beat is generally shorter, often considerably so, than the R-P interval of the initial ventricular complex. It is exceptional to observe R-P and P-R intervals of equal or nearly equal values, though in Case 1 (page 62) they will be found in Fig. 38 to almost equal each other.

Exponents of the second theory of the causation of this variety of ventricular bigeminy believe that the auricular activity is due, not to impulses received from the A-V node but from a second automatic centre situated low down in the auricle and initiating impulses undisturbed by the activity of any other centre. That is, they believe a variety of Parasytostole exists, there being two centres of impulse

formation to which the ventricles respond. Progressive lengthening of the R-P interval is explained by the two pacemakers possessing different rates of impulse formation, the auricular centre being slower than that of the A-V node, i.e., A-V dissociation. As in the theory of re-entry previously described interference with retrograde conduction is again assumed but in the theory of Parasystole it is regarded as being complete. Thus no impulses pass from the A-V node to the auricle and the auricular pacemaker is therefore guarded from the ventricular centre and there is no interference with its originating impulses. This block, moreover, is unidirectional, there being no interference with the passage of impulses to the ventricle. If impulses could not pass to the ventricles they could not produce ventricular systole and the resulting condition would be A-V dissociation. Since there is no impairment of forward conduction, impulses may pass from the auricular centre and excite the ventricles provided they do not encounter refractory tissue.

In this explanation, therefore, the mechanism is not regarded as one of A-V nodal rhythm since, owing to retrograde block, impulses cannot pass back and control the auricle. The sinus node is still depressed and a second auricular centre then forms impulses which activate the auricle. The situation of this secondary auricular centre lying low down in the auricle accounts for the variation in the shape of the P wave and its rate is necessarily slower than that of the ventricular centre, otherwise the auricular pacemaker would assume control of the ventricle.

Luten and Jesson (48) further point out that the degree of retrograde heart block need not necessarily be complete in a given case; that is, there may be a partial interference with backward conduction. The auricular pacemaker will then initiate impulses when undisturbed by the faster ventricular centre but impulses may travel back from the A-V tissues and if these faster impulses dominate the auricular centre completely simple A-V nodal rhythm will result. If the impairment of the retrograde conduction is sufficient to prevent A-V rhythm developing, it may be still insufficient to permit of the occurrence of parasystole. The mechanism of the bigeminal contractions under consideration may well lie between these two extremes, the degree of retrograde block permitting an impulse from the ventricular centre to pass back and prematurely discharge the impulse material being formed in the auricular centre. This could occur if the ventricular impulse reached the auricular centre towards the end of its automatic period; a similar occurrence has been described in cases of almost complete heart block where although an idio-ventricular rhythm has become established, a ventricular response may be prematurely initiated by the arrival of an auricular impulse just prior to the end of the ventricular automatic period.

Luten and Jesson discuss these two theories and further criticise the theory of re-entry. They point out that the work of Mines previously described and largely cited by exponents of the theory of re-entry

was concerned not with A-V rhythm but with movement in a ring of auricular and ventricular tissue. Nor has a similar mechanism been observed in the mammalian heart experimentally. These authors deny that a similar condition to that circus movement in the ring of auricular and ventricular tissue of Mines' experiment should be accepted as the cause of reciprocal rhythm. The hypothesis of parasystole on the other hand, is based on well-recognised physiological conceptions - variation in forward and backward conduction, separate centres of stimulus production, escape from one centre with the release of a second, the discharge of an impulse prematurely by a stimulus from a second centre and the transmission of the released impulse producing ventricular contraction with resulting parasystole.

Luten and Jesson thus consider A-V nodal rhythm, so-called reciprocal rhythm and parasystole to be fundamentally related, their occurrence depending upon the degree of retrograde interference present.

A further distinction between Mines' observations on reciprocating rhythm and reciprocal rhythm is that in the former the mechanism continued indefinitely until interrupted by a second stimulus, whereas reciprocal beats generally occur singly. It is interesting to note that in the example I quote in Case 1 (Fig. 44 et seq.) reciprocal rhythm continued, uninterrupted by single beats, for nearly half an hour.

In my case reciprocal rhythm occurred a few minutes after the administration of atropine. This also has been noted in cases described by Gallavardin (19), White, Wilson (75), Bishop (4) and Dock (10). White explained it as due to increased rate of the A-V rhythm following the administration of the drug leading to a prolongation of the R-P interval, the auricular impulse coming earlier than usual and finding the conducting tissues still somewhat refractory. In a case described by Blumgart and Gargill (6) as also occurred later in Bishop's case, atropine abolished reciprocal rhythm; in these cases this drug caused a shortening of the Q-P interval.

Gallavardin (19) in 1914 described a case in which carotid sinus pressure produced reciprocal rhythm and in Blumgart and Gargill's case right or left sided pressure increased the number of coupled beats by lengthening the R-P interval but in Dock's case vagal pressure diminished the tendency to coupling. In White's case digitalis as well as carotid sinus pressure produced reciprocal rhythm. Dock concluded that similar factors in the production of A-V rhythm were probably responsible for the occurrence of reciprocal rhythm provided their intensity were more marked in the latter condition, for the greater the A-V rate and the greater the degree of retrograde block the more frequently reciprocal beats occurred.

Reciprocal rhythm is a rare condition. Besides these references given cases have been described

by Gallavardin and Gravier (20), Jones and White (34), Cutts (8, 9) and Bain (1).

"PSEUDORECIPROCAL RHYTHM"

This name was given by Katz and Kaplan (35) to a bigeminy similar to reciprocal rhythm occurring in Interference Dissociation and caused by the conducted auricular impulse.

In this condition a P wave is also situated between the two ventricular complexes of the couplet in a similar position to that occurring between the coupled beats of reciprocal rhythm. If the impulse arise in the head of the sinus node this P wave will be upright and the distinction between reciprocal and pseudoreciprocal rhythm is then obvious. But difficulty in this differentiation occurs when the P wave arises low in the auricle, its shape being abnormal or even inverted. Zeissler (79) emphasises that before the condition can be accepted as reciprocal rhythm the P wave between the coupled ventricular beats must be actually demonstrated to be of retrograde origin and that a deformed or inverted P wave is not sufficient evidence of this. Zeissler studied many cases reported in the literature as reciprocal rhythm and in his opinion many of these records are really examples of interference dissociation. (He considers that of records reported by White (70), Dock (10) and Blumgart and Gargill (5) fourteen are almost certainly examples of interference dissociation and not of reciprocal rhythm. In his opinion there are actually only four or five true cases of reciprocal rhythm reported).

Hermann and Ashman (80) give two criteria which they regard as of value in the differentiation between reciprocal and pseudoreciprocal rhythms:-

1. The direction of the P wave; if this wave is upright in Leads I and II or I, II and III, the case is certainly one of interference dissociation.

2. The auricular regularity; if the auricles are regular, interference dissociation is again the probable mechanism for it is most unlikely that regular auricular contraction could occur with the progressively increasing interference with retrograde conduction seen in reciprocal rhythm.

Many examples of "pseudoreciprocal rhythm" are illustrated in Case 1.

*

Symptoms and Physical Signs.

The conditions discussed are frequently unaccompanied by any symptoms. One symptom which does occasionally occur is palpitation and it may be accompanied by a feeling of tension in the neck. In A-V nodal rhythm it is probably due to the simultaneous contractions of auricle and ventricle, the former chamber being unable to force blood into the ventricle forces it back into the great veins. In paroxysmal tachycardia where similar palpitation occurs, the cause is the same. In interference dissociation the palpitation is due to the conducted auricular beats interfering with the otherwise regular ventricular sequence. It is possible that individual patients differ in their sensibility to appreciate these forms of palpitation just as individuals differ in their realisation of the intensity of pain. Less sensitive individuals may fail to appreciate these more forceful beats and the situation is similar to the appreciation or absence of palpitation with extrasystoles. There may occasionally be a feeling of dizziness or faintness which is generally associated with bradycardia or possibly with short periods of ventricular standstill.

The physical signs are also very few and as has been stressed previously, it is impossible to diagnose these arrhythmias without the aid of the electrocardiogram. The conditions are so uncommon that they are likely to be overlooked by the physician during clinical examination. A curious double pulsation of the jugular veins is often observed due to the simultaneous contraction of the auricle and ventricle. Another sign occasionally noted is an alteration in the character of the first heart sound (Mathewson, 49; Belski, 5; Cutts, 8). Oettinger and Neslin (55) studied this change in the heart sound by means of the phonocardiograph and demonstrated an increased intensity of the first sound when a P wave fell shortly before or occurred simultaneously with the QRS complex. This is analogous to the increased intensity of the first sound when the P wave and QRS complex coincide in complete heart block (Lewis, 44). An accompanying murmur may also be altered in its intensity, as occurred in Mathewson's case.

X-ray screening of the heart is unlikely by itself to furnish the diagnosis. It is very difficult to identify dissociated contraction of both the auricle and ventricle on the screen owing to the normally short interval between their respective contractions and because the radiologist cannot stand sufficiently far away to accurately observe the time relations of the contraction of both chambers in respect of each other. In Case 1 of this thesis, however, owing to the slow heart rate, it was possible to distinguish certain changes in the auricle-ventricle sequence and which will be described later. A similar pulsation in the superior vena cava to that occurring in the jugular veins may also occasionally be observed by means of the X-ray screen.

Diagnosis.

The necessity for some form of graphic recording of the heart beat in the diagnosis of the arrhythmias under discussion has been repeatedly stressed. The polygraph, with which many of the earlier records were obtained, has now been replaced by the more accurate electrocardiograph. Errors are very likely to arise in the interpretation of polygraphic records in the jugular waves of which the a and c waves almost or completely coincide. It is also very difficult to distinguish between A-V nodal rhythm and A-V dissociation with or without interference in the polygram.

The electrocardiograph is the instrument of choice as the two arrhythmias can be easily recognised and differentiated in the record. The electrocardiographic records of A-V rhythm and A-V dissociation with or without interference and of reciprocal rhythm have been fully described and it is not my intention to repeat their features here, beyond drawing attention to one or two points.

It is the shape of the P wave as well as its relation to the QRS complex which is of importance in deciding the place of origin of the stimulus. It has already been pointed out that a downward dislocation of the pacemaker in the auricle leads to alterations in the shape of the P wave (see page 19) and although the centre of impulse formation be located in the lower parts of the auricle, not in the A-V node, the P wave may be inverted. This low position of the centre in the auricle may also lead to a shortening of the P-R interval and an erroneous interpretation of A-V rhythm may be made. In some instances an abnormal path of the impulse through the auricle may lead to deformity or even inversion of the P wave. Conversely, the P wave may be upright even although the impulse has arisen in the A-V node (Scherf and Shookhoff, 65). Consequently it may be impossible to come to an accurate diagnosis of A-V rhythm. One has to take all records and complexes into account and endeavour from a study of them to localise the point of origin of impulse formation.

Prognosis.

The conditions described are relatively rare, although A-V dissociation may be more frequent than is generally supposed. Their occurrence would appear to be of intrinsic interest rather than of great clinical importance, although their study, especially that of reciprocal rhythm, may throw some light upon other cardiac irregularities such as paroxysmal tachycardia. Generally these arrhythmias are temporary and frequently recurrent phenomena lasting for a few beats, minutes or hours and commonly alternating with periods of normal sinus rhythm. Probably the case of longest duration previously described is that of Williams and James (73) in which A-V nodal rhythm persisted for over a year but nevertheless with signs of improvement. A case described by Schott (68) was known to have had a sinus bradycardia for over twenty

years, when temporary A-V rhythm and A-V dissociation lasting about a fortnight developed. One of my cases has shown periods of A-V rhythm, A-V dissociation with interference and sinus bradycardia for eighteen months whilst under my observation and very probably for at least two years according to the history.

These arrhythmias are not in themselves serious and cannot be regarded as indications of heart disease. Disease of the heart may or may not be present; at least no evidence of cardiac disease may be identified by clinical, instrumental or laboratory methods. Many of the reported cases occurred in association with myocardial or coronary disease but it is this associated pathological process and not the arrhythmias which determines the prognosis of each case. In 1922 Richardson (58) made a careful study of the reported cases of A-V rhythm (at that time he could only find twenty) and concluded that in no case did death occur as a result of the abnormal rhythm alone; there was in each fatal case ample cause revealed post-mortem to account for death. The remaining cases were transient or of short duration, apart from Williams and James' case where improvement was taking place. The cases reported since Richardson's review in 1922 favour his conclusions.

Treatment.

As these arrhythmias are generally of short duration treatment is not usually required. Effective therapy to restore normal rhythm may not be possible in some cases. As vagal hypertonia is the most common underlying cause atropine or tincture of belladonna may be of value. The usual symptom of these arrhythmias is palpitation which occasionally is very troublesome and according to Schott (69) a symptomatic cure may sometimes be obtained by small doses of digitalis (see page 26).

*

PART III.

In this section cases are described illustrative of the conditions described in Part II.

Case 1. V.A. A married man aged 34 years.

This case is in many ways unique, and as it illustrates all the conditions which have already been described, I therefore propose to give a full description of it. Many of the published cases illustrating A-V rhythm, A-V dissociation with or without interference and reciprocal rhythm are too briefly described, so that their value is considerably lessened. For this additional reason I give a full account of the history, physical examination, laboratory and other investigations, together with many illustrative electrocardiograms.

The patient attended the Out-patient Department at the Leicester Royal Infirmary for the first time in May, 1939. He then complained of tiredness and dizziness, severe palpitation and aching pains in the legs. As on physical examination his pulse was found to be regular, but having a rate of only 32 beats per minute he was provisionally regarded as a case of Heart Block. On the 1st. June, 1939 he was admitted to the above institution when the following history was obtained.

He joined the Army in 1918 being passed A.1. His previous health was good, and he had never had any serious illness. He was sent to India and whilst there, in 1925, developed Malaria. Altogether he had four attacks but when he left the Army in 1927 he felt perfectly well. He was fond of sport and regularly played cricket, hockey and football. On returning to this country in 1927 he commenced work in a warehouse where he remained for five years. Following this he was a snack-bar chef for about six years. Until nearly the end of this time, i.e., until 1938, he remained well and active. Then failing health finally compelled him to give up his employment.

About twelve months previous to his attending the Infirmary he began to experience dizziness and palpitation which became progressively worse. He cannot recall any reason for their commencement, and he did not suffer from any illness such as influenza or tonsillitis, so far as he can recall.

The dizziness became very severe and as he expressed it, "he had to take a firm grip of himself or he would have gone right off", but though his mind seemed to go blank for a few seconds he never actually fainted. This symptom would recur several times a day irrespective of what he was doing, - even when he was sitting quietly in a chair.

The attacks of palpitation also would come on at any time and he has had severe attacks when in bed. His heart "thumped" very forcibly but always

slowly. He has never experienced a rapid form of palpitation. Occasionally the palpitation commenced after a meal, and sometimes exertion brought it on. This symptom appeared to have no relation to the dizziness.

He also experienced other subjective symptoms, - a "singing sensation" in the head during the giddy attacks but he had no actual headache, "burning sensations" in the hands, knees and feet fairly frequently and aching pains in the legs and shoulders, particularly when he had been using the limbs as for example in walking, never when lying at rest.

When these symptoms were at their worst he often "felt as though he were going to die".

There were no other symptoms referable to the heart. He did not complain of breathlessness although on careful questioning he admitted slight dyspnoea only on undue exertion and occasionally after a meal. His ankles never became swollen.

His appetite was poor but he had no digestive disturbance, though inclined to be constipated.

Nothing revelent was found in the Family History.

On examination his general condition was found to be good and he was quite well nourished, but he looked tired and ill. There was no evidence of cyanosis or dyspnoea. His intelligence was well above the average.

The pulse was slow, 32 per minute, with occasional irregularity. The slow heart rate could also be observed in the pulsation of the jugular veins which were not distended between the heart's contractions, but frequently showed a curious double flicker coincident with the heart beat.

The apex beat was located in the Vth. left intercostal space just internal to the mid-clavicular line.

On auscultation the slow heart rate was noticeable with occasional premature beats, but the sounds were closed in all areas.

Blood pressure was 110:66.

There was no dyspnoea.

The teeth were artificial, the tongue was clean and moist; the throat was clean and there was no evidence of infection of any of the nasal sinuses. The abdomen was muscular; the liver was not enlarged and the spleen was not palpable.

Examination of the respiratory and central nervous systems was entirely negative.

The temperature was normal or slightly subnormal during the whole of his stay in hospital.

The pulse rate remained on the average in the neighbourhood of 36 per minute until shortly before discharge when it rose to about 50 per minute.

Respiration was regular at 20 per minute.

The urine was clear, usually slightly acid; S.G. 1025. An occasional trace of albumen was noted.

Blood examinations revealed normal cell counts and films, apart from a mild leucocytosis. (Hb. 100%: red cells 5,000,000; C.I. 1.0; halometer reading 7.4. Leucocytes 12,187 per c.m. of which 76% were polymorphs, 14% lymphocytes and 10% mononuclears.)

The blood Wassermann Reaction (and provocative reaction) was negative.

X-ray screening of the heart failed to reveal any cardiac abnormality or enlargement, other than the obvious bradycardia.

At this time the case was regarded as one of Heart Block as the full significance of the electrocardiographic changes was not realised. He was therefore given a course of anti-syphilitic treatment in spite of the negative Wassermann Reaction and the absence of other signs of syphilis, and even then it was felt that the cause was not due to such a condition. However he did show some improvement whilst in hospital, the pulse rate rising to 50 beats per minute and his symptoms also became less marked.

He was discharged on 28--6--39 and continued with the course of injections as an out-patient and he also regularly attended the Cardiological Out-patient Clinic.

It was whilst he was attending this Clinic that I realised the true nature of the arrhythmia present, particularly as with the recently acquired Victor Electrocardiograph such clear tracings were obtained. The previous records which I had taken with the Cambridge machine were then re-examined and they too undoubtedly showed the characterisation of A-V nodal rhythm and A-V dissociation described in Part II.

I continued to watch him as an out-patient for the following eight months. Anti-syphilitic treatment was discontinued early in September. On the whole there was very little change in his condition but the pulse rate returned to the neighbourhood of 36 beats per minute. He continued to complain of occasional slow, forcible palpitation, attacks of dizziness, and of tiredness, but these symptoms were not nearly so severe as previously. He was advised to take exercise and was given small doses of tincture of belladonna, but no significant alteration in his condition resulted.

On 26--2--40 he was re-admitted to hospital in order to carry out more extensive investigations. The physical examination was similar to that given above, and no additional features presented themselves. I tabulate the results of these investigations below:-

Blood examination - repeated several times - was always within normal limits. No leucocytosis occurred.

Blood sedimentation rate (Westergren's method): The readings were taken on some half dozen occasions and never exceeded 2 mm. in one hour and 5 mm. in two hours.

Blood urea - 27 mgm. per cent.

Basal Metabolic Rate (repeated on two successive days) -3% and -2% respectively.

Estimations of Circulation Times: By Histamine Method - antecubital vein to flushing of the face, 35 seconds (average of several readings). By Sodium Cyanide Method - antecubital vein to carotid sinus - 41 seconds (average of several readings).

Urine: S.C. 1012. Acid. No abnormal constituent was present.

On X-ray screening of the heart no gross cardiac change was noted.

Attempts were also made to produce an artificial rise of temperature first by the administration of 5 c.c. of boiled milk intra-muscularly, and later by the subcutaneous injection of a dose of 500 million T.A.B. vaccine. No rise in temperature occurred with the former method, and only 99°F. was recorded following the latter method; no change in the pulse rate took place.

The action of various drugs was also investigated with the aid of the electrocardiogram, the results of which are given later.

He was again discharged on 13--4--40, there being practically no change in his condition, and he continued to attend the Out-patient Clinic until the end of September, 1940. During all this time there was little change in the pulse rate and the arrhythmias, which will be described with the appropriate electrocardiograms, continued as before. His general clinical condition has definitely shown improvement since he first came under my observation and his symptoms have become much less marked. He is still easily fatigued and unfit for work.

On 30--8--40 his heart was examined more carefully by means of the X-ray screen. The heart's action was extremely slow and the pulsation of the left auricle and ventricle appeared irregular and followed roughly the rhythm given below:

VA-----VAA-----VA-----VAA-----VAA-----VA.

where V = the ventricular contraction and A = the auricular contraction. The contraction of the auricle at this time definitely succeeded that of the ventricle and occasionally there was the impression of two auricular contractions occurring immediately after one another.

The heart on a whole was not enlarged, and apart from a doubtful increase in size of the left auricle no alteration in the size of the cardiac chambers was observed.

Figures 11 - 14 are reproductions of X-ray

films taken at this examination in the antero-posterior, left lateral and right and left oblique positions respectively.



Fig. 11.

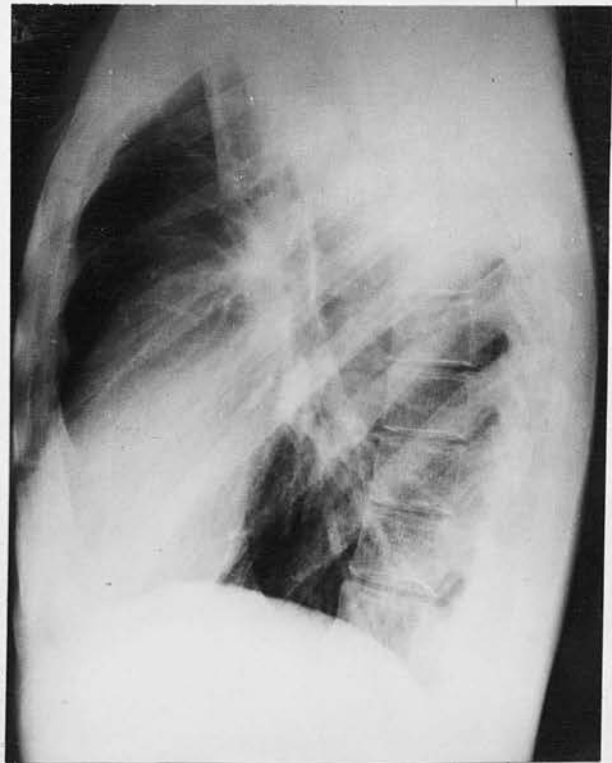


Fig. 12.



Fig. 13.



Fig. 14.

Case 1 - Electrocardiograms.

I have not kept to the order in which these records were taken, but have re-arranged them in order to discuss and compare the individual records in a more logical sequence. Each record has, however, been dated according to the time when it was taken.

As has previously been stated the true nature of the arrhythmias was not realised at the times when the first records were taken with the Cambridge Electrocardiograph, and the case was regarded as one of Heart Block. Later records taken with the Victor Machine revealed its true character and these previous records were then re-examined. The fact that too little attention had been paid to these tracings was largely due to the patient having been mainly examined using a Cossor Cathode Ray Oscillograph where also the condition was missed.

Figures 15, 16 and 17 are examples of these records taken with the Cambridge machine.

Before studying these three records in detail, one notices the slow rate of the heart and slight irregularity occurs in all of them. The ventricular complexes conform in character to those arising from supraventricular impulses. The diastolic line is usually smooth and unbroken, uninterrupted by the occurrence of a P wave preceding the ventricular complex.

In Fig. 15, which was the first plate taken, changes in the position and character of the P wave are readily seen. In Lead I, the P waves are of low amplitude, but are seen as small upright deflections on the S-T interval. In Lead II, the P waves are similarly placed, but are deeply inverted; they occur at the same interval ($Q-P = 0.18$ second) after each ventricular

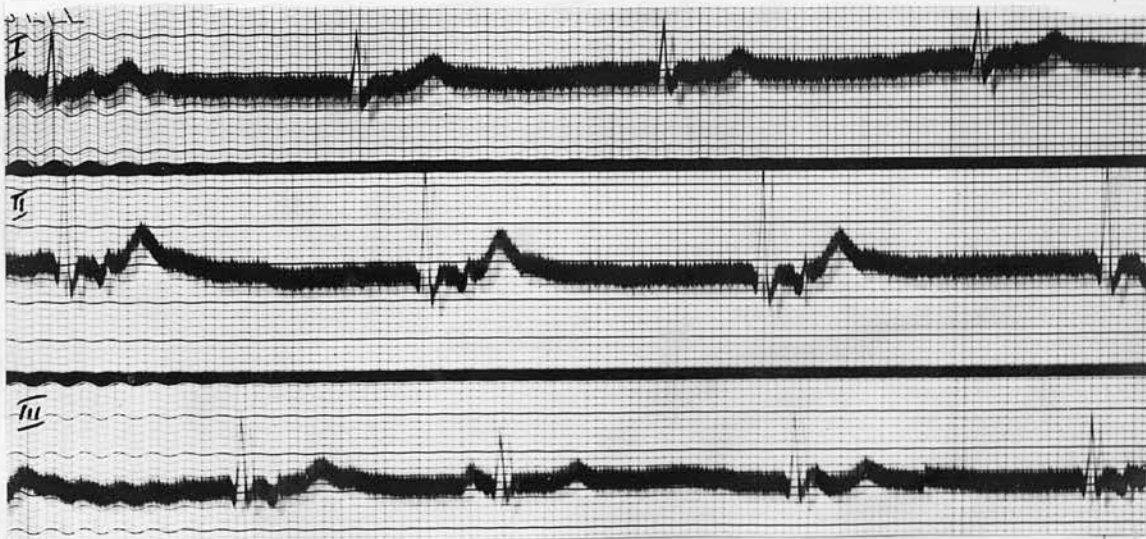


Fig. 15. 5--6--39

deflection. In Fig. 16, a similar state is seen, but occurring in all three Leads. (The distortion of the latter part of Lead III is due to the plate having come off the runners in the camera box). In this instance the Q-P interval has an average duration of 0.28 second. Both Lead II of Fig. 15 and Fig. 16 show Atrio-ventricular Nodal Rhythm, the impulse arising in the lower portion of the A-V node.

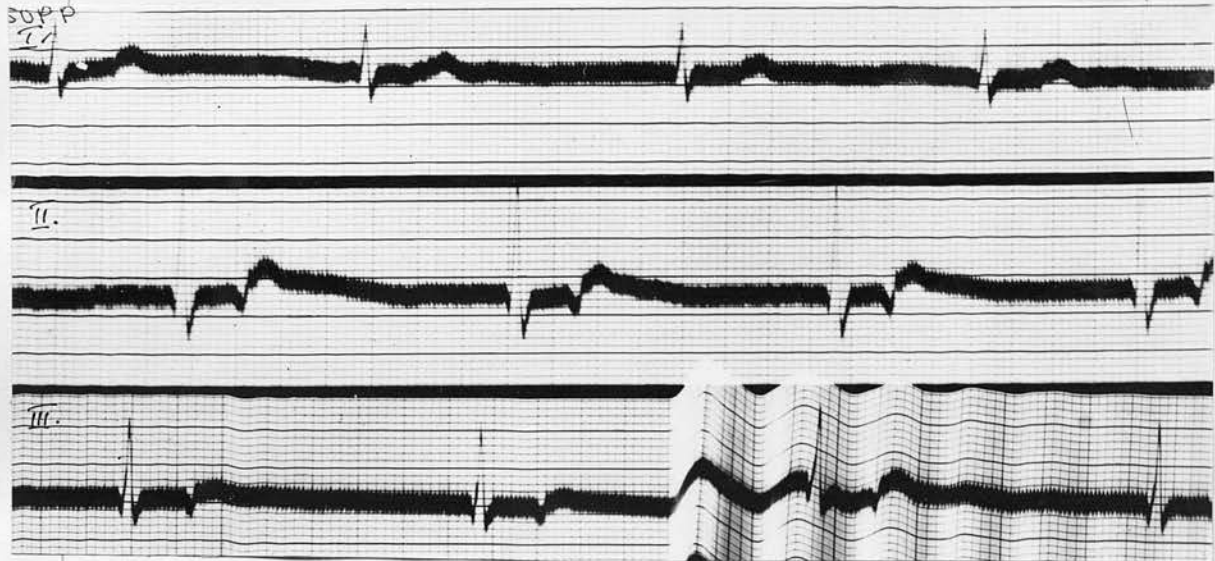


Fig. 16. 8--9--39.

Lead III of Fig. 15 shows a similar inverted P wave lying in the S-T interval in the cases of the first and last complexes. The second ventricular complex is preceded by a normally shaped upright P wave with a P-Q interval of 0.16 second and is presumably a response to an impulse arising in the head of the sinus node. The third beat, however, shows a normal upright P wave following the QRS deflection; here the ventricular centre has escaped just before the sinus impulse is due.

In Fig. 17 some additional features are shown. There has been some distortion of the beam probably due to restlessness of the patient and it is difficult to be certain of the form of the P wave in Lead I with the exception of the last complex where it appears deeply inverted on the S-T interval.

In Lead II of this figure, the first two complexes are preceded by normally shaped upright P waves and appear to be sinus beats. Following this second beat there appears a premature deformed complex followed by a compensatory pause - a ventricular extrasystole. Its main feature of interest lies in the deformity of the S-T interval, which appears to be due to a downward wave just prior to the commencement of the T wave; this may be caused by a negative P wave due to retrograde conduction of the stimulus producing the extrasystole - a very uncommon feature in ventricular

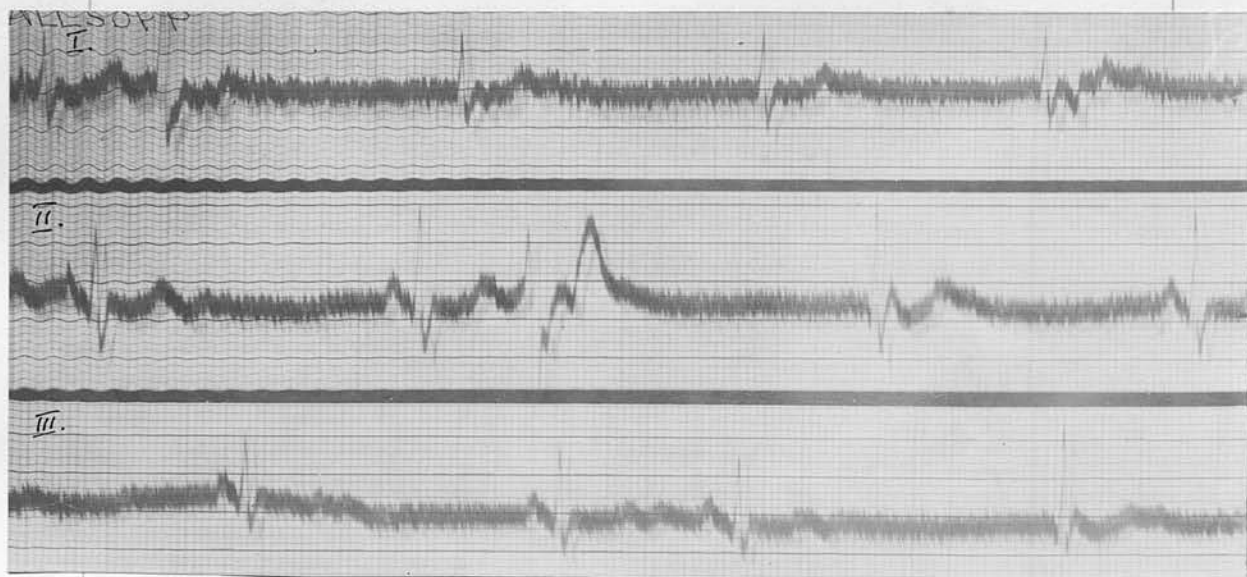


Fig. 17. 22--6--39.

premature beats. At the end of the following compensatory pause the ventricle escapes in response to an impulse arising in the A-V node, and is immediately followed by the upright sinus P wave. The final beat shown in Lead II is again a normal sinus response, the P wave being followed by the QRS complex after a P-Q interval of 0.16 second.

In Lead III the first three ventricular beats are preceded by normal upright P waves occurring at intervals of 0.12, 0.14 and 0.18 second respectively. This increase is probably due to transition from A-V dissociation (illustrated later) to sinus rhythm. The third cycle is also considerably shorter than the preceding one, measuring 0.92 second as compared with 1.64 seconds. The final cycle of Lead III has an R-R interval of 1.74 seconds, and is another example of escape of the ventricle, the P wave occurring almost simultaneously with the QRS complex. Lead III might be taken as illustrating marked sinus arrhythmia, the ventricles escaping when the R-R interval reaches a duration of about 1.74 seconds.

The following reproductions are from records taken with the Victor Amplifying Electrocardiograph.

Fig. 18 probably illustrates the simplest mechanism occurring in this case. It shows a sinus bradycardia with a heart rate of 35 per minute. The rhythm is regular except at the beginning of Lead III where an aberrantly shaped ventricular complex occurs prematurely. There is no P wave preceding the first ventricular complex of Lead III, but a notching occurs on the ascending limb of its T wave which is due to an auricular complex. This coupling of ventricular beats will be more fully described later, and I shall not consider this change further at present. Pure sinus bradycardia was recorded in relatively few records in



Fig. 18. 24--11--39.

this case and at widely separated times. The P-Q interval in this record measures 0.16 second.

Figures 19, 20 and 21 show uncomplicated examples of A-V nodal rhythm, in each instance the deeply inverted P wave lying on the S-T interval and occurring at the same time interval after the QRS complex in each of the respective records. The Q-P intervals of these three records are 0.21, 0.23 and 0.34 second respectively. In Fig. 21, which has the longest Q-P interval of the three records, the inverted P wave is seen at the commencement of the ascending limb of the T wave. In each instance, the impulse causing contraction of both auricle and ventricle probably arises low in the A-V node.



Fig. 19.

21--3--40

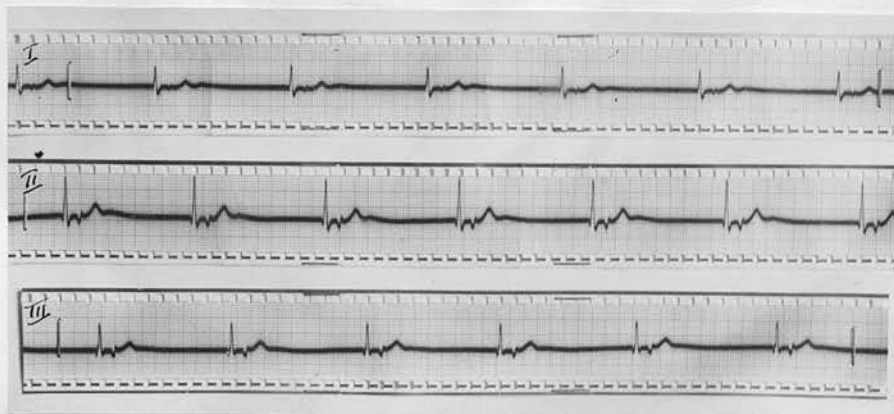


Fig. 20.

4--4--40.

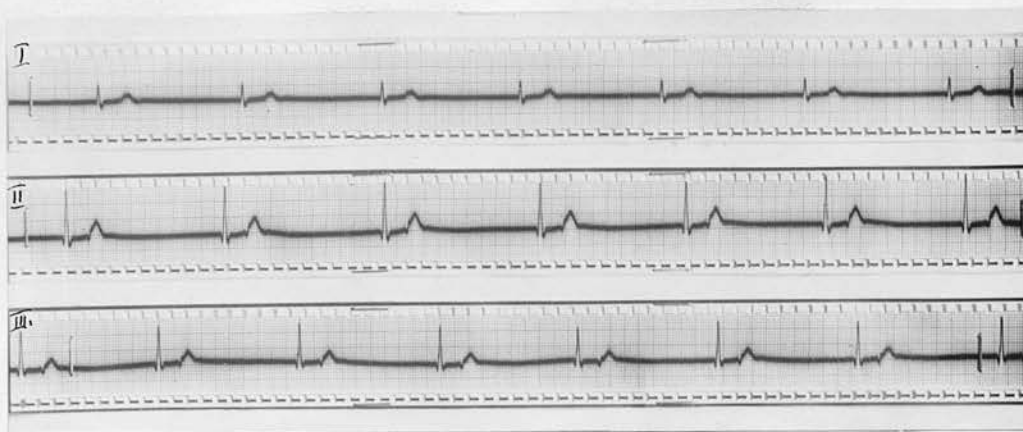


Fig. 21. 29--2--40.

Other records frequently show a dissociation of auricle and ventricle. Simple examples of this change are shown in Figures 22 and 23.

In Fig. 22, there is a sinus bradycardia shown in Leads I and II, the P wave being upright and preceding the QRS complexes by a P-Q interval of 0.16 second. In Lead III, however, an alteration occurs. The first two beats are similarly of sinus origin; but in the case of the third beat the P and QRS complexes occur very nearly simultaneously, and no P wave is apparent in the case of the fourth ventricular systole. Then an apparently normal sinus beat occurs, and is followed by two beats with no evident P waves. It is probable that the auricular contraction coincides with that of the ventricle. Measurement of the R-R intervals indicates a very gradual shortening up to the fifth complex, when they again become a little longer. This Lead has been illustrated diagrammatically below the record and the values of the P-Q and R-R intervals are inserted.

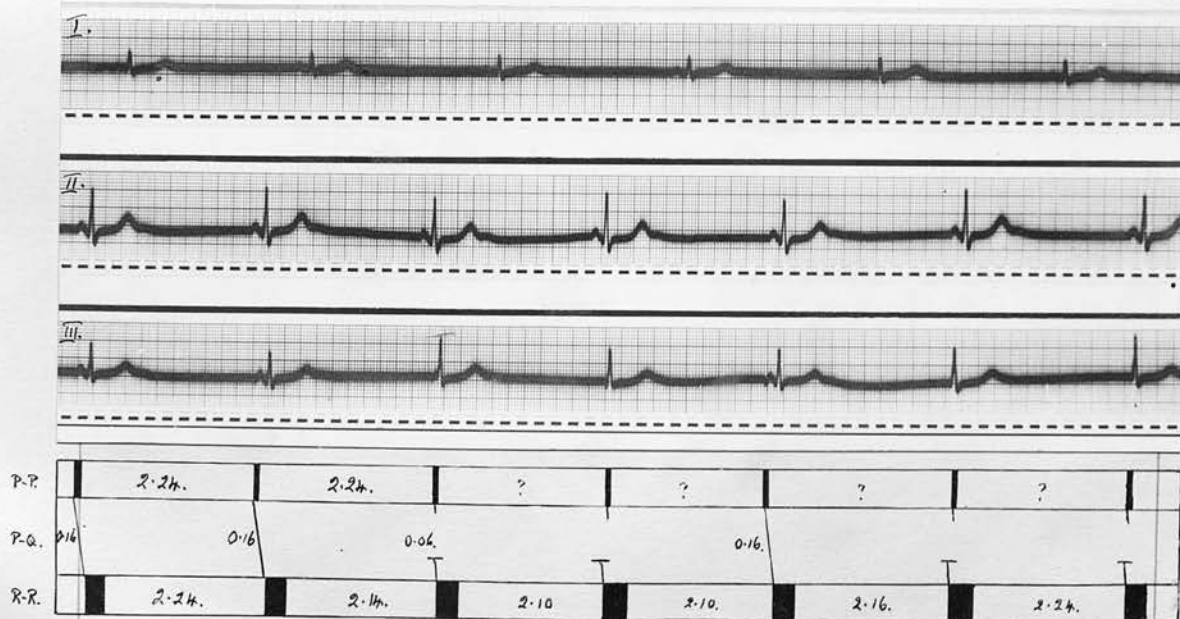


Fig. 22. 19--7--40

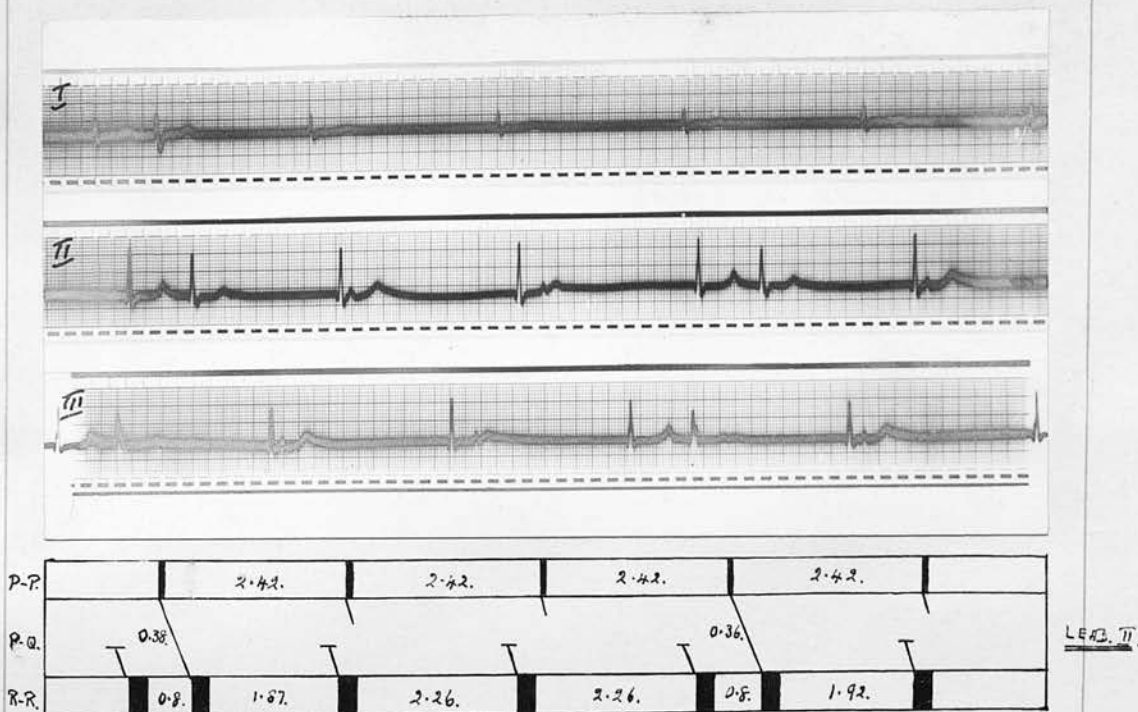


Fig. 23. 2--8--40.

Fig. 23 shows a further variation of the condition illustrated in Fig. 22. The P waves are visible throughout the record and are always upright, indicating their origin in the sinus node. Their relation varies, however, to that of the ventricular complexes. As the P waves are of low amplitude and difficult to see in Lead I, only Leads II and III will be considered. Disregarding the coupled beat at the beginning of Lead II for the moment, the upright P wave is seen following the initial QRS complex of the second beat. In the case of the third beat it occurs even later after the QRS complex, and later still in the case of the fourth beat, where it produces a sharp peak to the T wave. This last P wave is then followed by a second ventricular contraction which occurs prematurely; this is an example of Interference Dissociation, the auricular impulse occurring so late after the primary ventricular systole that it has not met with completely refractory tissue on its way to the ventricles and has initiated their contraction. No compensatory pause follows this second ventricular beat, but on the other hand the R-R interval is shorter than the R-R interval between single ventricular beats. This shortening of the R-R interval has been explained by Scherf and is considered on page 24. Similar coupling of beats occurs in both the other Leads. In Lead III an additional feature is well illustrated, namely notching and widening of the second ventricular complex of the couplet. This is due most probably to aberrant conduction of the impulse to the ventricle owing to its meeting with tissue still somewhat refractory. The auricular rate in this record is 25 and the ventricular

rate is 27 beats per minute. The P-Q interval of the conducted beats is prolonged to approximately 0.36 second, probably due to a hold up of the impulse in the still partially refractory junctional tissues.

These coupled beats due to Interference Dissociation are examples of the "pseudo-reciprocal rhythm" to which attention has been drawn on page 34.

I have again produced Lead II of this record diagrammatically, the time values being given in seconds.

Of the many records taken routinely in this case relatively few illustrated only one of the three conditions just described; the majority of the electrocardiograms showed transitions between one or other of these conditions. I have chosen the electrocardiograms reproduced in Figures 24 and 25 as examples of these changing mechanisms.



Fig. 24. 25--3--40.

In Fig. 24, Lead II shows an uninterrupted sinus bradycardia, the QRS complexes following the upright P wave at an interval of 0.18 second. Lead III, on the other hand, is an example of A-V nodal rhythm similar to Fig. 21, the Q-P interval measuring 0.32 second. The first three complexes of Lead I also show an A-V nodal rhythm, the inverted P wave lying on the S-T interval 0.24 second after the commencement of the R wave. The remaining four beats, however, reveal upright P waves occurring at slightly diminishing intervals after the R wave. Closer examination of the inverted P waves of the first three complexes reveals that slight changes are also progressively occurring in their shape. The ventricular rhythm is practically regular and the fact that the P waves of the first three beats fall at identical intervals after the QRS complex strongly favours their A-V origin. The changing shape of the P waves is probably due to the meeting of the positive and negative waves from the S-A and A-V nodes respectively, transition taking place between the two mechanisms and A-V dissociation resulting.

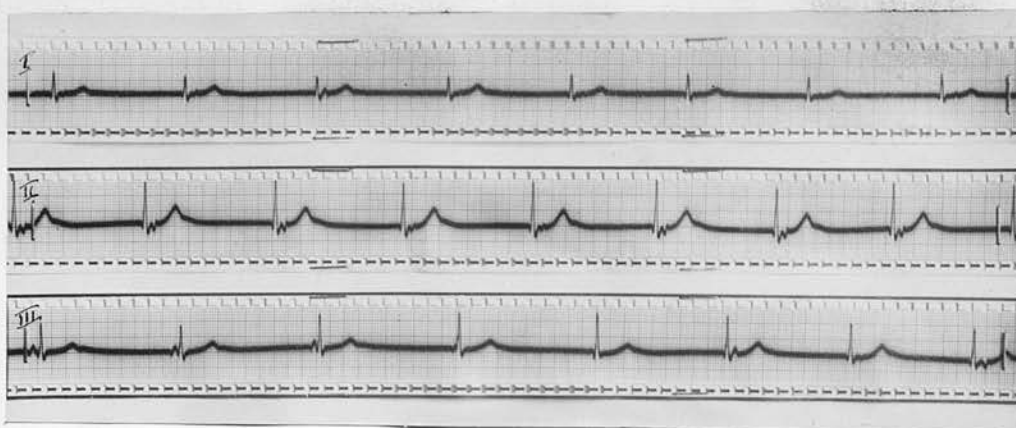


Fig. 25. 2--2--40.

Fig. 25; Lead II again reveals the typical appearance of A-V nodal rhythm, the inverted P wave falling shortly after the QRS complex. In Lead I the P wave again follows the ventricular complex, but its shape alters as one looks along the record. At first it is almost iso-electric, but appears to be slightly inverted; in the second and third beats it becomes upright; then it gradually becomes almost iso-electric again, but in the last two beats it just regains its upright form.

Lead III provides a good example of the transition through sinus bradycardia, A-V dissociation and A-V nodal rhythm. The first beat of this Lead is probably of sinus origin, although the P-Q interval of 0.12 second is low. During the second, third and fourth beats the P wave is seen to gradually approach the QRS complex; it is merged in the fifth QRS complex, and appears on the far side of the sixth ventricular systole, but it is definitely upright. In the case of the seventh response we see a transition form of the P wave which is small and negative and in the final complex the P wave, now inverted, appears to have been formed in response to a retrograde impulse from the A-V node. There is a gradual increase in both auricular and ventricular rates during the second half of the record, the latter ranging from 30 to 33 per minute. The relative rates of both chambers are too nearly identical to allow of accurate comparison.

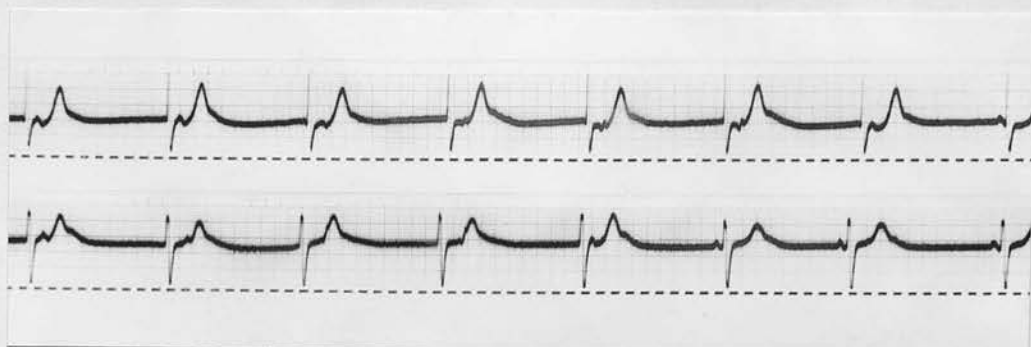


Fig. 26. 27--6--40

In Fig. 26 the changes occurring in chest leads are illustrated. The alterations in the shape and location of the P waves are clearly shown, and changes to or from sinus bradycardia, A-V nodal rhythm and A-V dissociation are present.

The exceptional constancy of the three mechanisms, sinus bradycardia, A-V nodal rhythm and A-V dissociation with or without interference over such a long period of time enabled many observations to be made and I propose now to describe in detail the effects of various clinical and pharmacological procedures upon the electrocardiographic pattern.

The Effect of Exercise.

The usual method of exercise employed was standing erect and lowering and raising the body by bending and straightening the knees some twelve times, the electrocardiogram being taken immediately afterwards with the patient sitting. On nearly every occasion this resulted in a quickening of the heart rate, but there was no alteration in the nature of the cardiac mechanism. Of the several records taken following exercises I have chosen Fig. 27 as a typical example.

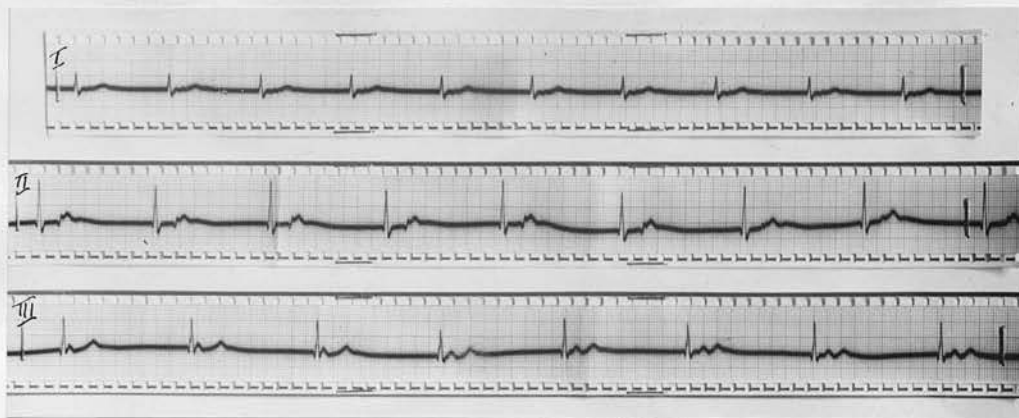


Fig. 27. 10--5--40.

Lead I was taken immediately after this exercise and the remaining Leads were recorded in rapid succession. Thus the greatest effect on the heart rate is seen in Lead I. The rhythm is entirely regular and the heart rate is 43 per minute. A record taken immediately prior to the exercise had a rate of 35 beats per minute. Thus the exercise had increased the heart rate by 8 beats per minute. By the time Lead II of Fig. 27 was recorded the heart rate has decreased to approximately 35 beats per minute and by the time Lead III was recorded a further slight slowing to 33 beats per minute has taken place.

But the effect of exercise has not resulted in a sinus rhythm. In Lead I the P is a small diphasic wave on the S-T interval occurring approximately 0.20 second after the commencement of the R wave. In Lead II the P wave is again diphasic with a Q-P interval of

0.30 second. In the last three beats of Lead II the P wave is of transition form and in Lead III A-V dissociation is seen, the P wave being a well-defined upright wave lying shortly after the QRS complex. The rates of auricle and ventricle in Lead III are very nearly equal.



Fig. 28. 5--7--40.

Fig. 28 is another example following exercise, but on this occasion he walked up and down two steps totalling 18" high, twenty times, i.e., he performed 4050 foot-pounds of work since his body weight was 135 lbs. Fig. 28 was taken immediately following this exercise and comparing the rate of Lead I with that occurring in a previous record taken at rest before starting the exercise, one finds an increase of 7 beats per minute. Again no change occurred in the cardiac mechanism, - alternating A-V dissociation with A-V nodal beats being clearly seen.

Fig. 29, however, shows a marked difference from the preceding two records and is of exceptional interest. It was taken following exercise performed as in the case of Fig. 28, but more vigorously, the amount of work done being 6075 foot-pounds. The most striking feature is the arrhythmia. It will be noticed that the ventricular complexes are all preceded by upright P waves, the P-Q interval being 0.20 second, indicating the sinus origin of the impulse. But in each Lead long pauses occur, the R-R intervals of which are approximately equal to the interval between three of the more rapid QRS complexes. Thus it would appear as though a complete beat comprising both auricular and ventricular complexes had been omitted; that is the impulse presumably has never left the sinus node and a condition of sino-auricular block appears to be the reasonable interpretation. (The small deflection occurring during the second long pause in Lead I is an artefact).

In the electrocardiogram taken before the exercise (Fig. 30) sinus bradycardia (ventricular rate

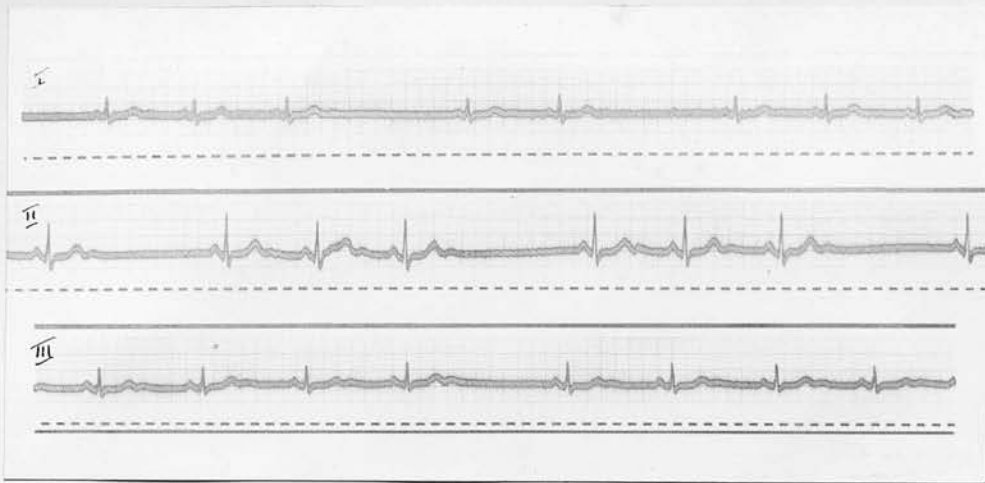


Fig. 29. 27--6--40.

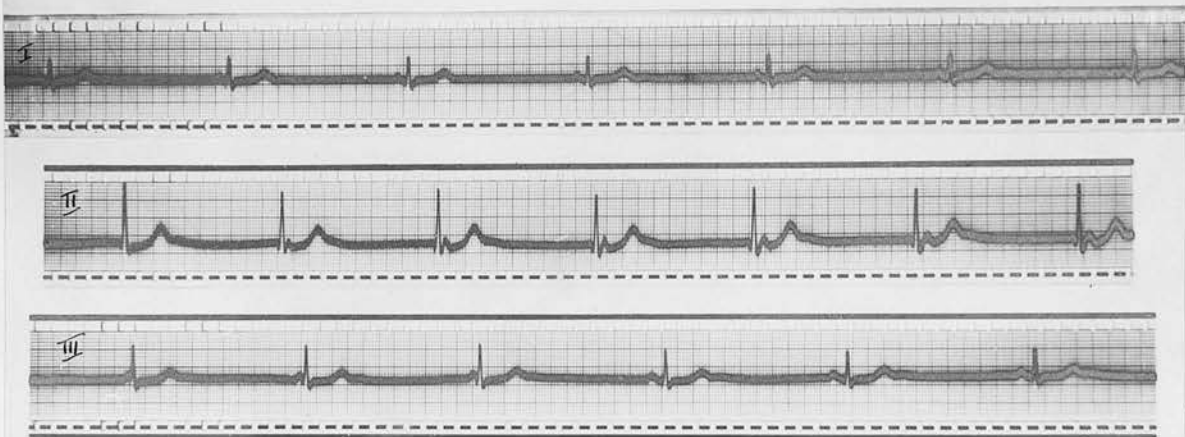


Fig. 30. 27-6-40.

26 per minute) is present in the whole of Lead I and in the latter half of Lead III, Lead II and the first half of Lead III showing A-V dissociation. Some ten minutes after the exercise the effect of intravenous atropine was studied and the first part of this record (Fig. 44A) again shows a sinus bradycardia uncomplicated by any other form of mechanism until the atropine begins to take effect. The unexpected appearance of sino-auricular block shown in Fig. 29 makes one wonder whether the sinus bradycardia occurring at other times is also due to this mechanism, every second sinus impulse being blocked before it reaches the auricle. A study of the numerous records taken in this case reveals one other electrocardiogram (not reproduced) which might favour this hypothesis.

The increase in rate shown in Fig. 29 following exercise is very marked. The heart rate both prior to the exercise (Fig. 30) and after the effect of the exertion had passed off (Fig. 44A) was practically regular at 26 beats per minute. Assuming impulses had

yielded ventricular contractions during the periods of sino-auricular block, the heart rate in Fig. 29 would have been 47 beats per minute - nearly double the heart rate before exercise.

The Effect of Adrenaline.

As one might expect Adrenaline produced a similar effect to that of exercise. 10 minims of adrenaline were given subcutaneously and the electrocardiogram reproduced in Fig. 31 was taken five minutes later. A record taken previously had sinus bradycardia with a rate of 29 as its main feature, A-V dissociation occurring occasionally.

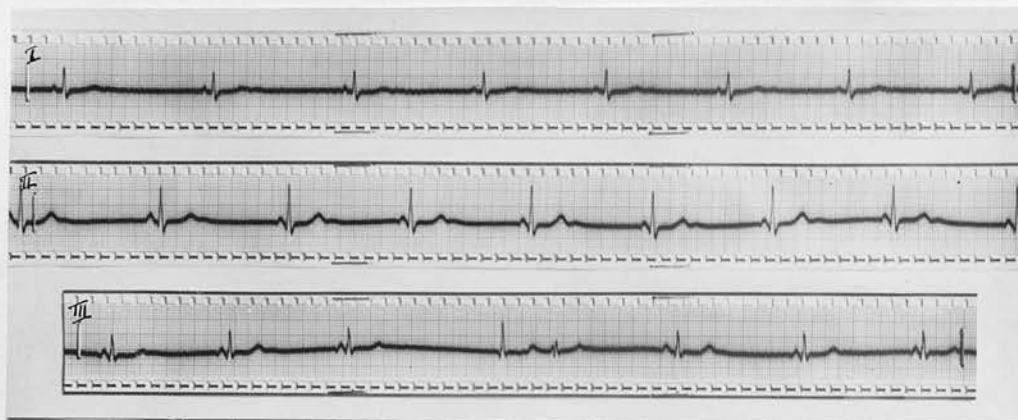


Fig. 31. 26--4--40.

In Fig. 31 the rate increases very slightly to 33 beats per minute, and the rhythm is predominantly of sinus origin.

The Effect of Amyl Nitrite.

In halation of amyl nitrite causing flushing of the face and dizziness also produced increase of rate with sinus rhythm as shown in Fig. 32.

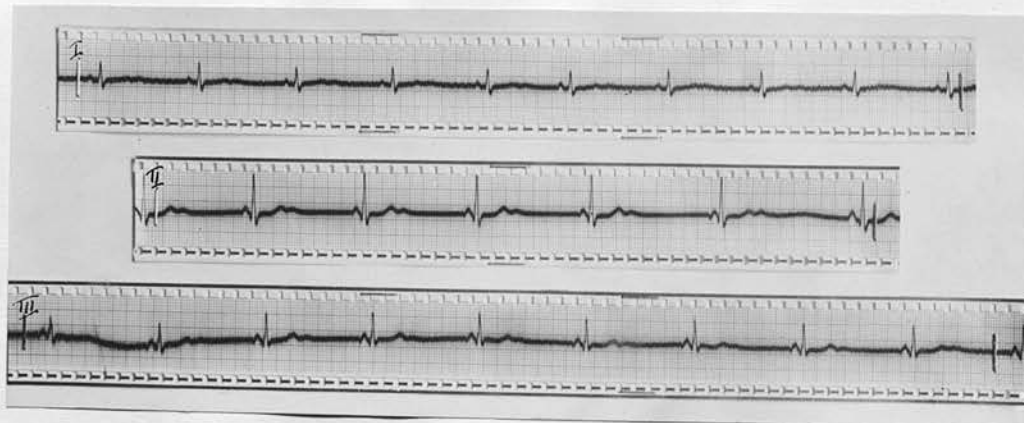


Fig. 32. 26--4--40

The Effect of Frenitan.

Frenitan (Dr. F. Debat's Laboratories, Paris) is a recently introduced proprietary drug containing 2 mgms. of trimethyl-amino-ethyl-urethane chloride and 0.5 mgm. of adenosine-phosphoric acid in its tablet form. The former constituent regulates vascular tone and suppresses vaso-constrictor spasm by direct action upon the parasympathetic nervous system; and the latter constituent is a powerful vaso-dilator as well as a regulator of vago-sympathetic tone. Frenitan is said to be of particular value in arterial hypertension and angina pectoris and has no harmful effect on the cardio-vascular system. Under the supervision of Dr. J.V. Braithwaite I had been observing the effects of this drug in cases of essential hypertension and in several instances a remarkable and sustained fall in the blood pressure was observed. (The drug is still in its trial stage, and I understand it is not now available in this country owing to the military situation.)

Because of its sustained effect upon the para-sympathetic nervous system, I decided to see what result it produced upon this patient. He was therefore given one tablet to take each night for a week. Clinical examination revealed no change from that given above when the drug was commenced. His blood pressure was noted to be 150:90. He still complained of palpitation, with occasional attacks of giddiness, tiredness and slight breathlessness on undue exertion. The electrocardiogram on that day had an average rate of 26 beats per minute and showed simple A-V dissociation. On the expiry of the week, he complained of not feeling so well and of feeling even more easily tired; and at times he experienced slight praecordial pain. On examination the pulse was 30 per minute, and the blood pressure had fallen to 105:75. The electrocardiogram then taken is reproduced in Fig. 33.

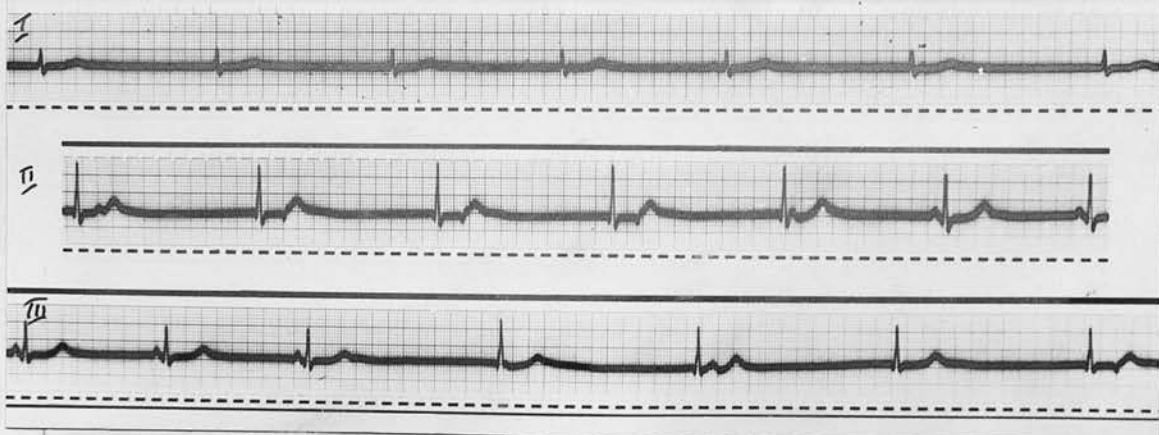


Fig. 33. 26--7--40.

The rate varies from 23 to 30 beats per minute and the mechanism alternates between A-V nodal

rhythm and A-V dissociation.

On the whole the electrocardiographic features were not greatly altered by the drug, the most that one can say being that there is a slight decrease in rate. The most marked changes following the administration of Frenitan appeared in the patient's symptoms which were made worse, and in the lowered blood pressure. The drug was then stopped, but even a week later his blood pressure was still lower than was usual in his case - 110:70.

The effect of Atropine will be discussed later.

The Effect of Carotid Sinus Pressure

Both right and left sided pressure was performed on several occasions.

Fig. 34 comprises a series of photographs from a long strip of film taken on Lead II. Fig. 34A

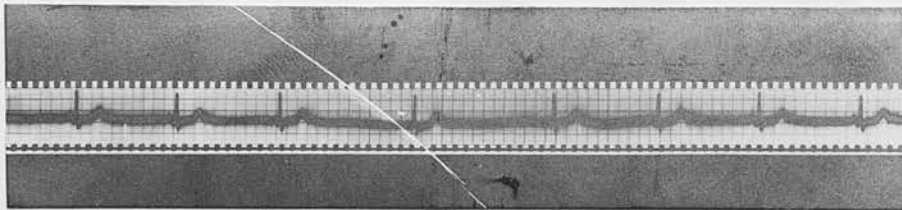


Fig. 34A. (Lead II). 19-7-40.

was taken just before the pressure was applied to the RIGHT carotid sinus and shows a sinus bradycardia interrupted by a single idio-ventricular beat in its centre.

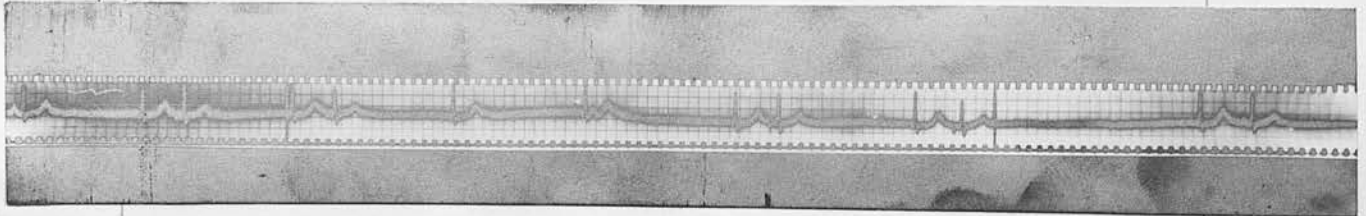


Fig. 34B. (Lead II). 19--7--40.

In Fig. 34B the pressure was applied at the first vertical line and was removed at the second vertical line. A really dramatic series of events occurred!

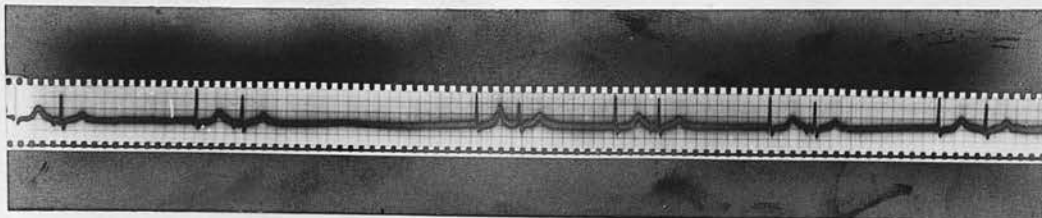


Fig. 34C. (Lead II). 19--7--40.

In Figures 34B and 34C, which are continuous one sees a coupling of the ventricular

complexes, the second ventricular response being preceded by an inverted P wave with a P-Q interval of 0.16 second. There is no evidence of any auricular contraction associated with the first ventricular complex of these couplets, and the long Q-P interval to this inverted P wave excludes the possibility of the second ventricular systole being a reciprocal one in response to an impulse arising in the A-V node at the same time as that causing the primary ventricular contraction. It seems inconceivable that on the theory of re-entry this impulse could have been so long delayed before giving rise to even the auricular response. The R-R intervals of these coupled beats also vary from one to the other (from 0.8 to 1.0 second). Furthermore, the P wave of the last couplet in Fig. 34B is upright although the P-Q interval remains unchanged at 0.16 second. In Figures 34C and 34D, moreover, the T wave of the primary complex is seen to be deformed or humped by the encroachment of the upright P wave on its descending limb, the P-Q

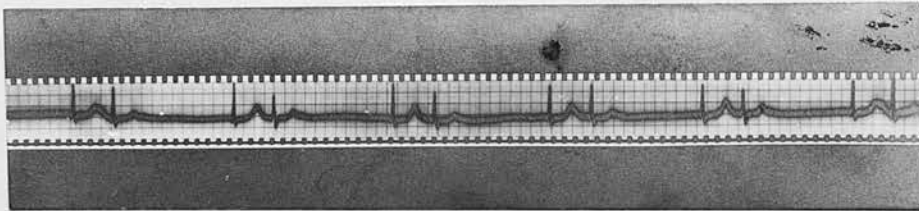


Fig. 34D. (Continuous with 34C).

interval gradually becoming longer and longer until eventually the P wave occurs superimposed on the apex of the T wave giving it a sharp peak (Fig. 34D). Then finally the bigeminy ceases abruptly and the P wave, now definitely upright, is seen at an interval of 0.10 second before the single ventricular complexes, and gradually this P-Q interval lengthens and sinus bradycardia again results (Fig. 34E).

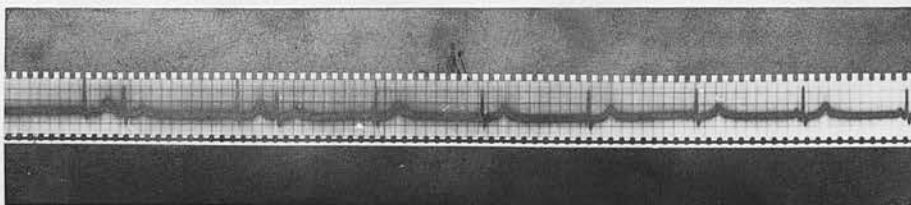


Fig. 34E. (Continuous with 34D).

This unusual form of coupling and the unusual position of the inverted P waves require further consideration. Could the second beat of the couplet be an A-V nodal one, the impulse arising high in the A-V node and spreading to the auricle before it reaches the ventricle? There are several points against this being the case. Firstly, the P-Q interval of this complex is 0.16 second, a value rather too high were the impulse arising in the A-V node. Secondly, the P

wave is not always inverted (e.g., last beat in Fig. 34B) and in several of the beats in Fig. 34C and in all of the beats in Fig. 34D it changes its position as described above and alters its character, at times being a small diphasic flicker on the descending limb of the T wave or it produces obvious humping of this limb. Finally, the R-R interval of this coupled beat is considerably shorter than that between A-V nodal beats. These points together with the upright character of the complex strongly suggest an auricular origin of the impulse, and this view is also favoured by the change in the shape and location of the P wave in other couplets, as the latter could be produced by a shift in the position of the auricular pacemaker. Hence the bigeminy can readily be explained on the assumption of A-V dissociation, and it will be noted also that in Fig. 34B two single beats occur typical of that condition. This record can also be regarded as a form of Parasystole.

It will also be observed that a coupled beat with inverted P wave as described above occurs immediately before the onset of the carotid sinus pressure. This is probably due to a hypersensitive state of the carotid sinus, which was stimulated by the slight pressure employed whilst feeling for its pulsation.

There is still another feature of this record to which attention must be drawn. In Figures 34B and 34C there occur two very long pauses in the ventricular rhythm, the interval in each case from the second R wave of the preceding couplet to the R wave ending these long periods measuring 4.6 seconds. In each case the iso-electric line is unbroken and there is no evidence of auricular activity. Another curious feature is that in both instances the preceding R-R interval measures 2.68 seconds, whereas the average R-R interval between the second ventricular complex of a couplet and the next QRS complex has a value of 2.24 seconds. Why did not the A-V node liberate an impulse long before the period of 4.6 seconds was completed, that is at the moment when a ventricular contraction should have appeared, approximately 2.24 seconds after the preceding QRS complex? One can only assume a continued action of the vagus following the cessation of pressure, upon the A-V node as well as upon the sinus node.

The unique record described in Fig. 34 occurred when carotid sinus pressure was attempted for the first time. The procedure was repeated on many subsequent occasions, but the above changes were never reproduced. The only deduction one can make is that the carotid sinus was unduly excitable at that particular time.

I include several examples of both right and left sided pressure in the following electrocardiograms.

Fig. 35 is a continuous record taken on Lead II. RIGHT sided pressure was applied at the first vertical line and withdrawn at the second vertical line.

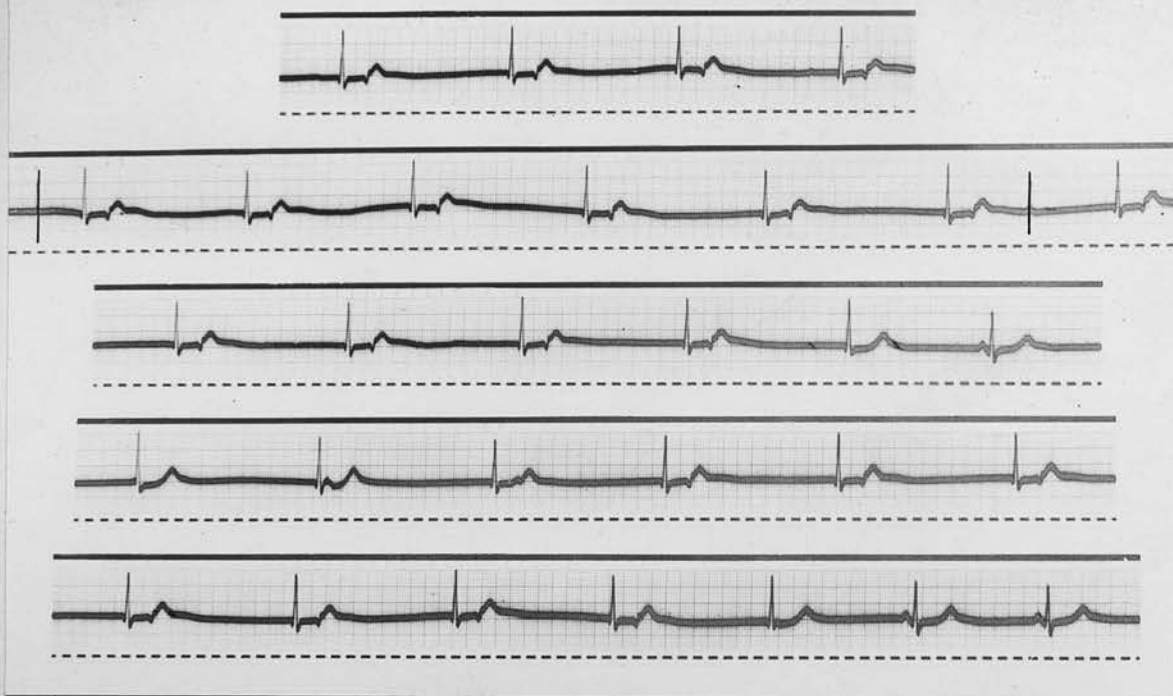


Fig. 35. 26--7--40.

The dominant rhythm is an A-V nodal one, the inverted P wave lying at the commencement of the ascending limb of the T wave, and there is a constant Q-P interval of 0.37 second. The heart rate is 25 beats per minute, the rhythm being very nearly regular. There is a slight increase of the R-R intervals during the period of pressure, but as this occurs considerably later also, it is unlikely to possess any significance.

In this instance reflex vagal stimulation has had no effect on the A-V rhythm.

Fig. 36 was taken shortly after Fig. 35 and is again a continuous record on Lead II, the interval during which LEFT sided pressure was exerted being indicated as in the previous record.

In the first two strips a similar A-V nodal rhythm is present as in the last example, but the rhythm then changes to one of A-V dissociation in the remaining three strips. Again a slight slowing of the heart rate occurred during the period of pressure and as it does not occur elsewhere in the record it may be of more significance than that occurring in Fig. 35. The variation is very small, however. Following the release of the pressure the cardiac mechanism abruptly changes from A-V nodal rhythm to A-V dissociation. It is not possible to say with any certainty whether this abrupt change is due to vagal stimulation, for similar alteration in the mechanism repeatedly occurs in other records taken routinely at rest. In the lowermost tracing the auricle and ventricle are beating at identical rates although dissociated, the upright P wave occurring at the same relation to the QRS complex

in each beat on the S-T interval.

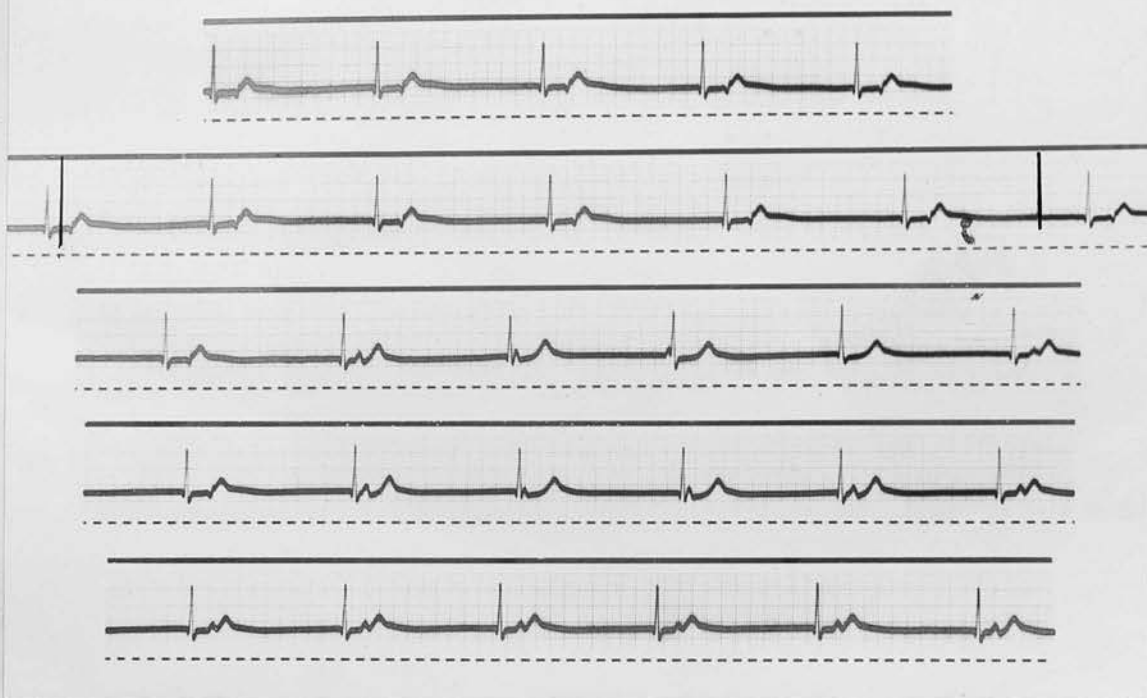


Fig. 36. 26-7-40.



Fig. 37. 2-8-40.

Fig. 37 is another example, in Lead II, of LEFT sided carotid sinus pressure and is similarly

marked with regard to the onset and release of pressure as in the previous records. The main interest lies in the possible effect of the pressure during A-V dissociation with interference.

The record is a continuous strip and the striking feature about it is the occurrence of coupled beats usually separated by a single complex. In the case of the single beats, the P wave occurs at varying distances from the QRS complex and lies on the S-T interval or on the ascending limb of the T wave. In the case of the coupled beats, the P wave falls either at the apex of the T wave or on its descending limb and gives rise to the second ventricular response, since the junctional tissues have had sufficient time to recover from their refractory period. Measurement of the Q-P intervals in the single ventricular beats and comparison with those occurring between the double beats gives a rough idea of the duration of the refractory period of the junctional tissues, which is just under 0.40 second. The auricular rate is approximately 21 beats per minute and the ventricles are contracting at a rate of approximately 36 beats per minute. This record is, therefore, an excellent example of dissociation with interference, every second beat of the couplet being produced by the auricular stimulus. The decreased R-R interval following the coupled beat and to which attention was drawn in the description of Fig. 23 is also particularly well marked. My reason for describing this record in such detail is to emphasise the character of these coupled beats between which are upright P waves and to distinguish them from the bigeminal beats of reciprocal rhythm in which the P waves, although similar in position, are inverted. The bigeminy here shown is an example of so-called "pseudo-reciprocal rhythm".

Turning now to the effect of carotid sinus stimulation during this form of cardiac mechanism, one sees that during the period of vagal stimulation and shortly afterwards the coupling tends to disappear. The position of the P wave in relation to the QRS complex is altered and it approaches that complex; in one instance it lies just before the ventricular beat and has a P-Q interval of 0.20 second, this complex therefore appearing to have a sinus nodal origin. Pronounced slowing of both auricle and ventricle is present during the period of pressure and persists for the greater part of the third strip accounting for the absence of the bigeminy.

In this record, therefore, left carotid sinus pressure has produced a reduction in the auricular and ventricular rates.

Fig. 38, another continuous record in Lead II, shows the effect of RIGHT carotid sinus pressure during A-V nodal rhythm. The pressure was commenced at the vertical line on the first strip and withdrawn at the corresponding mark on the second strip.

The rhythm appears to be predominantly atrio-ventricular, the deeply inverted P wave deforming the T wave at a Q-P interval of 0.37 second. Bigeminy

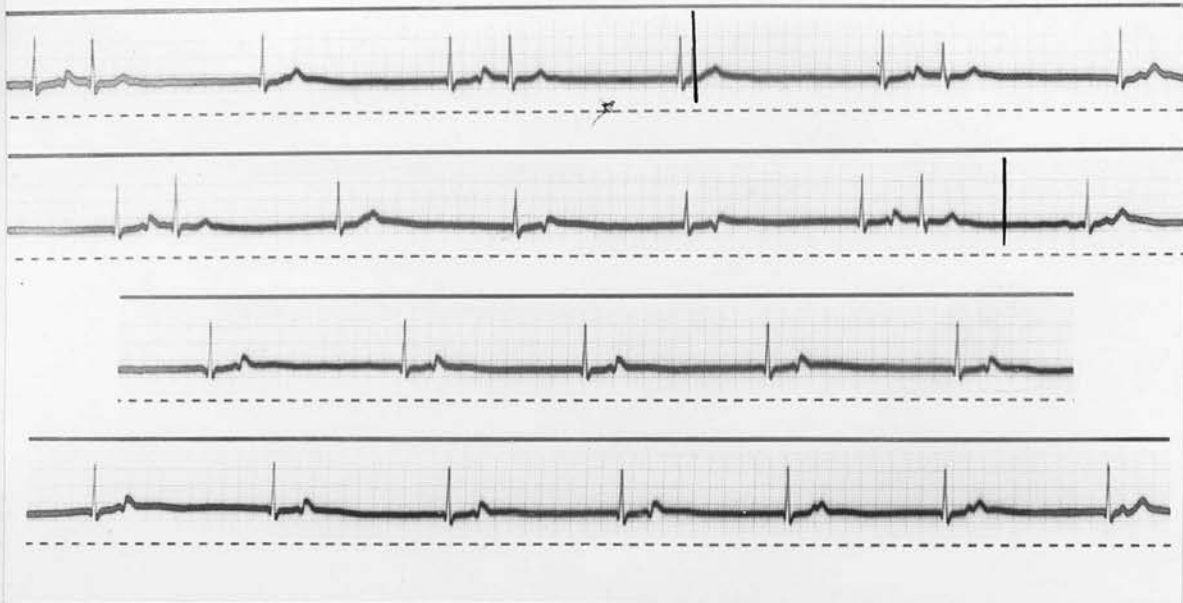


Fig. 38. 30--8--40.

again occurs, the Q-P and P-Q intervals being 0.40 and 0.38 second respectively. The bigeminy differs from that seen in Fig. 37, however, in virtue of the deeply inverted P wave occurring between the coupled complexes. Forward conduction in this instance appears to be almost as difficult as retrograde conduction and even after the relatively long interval following the Primary ventricular contraction the second QRS complexes show slight differences from the normal, probably due to interference with ventricular conduction. One is inclined to regard this record as an example of reciprocal rhythm, although the theory of Parasystole described on page 31 is applicable here.

The effect of vagal stimulation is to interrupt the regular alternation of single and coupled beats seen in the first strip and to produce the simple A-V rhythm seen in the third and fourth strips. Several cases have been reported where vagal stimulation produced reciprocal rhythm (5, 19) and in other reported cases vagal stimulation abolished it (10).

Fig. 39 was taken on Lead II shortly after Fig. 38 and shows the effect of LEFT carotid sinus pressure. One again sees a similar bigeminy as in Fig. 38, the inverted P wave being similarly placed between the two ventricular complexes. Many of the P waves are, however, seen as slight flickers on the T wave and the A-V nodal origin is more in doubt. This record favours the theory of parasystole in the causation of the bigeminy rather than the theory of re-entry.

The reflex vagal stimulation has perhaps not so marked an effect on the bigeminy, but is probably responsible for the change which occurs soon after its cessation to A-V dissociation. Ventricular slowing is even more apparent than in Fig. 38.

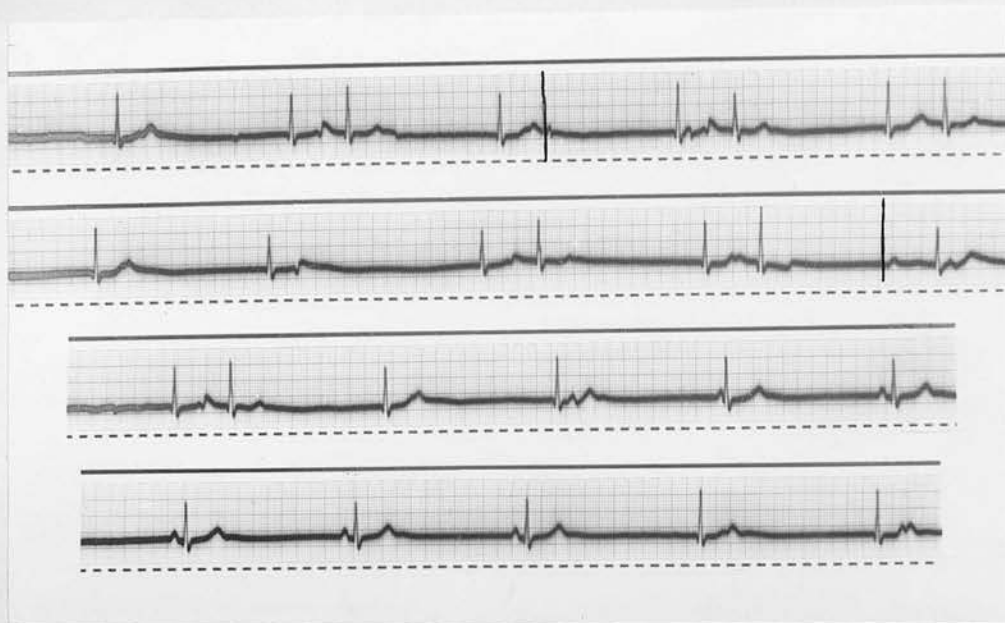


Fig. 39. 30--8--40.

The Effect of Atropine.

Atropine was given on two occasions and the changes in the cardiac mechanism were observed electrocardiographically.

On the first occasion atropine sulphate gr. $\frac{1}{160}$ was given subcutaneously and records were taken every five minutes for three-quarters of an hour on Lead II. The pulse rate was noted to increase from 30 to 52 per minute, regular coupled beats occurring towards the end of this time.

A record was taken immediately before the atropine was administered and has already been described in Fig. 24.



Fig. 40 A, B and C. 25--3--40.

Fig. 40 A was taken immediately after the drug was given and Fig. 40B was recorded five minutes later. Both show A-V dissociation without interference. Fig. 40C taken ten minutes after the injection shows a

change to A-V nodal rhythm with a Q-P interval of 0.34 second.

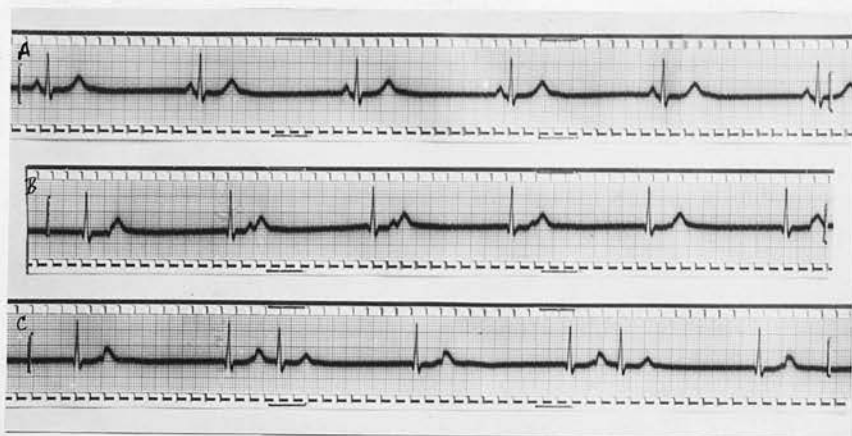


Fig. 41 A, B and C. 25--3--40.

Fig. 41A taken fifteen minutes after the injection, shows a simple sinus bradycardia with a rate of 26 per minute. Fig. 41B, taken twenty minutes after shows A-V dissociation with transition to A-V nodal rhythm towards its end. Fig. 41C, taken 25 minutes after the injection, shows a bigeminy alternating with single beats. The P wave is now inverted and occurs on the ascending limb of the T wave with a Q-P interval of 0.40 second in the case of the coupled beats.

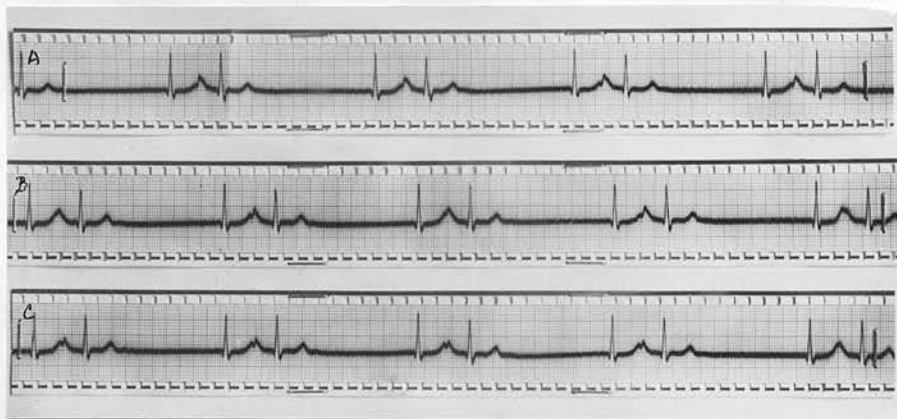


Fig. 42. 25--3--40.

Fig. 42 comprises records taken 27½, 30 and 35 minutes after the injection and all three records show uninterrupted coupled beats. The inverted P wave causes a depression on the peak of the T wave approximately 0.42 second after the preceding Q wave and approximately 0.34 second before the succeeding Q wave. There is slight change in the character of the second ventricular complex probably due to aberrant ventricular conduction. A similar state is seen in Fig. 43, the two records being taken at 40 and 45 minutes respectively after the injection.

Atropine therefore has produced reciprocal rhythm.



Fig. 43. 25--5--40.

On the second occasion of atropine administration $\frac{1}{6}$ gr. of the sulphate was given intravenously and a continuous electrocardiogram was taken for five minutes, the point of injection being marked on this film. Portions of this long reel have been photographed in sections and reproduced in Fig. 44.

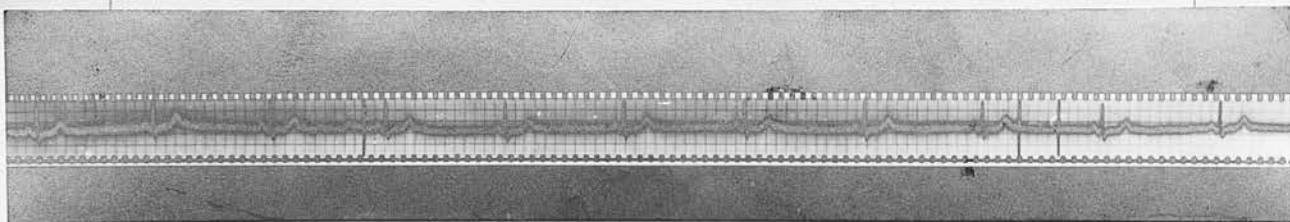


Fig. 44A. (Lead II). 27--6--40.

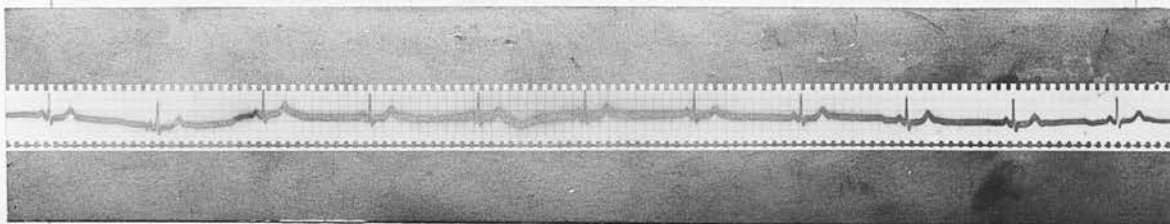


Fig. 44B. (Continuous with 44A).

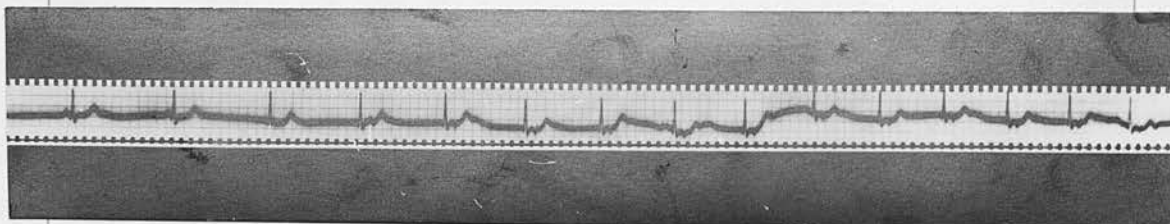


Fig. 44C. (Continuous with 44B).

In Fig. 44A one sees a sinus bradycardia, the upright P wave preceding the QRS complexes by 0.20 second, the rate being 25 per minute. The intravenous injection was commenced where the single vertical line appears and was completed where the two vertical lines are shown. The sinus rhythm continues unchanged as

seen in Fig. 44B at the same rate until the commencement

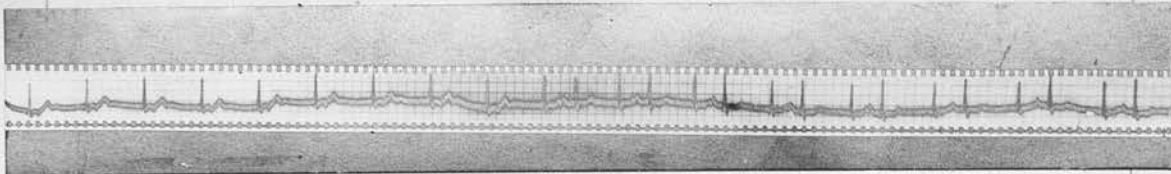


Fig. 44D. (220 seconds after atropine).

of Fig. 44C, when a temporary A-V dissociation occurred, the upright P wave approaching and then appearing on the far side of the QRS complex. This occurred approximately 45 seconds after the commencement of the injection. The heart rate then quickened rapidly and the mechanism became A-V nodal rhythm (Fig. 44C), the deeply inverted P wave lying on the S-T interval with a Q-P duration of 0.22 second. The heart rate increased rapidly to a maximum of 53 beats per minute approximately 100 seconds after the commencement of the injection and then gradually began to slow until Fig. 44D was commenced 220 seconds after beginning the injection, when the rate had become 46 per minute. During all this time the A-V nodal rhythm persisted, the P wave remaining deeply inverted and following the QRS complex at a constant interval which at the commencement of Fig. 44D measured 0.26 second.

At the centre of Fig. 44D a sudden change in the rhythm is seen occurring 234 seconds from the time of injection. The ventricular beats become coupled and there is an associated sudden increase in the length of the Q-P interval from its previous value of 0.26 second to 0.36 second. The P-Q intervals measure 0.28 second. Here again atropine has produced reciprocal rhythm, the inverted P wave indenting the apex of the T wave. The R-R interval between the second ventricular beat of the couplet and the succeeding QRS complex is relatively short in the first instance, measuring 0.89 second, but it rapidly increases to 1.17 seconds at the end of Fig. 44D. This reciprocal rhythm continued without interruption by any single ventricular complex until the end of this record, and Fig. 45 is a short length of the original film cut from its termination.

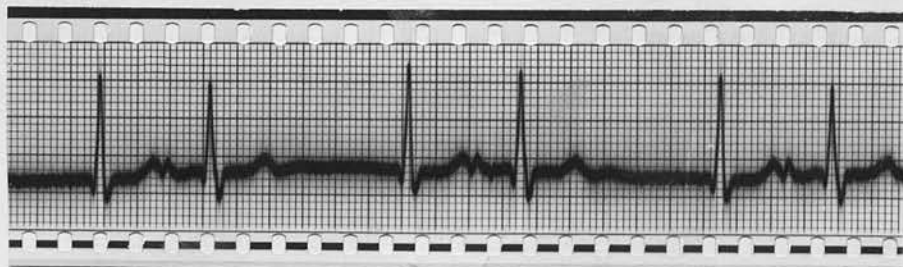


Fig. 45. (Original film).

This transition is unique, and provides another of the exceptional records yielded by this

patient. Of particular interest is the change from sinus bradycardia to A-V nodal rhythm and finally reciprocal rhythm. This production of reciprocal rhythm rapidly following the intravenous administration of a large dose of atropine is exactly comparable with its production during the later stages of the action of the smaller subcutaneous dose of the drug described under figures 40 to 43.

Following the intravenous administration of atropine further electrocardiograms were taken at short intervals and these records (on Lead II) are shown in Figures 46 to 49. The times at which these records were taken after the injection have been noted on each record.

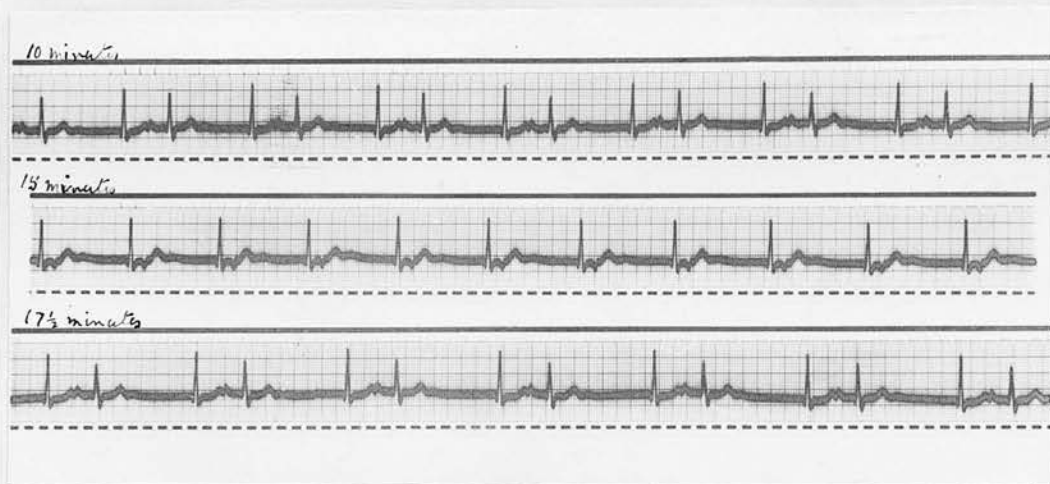


Fig. 46. (Lead II only).

In Fig. 46 reciprocal rhythm is present 10 and 17 $\frac{1}{2}$ minutes after the injection, but the record after 15 minutes shows a simple A-V nodal rhythm such as occurred before the development of the reciprocal rhythm. The transitions to and from this A-V rhythm were not recorded but the probability is that they were as abrupt as that transition to reciprocal rhythm shown in Fig. 44D. The P wave is still deeply inverted and the Q-P interval measures 0.22 second. It is not possible to say why this change took place at this time.

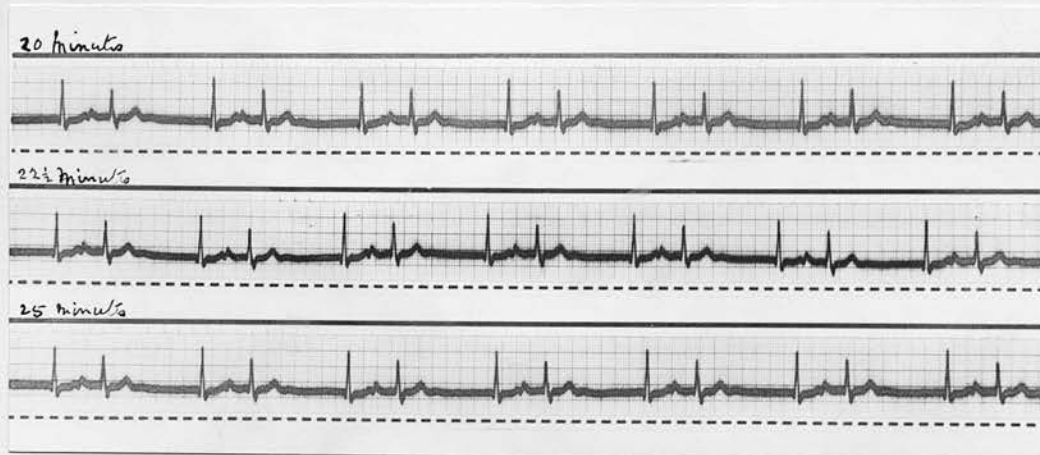


Fig. 47. (Lead II only).

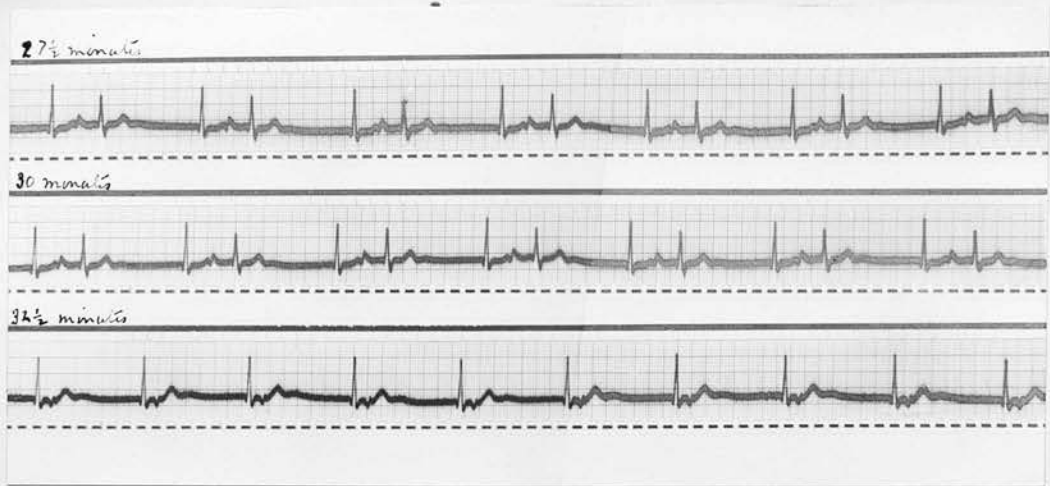


Fig. 48. (Lead II only).

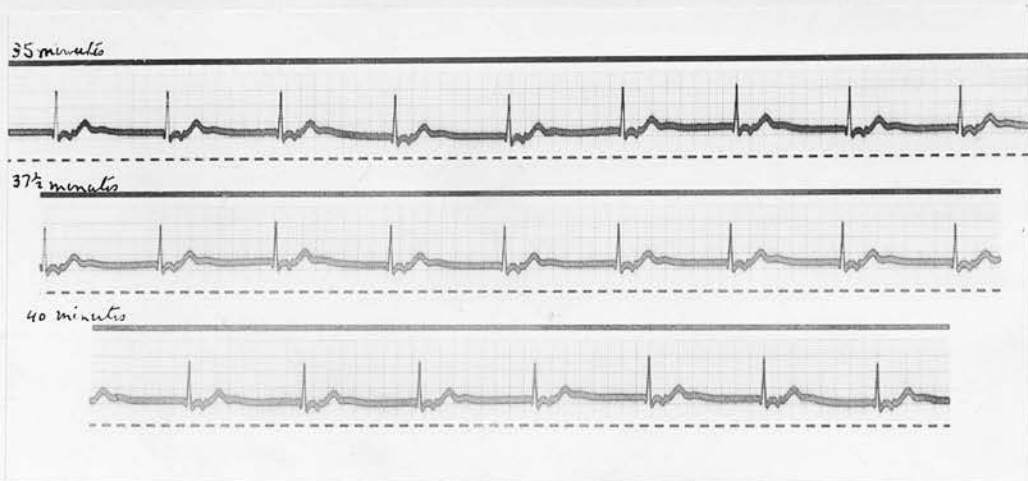


Fig. 49. (Lead II only).

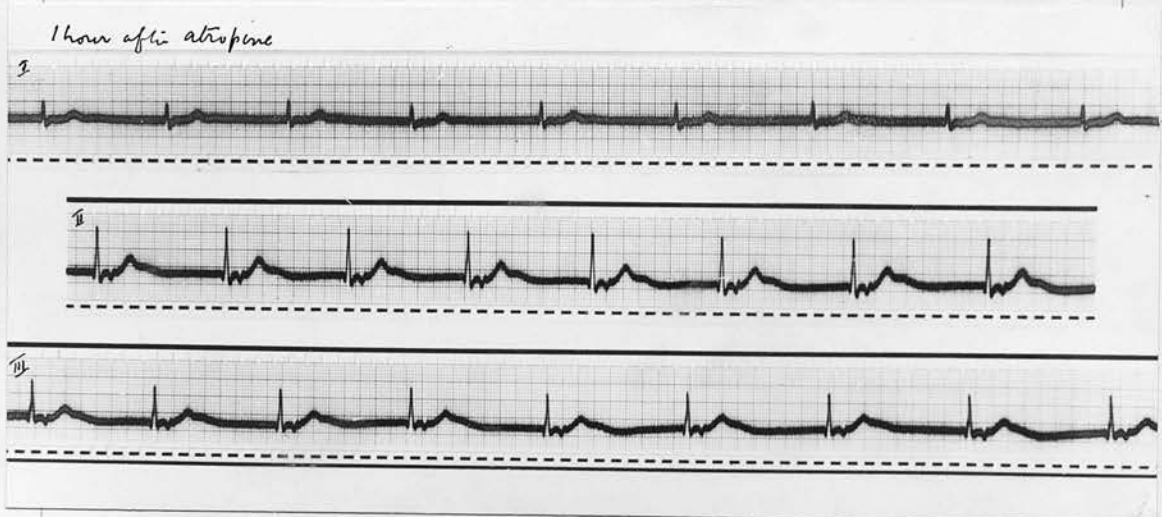


Fig. 50. (Leads I, II and III).

The records shown in Fig. 47 and the first two records in Fig. 48 continue to show reciprocal rhythm. In the lowest record of Fig. 48, taken $32\frac{1}{2}$ minutes after the atropine was given, the mechanism has again reverted to A-V nodal rhythm and this has continued throughout Figures 49 and 50, the last being a 3-Lead electrocardiogram recorded one hour after the injection when observations were stopped.

The occurrence of reciprocal rhythm requires some consideration. It will be noted that both preceding and following this mechanism A-V nodal rhythm occurred. The onset was definitely associated with a sudden lengthening of the Q-P interval, i.e., an increase in the degree of retrograde interference with conduction; and the temporary reversion to A-V nodal rhythm seen in the second strip of Fig. 46 is similarly associated with a reduction of the Q-P interval presumably caused by a decreased interference with retrograde conduction, although the cause of this is uncertain at that time. These facts strongly favour the theory of re-entry, but consideration of the argument in favour of Parasystole given on page 51 shows that this latter mechanism could also be held responsible for the coupling of the beats. These records do not appear to throw any further light upon the mechanism of "reciprocal rhythm".

During the hour following the intravenous administration of the atropine some clinical observations were made. Five minutes after the injections the pulse rate was in the neighbourhood of 80 per minute, the rate being largely due to the coupled beats. On auscultation of the heart a systolic bruit was audible in the aortic area; no murmur was ever heard at any other time. The intensity of this bruit varied with different beats, at one time being almost absent and at other times quite loud, this variation being apparently associated with respiration. At the end of one hour this bruit had disappeared. As time passed the pulse rate gradually decreased and had become reduced to 40 per minute at the end of one hour, the pulse also being regular. The blood pressure eight minutes after the injection was 128:82.

A well marked double pulsation of the jugular veins was observed, and was most noticeable 15 minutes after the injection - when A-V nodal rhythm was present. At other times only a single beat was observed in the jugular veins.

The patient did not experience any distressing symptoms following the intravenous administration of atropine. He could feel the heart beating forcibly and more rapidly than usual, but he was not conscious of the double beats. During the following week, however, he complained of increased tiredness, headaches and slight pains over the praecordium aggravated by deep respiration. On examination eight days after the above procedure, his pulse rate was 30 per minute and the heart sounds were clear and closed.

Discussion.

The very unusual nature of this case will be immediately recognised from a study of the records given. Few of the cases reported in the literature show such a variation between sinus bradycardia, A-V nodal rhythm and A-V dissociation with or without interference, and in a fairly intensive study of the Journals, I have never discovered a case persisting so long. The case of Williams and James (73) had persisted for twelve months previous to its being reported and probably lasted longer, but the main cardiac mechanism was A-V nodal rhythm. In all the other cases I have reviewed the arrhythmia was only temporary persisting generally for a few days at the most. Schott's case (68) is an example in point, where although sinus bradycardia (rate 48 per minute) had been known to exist for some 20 years, a temporary change to A-V dissociation and A-V nodal rhythm lasting less than a fortnight was observed.

The bradycardia present in this case is a very striking feature, the heart rate, calculated from the electrocardiograms, generally being under 30 beats per minute. Clinically the pulse rate varied between 30 and 40 beats per minute, the higher rates being due to premature or coupled beats. There is obviously very marked depression of the sinus node. The periods of the depressed S-A node and of the A-V node must be very nearly similar and this would account for the repeated alternations in the cardiac mechanism, one or other node assuming control of the whole or part of the heart at a given time.

The alternations between A-V nodal rhythm and A-V dissociation with or without interference obviously depend on the state of retrograde conduction present; an increase in the degree of retrograde block would enable the auricular pacemaker to gain control of the auricle, and change from A-V rhythm to A-V dissociation would result. In Fig. 36 attention has already been called to the lowermost strip where dissociation is present, the upright P wave lying on the S-T interval, but the rates of auricle and ventricle are identical. These upright P waves are of normal shape and size when compared with the P waves of sinus bradycardia and show no evidence of distortion due to retrograde conduction from the ventricle; one therefore assumes that the degree of retrograde block is at this time nearly complete. The upper two strips of this record show A-V nodal rhythm with a particularly long Q-P interval of 0.34 second. Such a prolonged interval could possibly be due to a very low origin of the impulse in the A-V node or possibly in the bundle of His, but a more satisfactory explanation probably lies in a certain degree of interference with retrograde conduction. It also seems probable that the left carotid sinus pressure exerted whilst this record was taken produced an increase in the retrograde block and the auricular pacemaker assumed control of the auricle with the resulting picture of A-V dissociation, the relative rates of auricle and ventricle being almost identical.

Increased difficulty in retrograde conduction is also seen in the onset of reciprocal rhythm during the effect of atropine. In Fig. 41, when atropine had been given subcutaneously and its full effect was gained relatively slowly, a gradual change to A-V rhythm and a prolonged Q-P interval are seen. In the case of the reciprocal beats the Q-P interval is just perceptibly longer than the Q-P interval of the single A-V nodal beats. In the case of Fig. 44D, following the intravenous administration of atropine, there is a very abrupt lengthening of the Q-P interval associated with the onset of reciprocal rhythm.

This case consequently furnishes an excellent illustration of the relation of varying degrees of retrograde heart block in the production of A-V nodal rhythm, reciprocal rhythm and A-V dissociation.

Fig. 37 illustrates a particularly clear example of interference dissociation, coupled ventricular complexes occurring fairly regularly and associated with the different rates of the auricle and ventricle. In this record retrograde heart block is complete, no impulse reaching the auricle from the ventricle. Attention has already been drawn to the similarity between these coupled beats and the bigeminy occurring in reciprocal rhythm. In the former the P wave is upright and in the latter it is inverted.

The occurrence of sino-auricular block (Fig. 29) is of great interest. Sino-auricular block is in itself a very uncommon condition and a few cases have been reported when bradycardia was regarded as due to blocking of every second impulse from the sinus node (Scherf and Boyd 66). Can this be the fundamental mechanism in this case? One might assume in support of this theory that the A-V centre escapes during the long pause in which a sinus stimulus is blocked (or possibly not formed) and A-V rhythm or A-V dissociation develops. A careful study of other electrocardiograms of this case taken routinely with the patient at rest reveals only one which might support this view. This electrocardiogram has not been reproduced but it shows a sinus bradycardia, during which occasional complexes of sinus origin (i. e., preceded at a normal interval by upright P waves) occur at regular intervals of 1.0 second after the preceding normal sinus beat and are followed by a pause of approximately twice that duration when the next upright P wave appears. These long P-P intervals are interrupted by escaped idio-ventricular beats. This record, then, is also an example of sino-auricular block. Attention might also be drawn to Fig. 17 in this connection where, in Lead III, an early sinus beat is seen and the distance between the first two and the last two P waves of this record are approximately double the P-P interval of the central two P waves. In the light of the features revealed in the two other records showing that condition this electrocardiogram could also be regarded as one of sino-auricular block.

Sino-auricular block may, therefore, be the fundamental disorder in this case, the other arrhythmias, A-V nodal rhythm and A-V dissociation, being produced by escape of secondary centres of impulse formation

during the periods in which sinus beats are blocked at their origin.

One can discuss the possible cause of the bradycardia from this viewpoint. Sino-auricular block in common with depression of the S-A node is generally due to vagal inhibition and digitalis administration is probably their commonest cause. No digitalis was given, however, in this case until the end of the period of observation. Although sympathetic stimulation by means of exercise or the administration of adrenaline increased the heart rate to some extent, no alteration generally occurred in the cardiac mechanism except in the isolated instance when sino-auricular block was recorded in Fig. 29. Atropine also failed to produce normal sinus rhythm, but on the other hand changed the rhythm from sinus bradycardia to A-V nodal rhythm at a relatively rapid rate. (Fig. 44). The dose of atropine given on this second occasion was sufficient to cause vagal paralysis and this proves conclusively that the depression of the sinus node was not due to vagal inhibition.

It is impossible to say to what cause the sinus depression was due. Disease of the sinus node itself is a possibility but cannot of course be confirmed without Post-Mortem examination. Owing to the large size of the node and its intimate connection with the auricle by its innumerable ramifications, a lesion would have to involve both the whole of the node and the connecting fibres before its control of the auricle would be completely lost. Mammalian experimental work demonstrates that sino-auricular block does not occur until the node is surrounded on all sides by injured tissue (7, 18). Digitalis produces the condition by its effect upon all the specific tissue of the node. Disease of the sinus node experimentally produced and resulting in sino-auricular block has been reported by Barker and Kinsella (2).

There is no help given in the history towards elucidating the cause of the cardiac condition. No illness, however slight, could be remembered at the onset and the only preceding illness was malaria some 14 years previously. I have been unable to find any reference to this disease causing a cardiac condition which might have been held responsible.

Certain other clinical points are worthy of mention. The palpitation which was so troublesome to the patient was due to the premature coupled beats occurring during reciprocal or "pseudo-reciprocal" rhythm. The patient never appreciated the bigeminal contractions, but only the conducted beat of interference dissociation and in the case of reciprocal rhythm induced by atropine, only the second "re-entered" beat. I gave the patient small doses of digitalis as advised by Schott (67) towards the end of September, 1940, in the hope of interrupting the interference dissociation and so stopping the palpitation by producing sinus bradycardia, but unfortunately I was unable to follow up the effect of this.

The other symptoms, - dizziness, paraesthesia and tiredness - are probably directly related to the

slow heart rate. The feelings of faintness occasionally accompanying the dizziness can be accounted for by short periods of cardiac standstill; no electrocardiogram, however, was obtained during such an attack.

Summary.

A unique case is described and illustrated by electrocardiograms which show alternations between sinus bradycardia, A-V nodal rhythm and A-V dissociation with or without interference.

A record showing sino-auricular block is included and the possibility of a regular interruption of every second sinus impulse in the production of the sinus bradycardia, with the escape of the A-V nodal centres, is considered as the possible fundamental mechanism.

The cause of the sinus depression is unknown. Administration of atropine resulted in the production of reciprocal rhythm.

Records illustrating the effects of other drugs and of carotid sinus pressure during sinus bradycardia, A-V nodal rhythm and A-V dissociation are reproduced and discussed.

Attention is drawn to the varying degrees of retrograde heart block in its relation to A-V dissociation, A-V nodal rhythm and reciprocal rhythm.

No digitalis was given to the patient until the end of the period of observation.

The arrhythmias have persisted for at least 18 months and most probably for two years or more.

There has been definite improvement in the patient's symptoms but no therapeutic procedure has been found to affect the cardiac mechanisms or to maintain an increased heart rate.

The case is a very unusual and very rare one and probably no similar case has previously been described.

Case 2. A-V Nodal Rhythm : Tuberculous
Broncho-pneumonia.

H.R. Aged 52 years. Male; Married. Died 7-3-40.

The patient was admitted to the Leicester Royal Infirmary on 2--3--40.

He complained of cough and increasing breathlessness during the previous fifteen months. Shortly before admission he had swelling of the feet, pain in the chest and marked shortness of breath.

Examination revealed a pale, ill-looking man with pronounced dyspnoea, not amounting to orthopnoea. There was slight cyanosis of the lips and lobes of the ears.

The radial pulse was regular with a rate of 120 per minute, the vessel being tortuous and its wall palpable. The apex beat was located in the VIth. left intercostal space half an inch outside the mid-clavicular line. The heart sounds were faint, but no murmur was detected. There was considerable oedema over the lower back and slight oedema of the ankles.

Blood pressure 160:94.

The patient showed clinical evidence of extensive tuberculous broncho-pneumonia. Crepitations were present in both lungs and most abundant at the bases.

There was no enlargement of the liver.

The temperature on admission was 102.6°F.
The respirations numbered 42 per minute.

Tubercle bacilli were found in large numbers in the sputum.

X-ray examination revealed heavy patchy infiltration of both lungs having the character of broncho-pneumonia.

His condition was very poor on admission and steadily became worse, terminating in death five days later.

Post-mortem examination revealed a massive tuberculous broncho-pneumonia of both lungs. The heart was slightly enlarged and weighed 13½ oz. No abnormality was seen on naked eye examination of this organ. The spleen was diffuent and moderately enlarged. No significant change was found in the other organs.

Unfortunately microscopic examination of the heart was not made.

Electrocardiograms were taken on two occasions.

Fig. 51 was recorded on 4--3--40 and shows a transition from sinus rhythm in Lead I to A-V nodal rhythm at the commencement of Lead II and the transition back to sinus rhythm towards the end of Lead II. The small strip in the centre of the photograph is a continuation of Lead II.

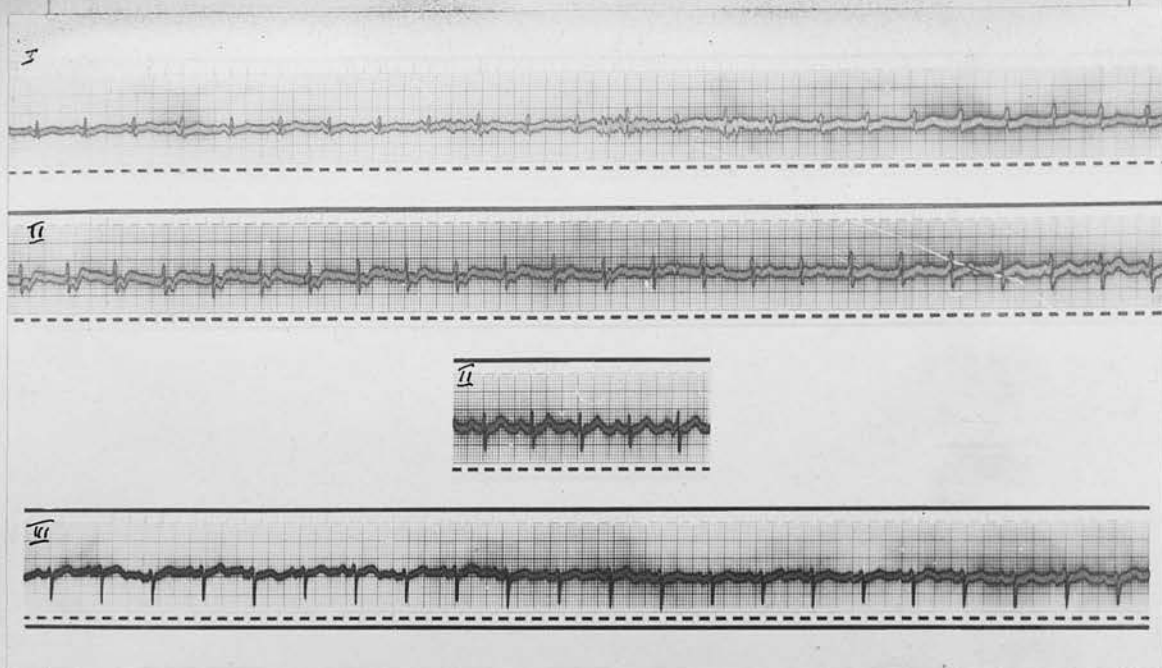


Fig. 51. 4--3--40.

At the commencement of Lead I the heart is approximately regular with a rate of 95 beats per minute and the P waves are seen as small upright deflections occurring 0.16 second before the QRS complex. The central part of this record is deformed by movement of the patient but the part of the record following this fault shows gradual approachment of the P wave to the QRS complex, the two waves finally merging.

Lead II was taken immediately following Lead I and here one sees a deeply inverted P wave following the QRS complex and deforming the commencement of the T wave; the diastolic line is unbroken by any evidence of a P wave. Here then, is A-V nodal rhythm, the impulse presumably arising low in the A-V node. The R-P interval measures 0.12 second at the beginning of this record. As one proceeds along the strip, the depth of the inverted P wave suddenly decreases and after the following beat the P wave becomes upright and at a much reduced R-P interval. Gradually this interval shortens and the P wave again becomes merged in the QRS complex, finally appearing before it at an interval of 0.17 second in the small third strip which is continuous with the end of the second strip.

In Lead III sinus rhythm persists.

The ventricular rate does not alter at all in Lead II, the R-R intervals measuring 0.62 second, corresponding to a rate of 95 per minute.

Fig. 52 was taken on the following day; normal sinus rhythm persists throughout the record.

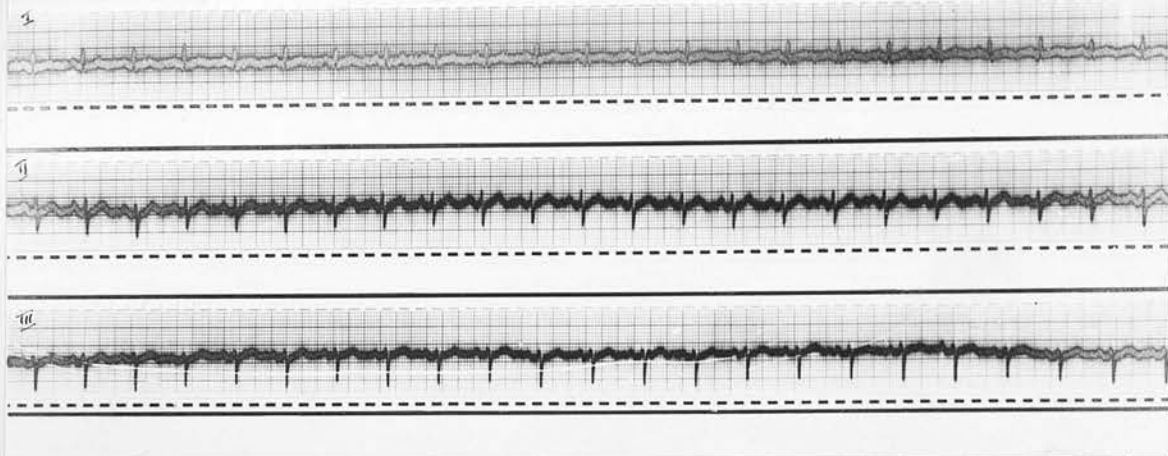


Fig. 52. 5--3--40.

Discussion.

Fig. 51 shows a temporary transition to A-V nodal rhythm but differs from the examples of A-V rhythm observed in Case I in the rapid rate of the heart. Here the period of the A-V node must have been very high. The cause is most likely due to irritability of the A-V node associated with mixed infection in a tuberculous process. In all probability the A-V node along with the other cardiac tissue was involved in a general myocarditis and it is unfortunate that no microscopical examination was made of the heart muscle and A-V node.

Summary.

A case dying from tuberculous bronchopneumonia and in which evidence of heart failure was present is presented.

The transitions between sinus and A-V nodal rhythm are described.

The A-V rhythm occurs at a rapid rate and the probability of myocarditis involving the node and so producing increased irritability of that structure is considered.

Unfortunately microscopical examination of the myocardium and A-V node was not made following autopsy.

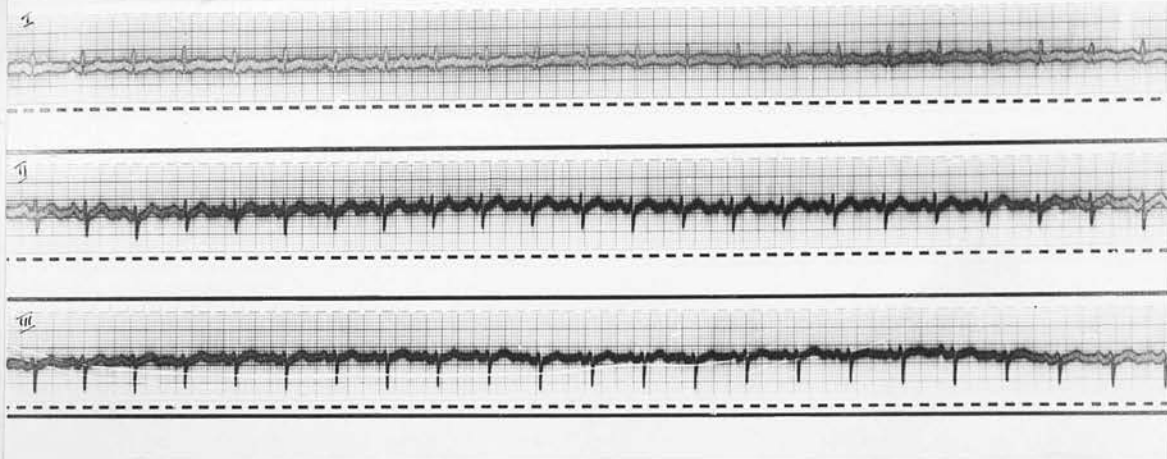


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Unfortunately microscopical examination of the myocardium and A-V node was not made following autopsy.

Case 3. Diabetes Mellitus: - A-V Dissociation.

The patient, a man aged 17 years, was admitted to the Leicester Royal Infirmary in an unconscious condition on 1st. May, 1940.

At examination he was seen to be very emaciated and was deeply unconscious. The respirations were regular but deep with mild air-hunger and a heavy odour of acetone was apparent.

Examination of the nervous system revealed a marked right external strabismus with an old injury to the right cornea; the pupils were unequal, the right being irregular in outline, and neither responded to light. All tendon reflexes were absent, but the plantar responses were flexor. Slight neck rigidity was present, but no head retraction, and Kernig's sign was definitely positive on both sides.

The mouth was clenched, the teeth were covered with dry sordes and the tongue was very dry and thickly coated. The abdomen was scaphoid, the skin being very dry and inelastic. Nothing abnormal was palpable in the abdomen.

Apart from a very marked pigeon breast (shown in the clinical photographs and reproductions of X-ray films in Figures 53 to 56) nothing abnormal was found on examination of the respiratory system.

The pulse was regular, 80 per minute, and of poor volume. The apex beat was situated in the Vth. left intercostal space internal to the mid-clavicular line and the heart sounds were clear and closed.

I regarded him as a case of Diabetic Coma, with a possible alternative of Tuberculous Meningitis. A blood sugar estimation was immediately made and gave a reading of 326 mgm. per cent. My first opinion was thus confirmed and treatment begun with intra-venous saline and large doses of insulin. In spite of the great severity of the diabetic condition he recovered from the coma satisfactorily; further stabilisation proved a long and difficult matter.

In view of the additional possibility of Tuberculous Meningitis I performed a lumbar puncture. A truly remarkable state of affairs was then discovered. No fluid was obtained, although the needle was inserted into three separate interspinous spaces, but in each case air was audibly sucked into the theca. My interest in this phenomenon was so great, that I repeated the lumbar puncture daily for several weeks. On five other occasions air was definitely heard to be sucked into the theca, no fluid entering the manometer; fluid was, however, successfully aspirated with a syringe on the second day. It was not until 27 days after his admission that Cerebro-spinal Fluid flowed freely from the theca. Unfortunately I did not employ a water manometer in order to measure the degree of negative intrathecal pressure.

My explanation of this phenomenon at first was that owing to the very severe dehydration, all

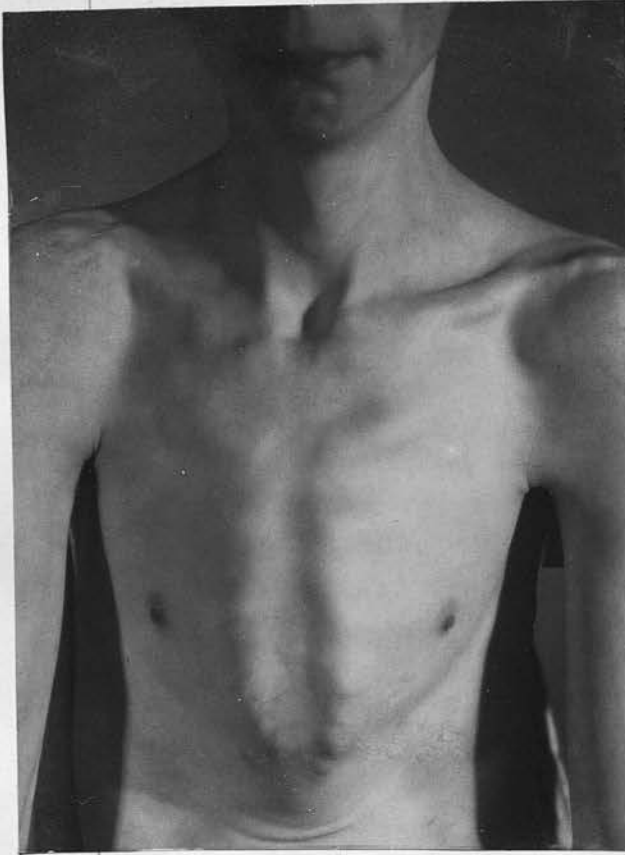


Fig. 53



Fig. 54.

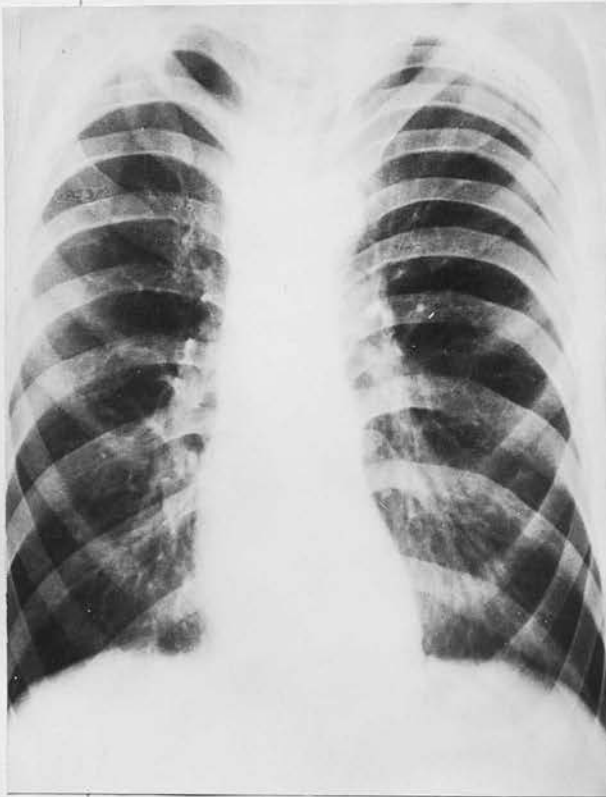


Fig 55.

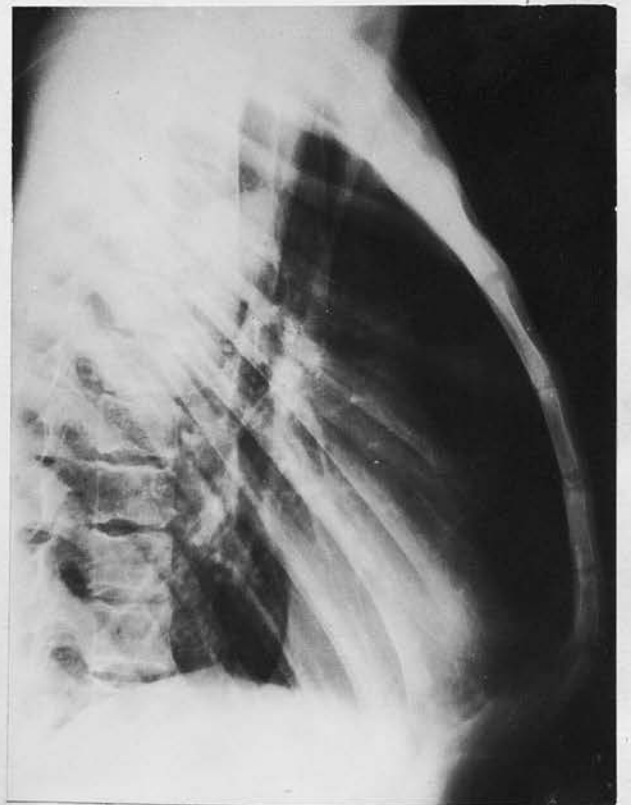


Fig. 56.

available cerebro-spinal fluid had been absorbed and I felt that this accounted for the meningeal signs present on admission. The dehydration alone, however, cannot have been entirely responsible for the negative pressure for, though clinical evidence of dehydration had disappeared after three or four days, surely the deficit in the amount of cerebro-spinal fluid should have been made good long before 27 days had passed.

I do not propose to describe the patient's history obtained later from relatives, or the multiple investigations into the blood chemistry and cerebro-spinal fluid examinations here, as no important bearing on the subject of this thesis occurs amongst them. The Wassermann Reaction was negative. I might say, however, that on careful examination a few days after the patient recovered consciousness no abnormality was detected in the nervous system. The strabismus in the right eye was due to an accident twelve months before admission. Examination of the cardio-vascular system was also entirely negative and no change in the cardiac outline was demonstrable on X-ray screening. The blood pressure was 120:65.

Also out of interest, I took an electrocardiogram on the day of admission whilst the patient was deeply unconscious. This record is reproduced in Fig. 57. The rhythm is regular with a rate of 75 per

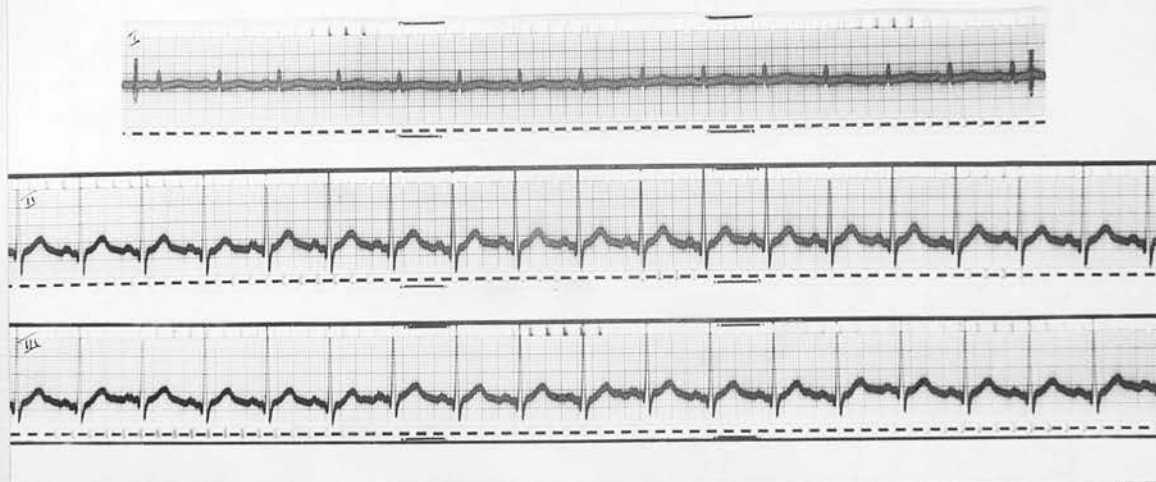


Fig. 57. 1--5--40.

minute and the ventricular complexes are of the supra-ventricular type. The P wave occurs 0.20 second before the QRS complex and in all three leads, but particularly noticeable in Leads II and III, it is bifid. The striking feature about the record, however, is the high amplitude of the QRS complexes in Leads II and III - too high to be included in the width of the film. The S wave is deep; the T wave is normal in shape. The splitting of the P waves and the high amplitude of the QRS complexes is due to the greatly increased viscosity of the blood consequent upon the extreme dehydration.

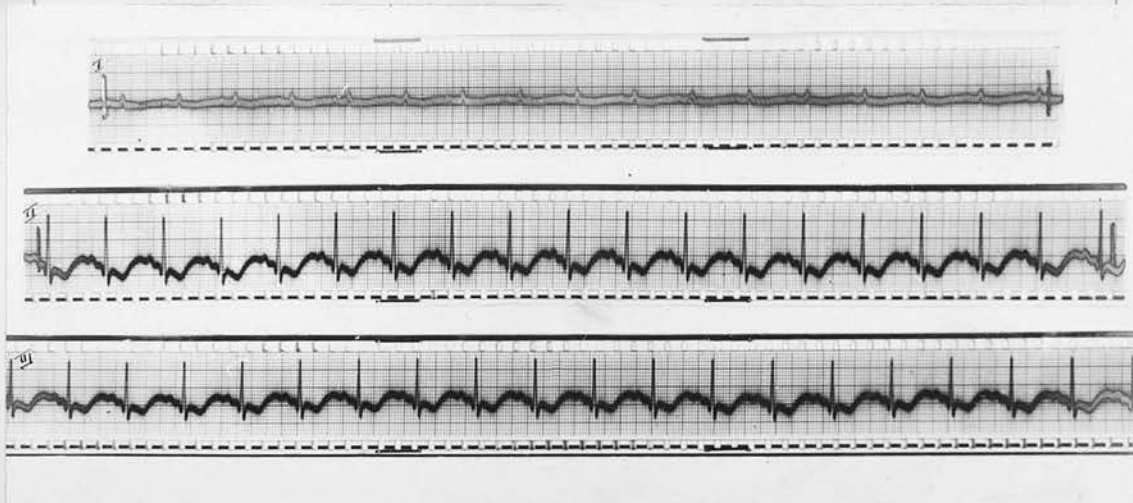


Fig. 58. 2--5--40.

Fig. 58 was taken on the following day. The patient was only semi-conscious at this time but there had been an enormous improvement in the degree of dehydration. In this record the splitting of the T wave has disappeared and the amplitude of the QRS complexes is considerably less, corresponding to the improved hydration. But a marked change has taken place in the T wave of Leads II and III; this wave is now diphasic. This alteration in the T wave prompted me to take daily electrocardiograms in order to watch its return to normal and it was this that led to the discovery of the arrhythmia with which I am at present concerned.

Fig. 59 was recorded five days after admission and a rather more pronounced diphasic T wave



Fig. 59. 5--5--40.

is seen. The heart rate is now 46 per minute, gradual slowing having taken place since the recording of Fig. 56.

In Fig. 60 we see the change in the cardiac

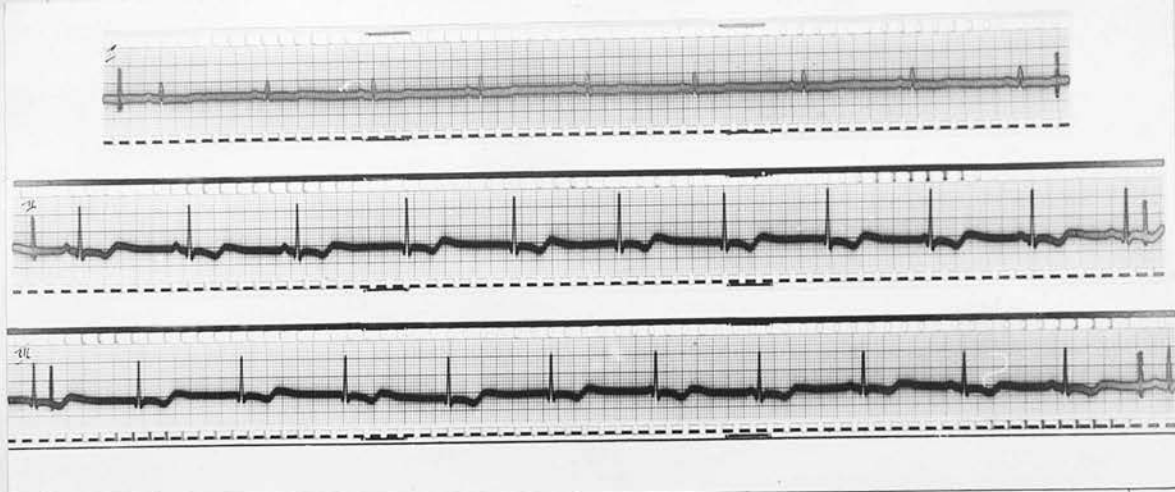


Fig. 60. 8--5--40.

mechanism. This record was taken eight days after admission. In Lead I, one sees a simple sinus rhythm with a rate of 43 per minute. The first three beats of Lead II are similarly of sinus origin, the P-Q interval measuring 0.17 second. The P wave then suddenly disappears entirely until in the third beat from the end of Lead II it is seen emerging from the QRS complex, the P-Q interval then measuring 0.08 second. In the last two beats of this Lead sinus rhythm has again been restored. A similar state is seen in Lead III, there being no apparent P wave associated with the QRS complexes of the first half of this strip; then it is seen to gradually emerge from the QRS complex until finally a normal P-Q interval is restored.

Here, then, is an example of A-V dissociation, the ventricles for a short time responding to a centre in the A-V node. This mechanism alternates at very short intervals with normal sinus rhythm. There is very slight difference in the relative rates of the auricle and ventricle accounting for the change in the location of the P wave. In Lead II there is also a slight but progressive increase in the R-R intervals towards the end of the atrio-ventricular rhythm. I use this term deliberately, because the mechanism shown in this and following records can be regarded as that described on page 14 as the second variety of A-V rhythm, although a diagnosis of A-V dissociation is equally applicable here (see Discussion).

Fig. 61 was recorded eleven days after admission and again gives a clear illustration of the mechanism described in Fig. 60. P waves are visible in some instances, mainly in Lead III, producing a small upright deflection immediately before the commencement of the Q wave. In only one instance (in Lead III) is there a P-Q interval of appreciable length - 0.10 second. It will also be noticed in passing that the T waves are no longer diphasic and their positive character is well marked.

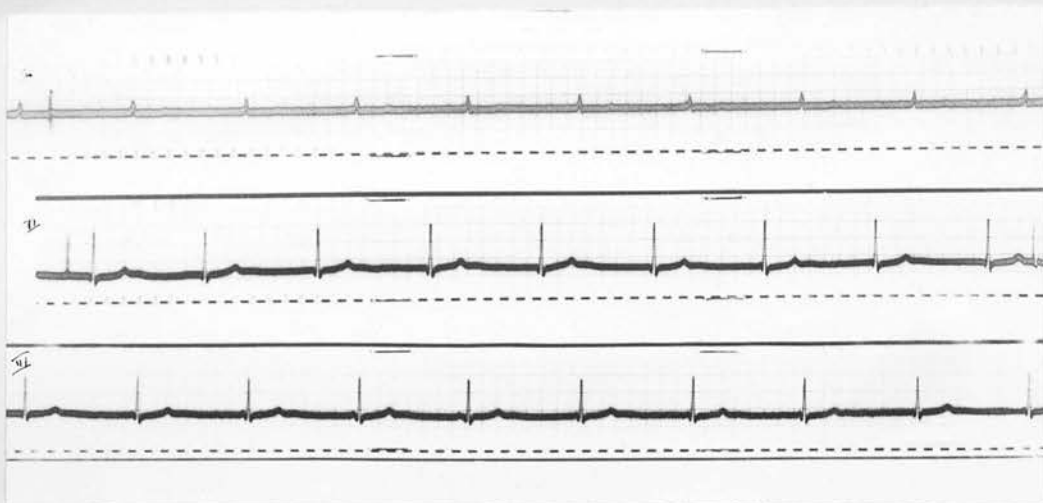


Fig. 61. 11--5--40.

Fig. 62 shows a modification of the previous two records. The P wave is never entirely absent but occurs at varying intervals, generally shorter than normal, before the QRS complexes. The heart rate is 40 per minute.

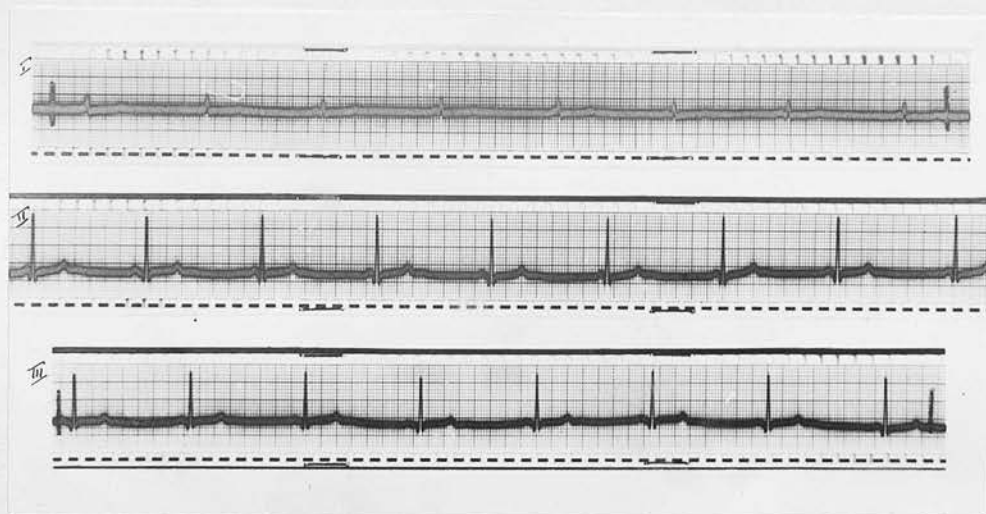


Fig. 62. 12--5--40.

This change in the cardiac mechanism was of short duration, persisting for about a week, then disappearing entirely and normal sinus rhythm persisted until the observations to be described below were commenced. The effect of reflex vagal stimulation was unfortunately not investigated at this time. Fig. 63 shows a typical record obtained seventeen days after the patient's admission. Sinus rhythm is present throughout the record, but bradycardia still persists, the rate being 40 per minute. Well marked upright T waves are present.



Fig. 63. 17--5--40.

The spontaneous appearance of A-V dissociation described above prompted me to try to induce this arrhythmia by the administration of digitalis. 20 minims of the tincture thrice daily was therefore commenced on 16--6--40, 47 days after the patient's admission. He was very well by this time although stabilisation of his diabetic condition was proceeding slowly. The heart was regular and the average rate from day to day was 56 beats per minute. During the period of digitalis administration electrocardiograms were taken daily. On 20--6--40 the dose was increased to 20m four times a day, and on 27--6--40, no toxic symptoms having appeared, Digoxin 0.25 mgm. was given night and morning in addition to the tincture. At this time he was therefore having a daily dose of digitalis equivalent to 110m of the tincture. This very large dose was continued until 3--7--40 when all digitalis was stopped.

On the evening of 29--6--40 he developed a temperature of 100.4°F. and next day his temperature rose to 102°F. where it remained with morning remissions for the next four days, after which it gradually returned to normal. There was an associated increase of the pulse rate during this pyrexial period to a fairly steady value of 72 beats per minute and a fall to 46 per minute as the pyrexia subsided. During this period the patient did not feel well, lost his appetite and complained of slight pain in both loins; but no symptoms of digitalis intoxication appeared until 3--7--40 when nausea, vomiting and occasional diarrhoea developed. The pulse was never found to be irregular on palpation.

No cause was found to account for the onset of the pyrexia. A catheter specimen of urine contained sugar and a trace of albumen, but no pus cells, casts or organisms were seen on microscopic examination and cultures were sterile. The patient made a rapid recovery following the subsidence of the temperature and the withdrawal of all digitalis. Blood examination revealed no leucocytosis.

A selection of the electrocardiograms taken before, during and after this period of digitalis administration are reproduced in the following figures.

Fig. 64 was recorded six days before any digitalis was given. A simple sinus bradycardia is seen, the heart rate being approximately 37 per minute, slight sinus arrhythmia being present. The T waves are upright.

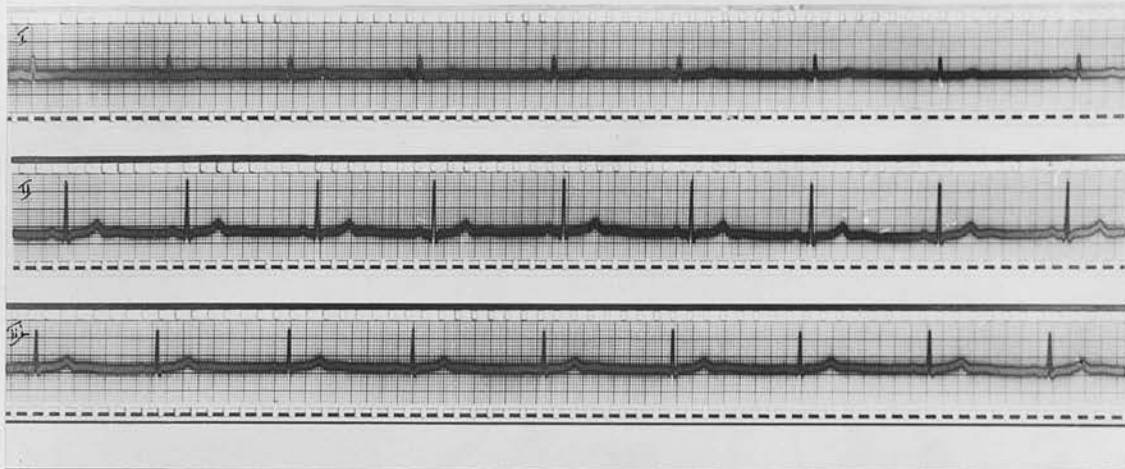


Fig. 64. 10--6--40.

Fig. 65 was taken three days after the commencement of the digitalis when the patient was receiving 20m of the tincture three times a day. Sinus bradycardia is still present, the rate being unchanged at 37 beats per minute. The T waves are now diphasic due to the action of the digitalis.

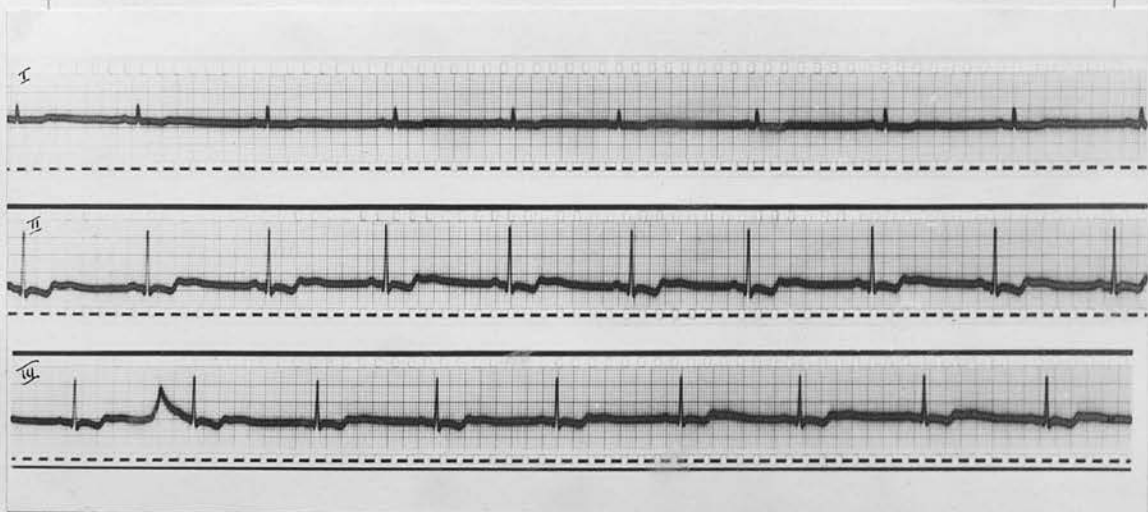


Fig. 65. 19--6--40.

Fig. 66 was taken six days after the commencement of digitalis and before the onset of the pyrexia. The patient was then receiving 80m of the tincture daily. Sinus rhythm is still present but

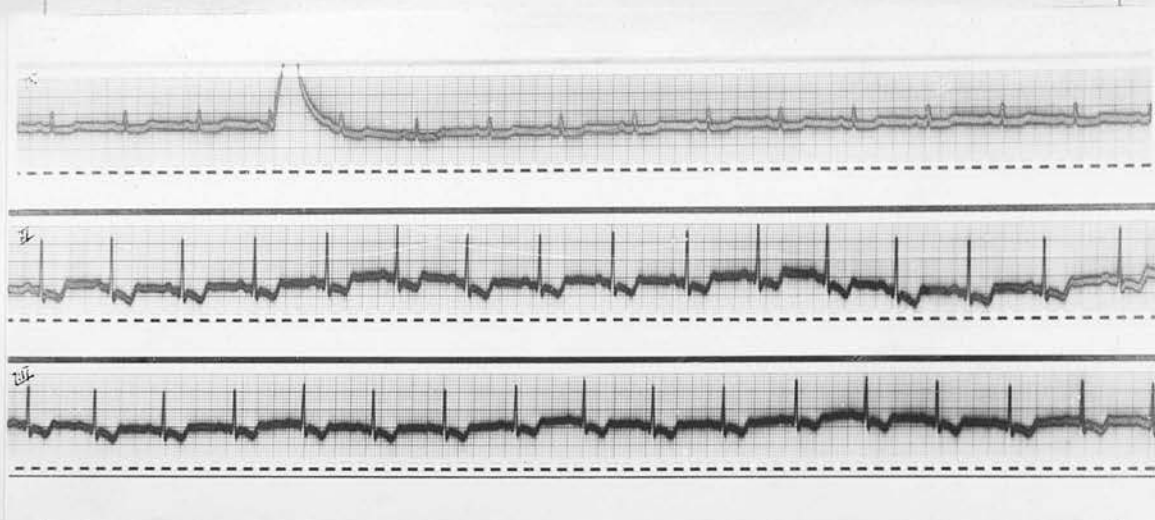


Fig. 66. 21--6--40.

rather surprisingly the heart rate has increased to 65 beats per minute.

Fig. 67 was recorded on 2--7--40 which was the fourth day of pyrexia after the patient had had 110m of the tincture daily for five days. In this record A-V dissociation appears and is seen in the first four beats of Lead II. The P wave appears immediately following the QRS complex and in the case of the first three beats causes either a peaking or a tremor on the S-T interval at the upper end of the

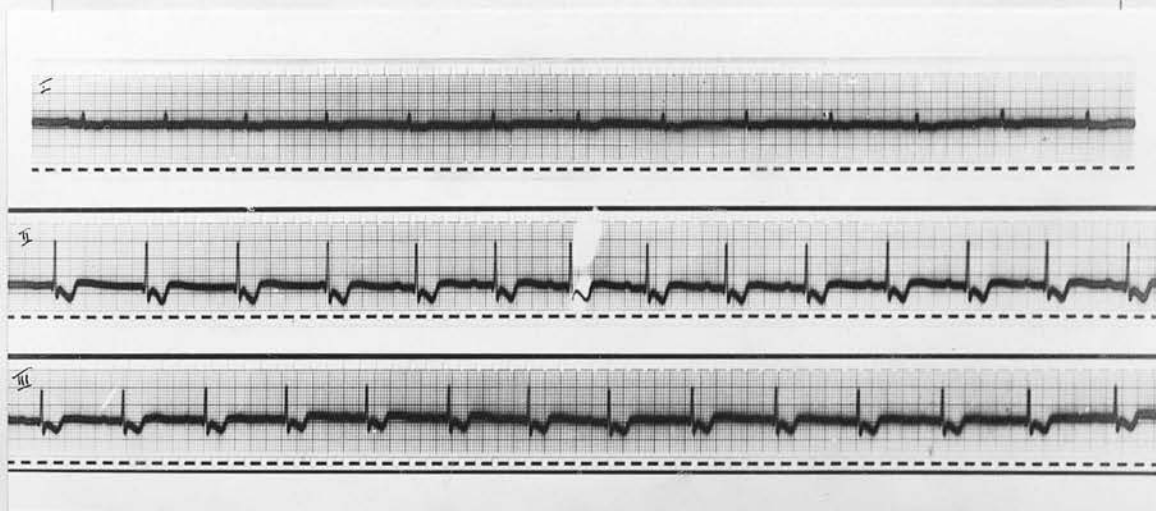


Fig. 67. 2--7--40.

descending limb of the T wave. In the case of the fourth beat the P wave is seen immediately before the QRS complex, there being a P-Q interval of 0.06 second. Thereafter, as in Leads I and III, sinus rhythm occurs. The other important point in this record is the lengthening of the P-Q interval in the case of the

sinus beats to 0.27 second. Here, then, we also have evidence of impairment of conduction between the auricle and ventricle. The R-R intervals also vary in duration and are longest during the short period of A-V dissociation; i. e., the heart rate is slowest during this arrhythmia.

Fig. 68 was recorded on the following day when the temperature had fallen to between 99.4 and 99.8°F. In this record a very obvious A-V dissociation is seen, the P waves occurring at varying intervals on the iso-electric line or in relation to the QRST complexes. Except in two possible instances no auricular impulse reaches the ventricles and an almost complete forward heart block therefore exists. The R-R intervals have a very regular duration of 1.48 seconds, corresponding to a ventricular rate of 40 beats per minute. Two of these intervals, however, in Lead II show a shortened R-R interval and have been lettered "A" and "C", the duration of the R-R interval being inserted in each case. The R-R interval "B" is inserted as an example of the average or "normal" R-R interval for this record. It will be noticed that in these instances

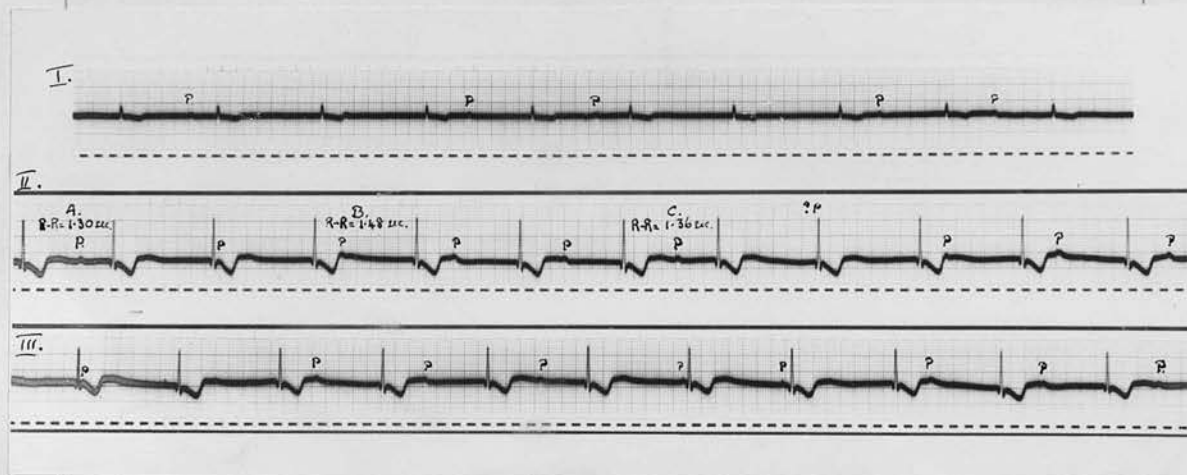


Fig. 68. 3--7--40.

the R-R intervals are 0.18 and 0.12 second shorter than the average respectively. The P-Q intervals in the case of "A" and "C" measure 0.46 and 0.58 second respectively. It seems reasonable to assume that the conspicuous shortening of the R-R intervals in these two instances is due to the passage of an impulse from auricle to ventricle after a considerable delay in the conducting tissues. Shorter P-Q intervals are seen elsewhere in the record but no appreciable change in the length of the R-R interval occurs.

This record can therefore be regarded as showing a very high degree of forward heart block. Complete retrograde block is also present as no evidence of auricular activity due to an impulse from the ventricle is to be seen associated with the QRS complexes.

The other point concerning this record, and which places it in the category of A-V dissociation discussed in Part II, is that the auricular rate is

slower than that of the ventricle. In contradistinction to the fairly regular ventricular complexes, however, the P waves often fall at irregular intervals and at times no P waves are visible in their expected positions. For example, following the R-R interval "C" no P wave is seen for a distance of 3.8 seconds although one would have expected it to fall shortly before the QRS complex following "C". The P wave is most likely hidden in this QRS complex and its apparent absence is most readily explained by the irregularity of the auricular complexes seen elsewhere in the record. The P-P intervals on careful measurement are found to vary between 2.04 and 1.58 seconds, corresponding to an auricular rate between 30 and 40 beats per minute. It might also be noted here that the interval from the P or the R-R interval "C" to the following R wave measures 2.04 seconds.

This record therefore illustrates A-V dissociation with a ventricular rate of 40 per minute - i. e., faster than that of the auricle which varies in rate between 30 and 40 beats per minute.

All digitalis was stopped on 3--7--40, and Fig. 69 was taken on the following day. Here again dissociation is at once apparent. No P wave occurs preceding the QRS complexes but it is seen in most instances as a small upward deflection or tremor on the descending limb of the inverted T wave. In this record the position of the P waves has again been indicated. Its relation to the QRS complex is fairly constant and the rates of auricle and ventricle are almost identical.



Fig. 69. 4--7--40.

Fig. 70 illustrates chest leads taken immediately following Fig. 69. Here again dissociation is apparent. In a few instances the P wave is seen on the iso-electric line, but generally it deforms the descending limb of the inverted T wave or is hidden in the QRS complex. The R-R intervals are equal throughout the record, even when a P wave precedes the ventricular

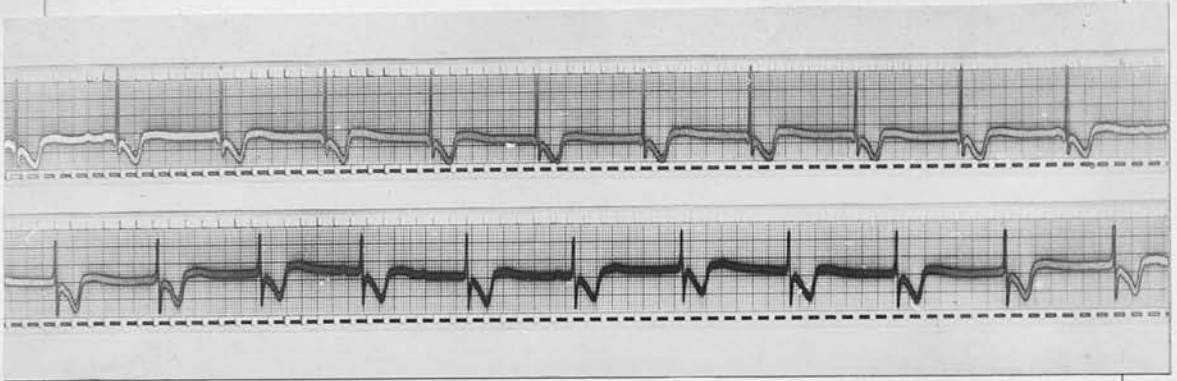


Fig. 70. 4--7--40.

complex and one must assume complete forward heart block. The irregularity of the P-P intervals is very well shown, these intervals being sometimes considerably shorter and sometimes appreciably longer than the R-R intervals. The ventricular rate is 44 per minute.

On 5--7--40 a further series of observations was made. Fig. 71 was first recorded and again a high grade of forward heart block is seen. Disregarding Lead I for the moment, the auricle is beating faster than the ventricle, the rates of the two chambers being 60 and 50 respectively (the ventricular rate is an average one owing to irregularity). This ventricular irregularity is very obvious and is seen to be due to many auricular impulses passing through to the ventricle; the delay in the conduction of the auricular impulse through the junctional tissues alters, and the P-Q intervals of these conducted beats vary between 0.48 and 0.27 second. The patient did not experience any palpitation at this time.

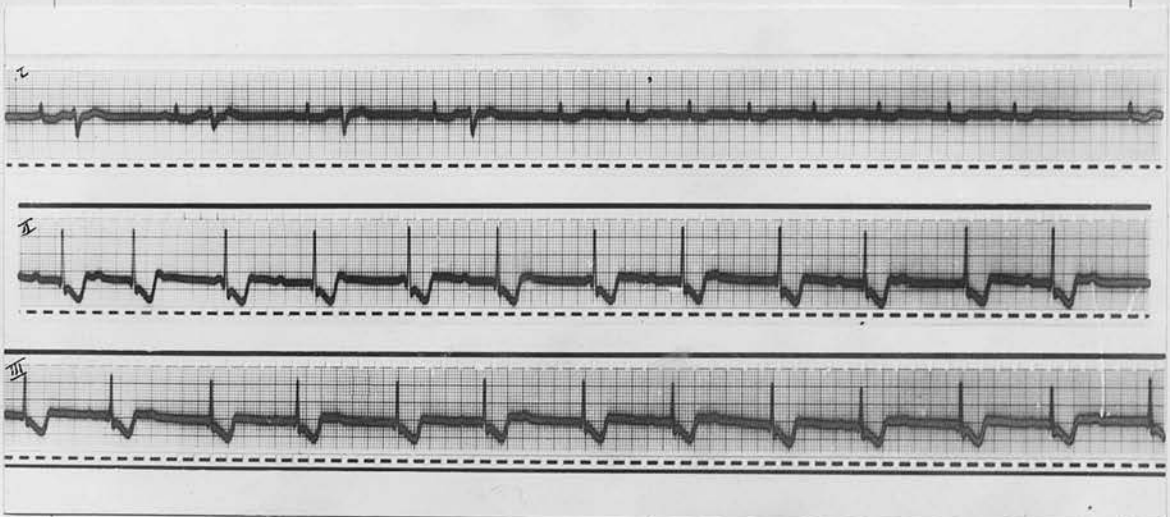


Fig. 71. 5--7--40.

In Lead I of Fig. 71 a different state of affairs is seen. At the beginning of this strip

ventricular extrasystoles are seen following the normal complexes and producing a bigeminy; this is a further indication of digitalis intoxication. In the latter half of the record, however, the extrasystoles disappear and the rhythm becomes regular with a rate of 75 per minute; each ventricular complex, moreover, is preceded by an upright P wave, the P-Q interval measuring, with slight variation from beat to beat, 0.30 second. Then at the end of the strip an auricular beat fails to excite a ventricular response and the A-V dissociation seen in Leads II and III commences. Thus a short run of sinus rhythm has occurred in Lead I and is of interest in showing the variation which occurs in the conducting power from moment to moment.

The effect of the intravenous injection of $\frac{1}{5}$ gr. of atropine sulphate upon this dissociation was then observed and a continuous record taken on Lead II before, during and after the injection was made. Figures 72 A and B are continuous sections reproduced from the commencement of this long record.

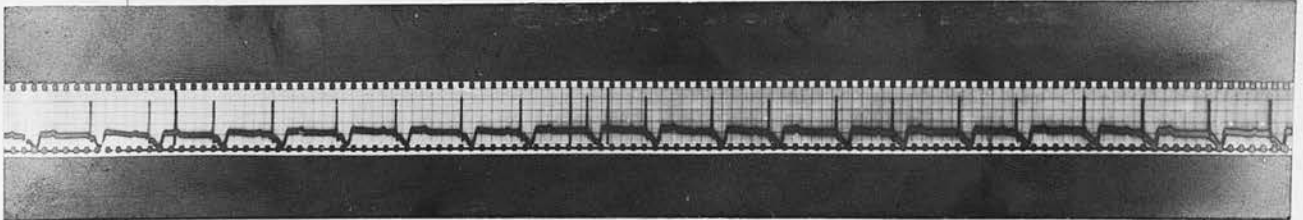


Fig. 72 A. 5--7--40.

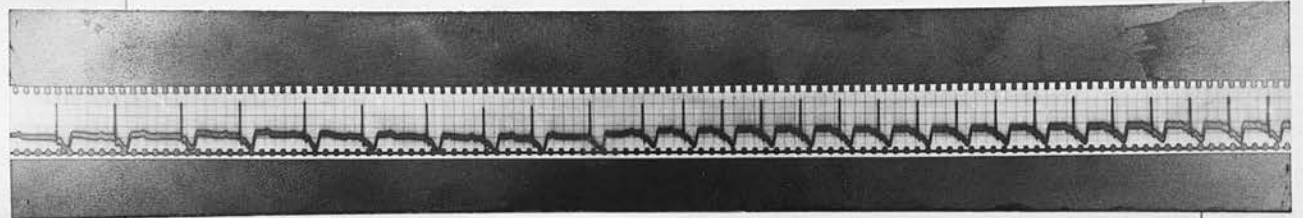


Fig. 72 B. (Continuous with 72 A).

The injection was commenced at the first vertical line and was terminated at the point marked by the two vertical lines shown in Fig. 72 A. A similar A-V dissociation with occasional conducted auricular impulses as described in Figures 70 and 71 is seen in the whole of Fig. 72 A and in the first half of Fig. 72 B. In the centre of the latter record a sudden change occurs, 35 seconds after the injection was commenced. Abruptly the A-V dissociation ceases and the rate jumps from its previous average of 50 to 75 beats per minute. Normal sinus rhythm is completely restored, each ventricular complex being preceded by an upright P wave; the P-Q intervals of the first and second beat of this sinus rhythm measure 0.23 second, but thereafter the interval attains a normal value of 0.20 second.

The dramatic effect of the atropine has therefore been to completely overcome the action of digitalis in producing the heart block.

Fig. 73 was recorded fifteen minutes later and the effect of the atropine is well illustrated. The sinus rhythm persists at a rate of 75 per minute and the P-Q interval measures 0.20 second. A slight variation occurs towards the end of Lead II where slight slowing of the ventricular rate is seen and the P-Q interval increases to a maximum value of 0.30 second. These changes are only temporary, however, and the normal P-Q interval and ventricular rate of 75 is again seen in Lead III.

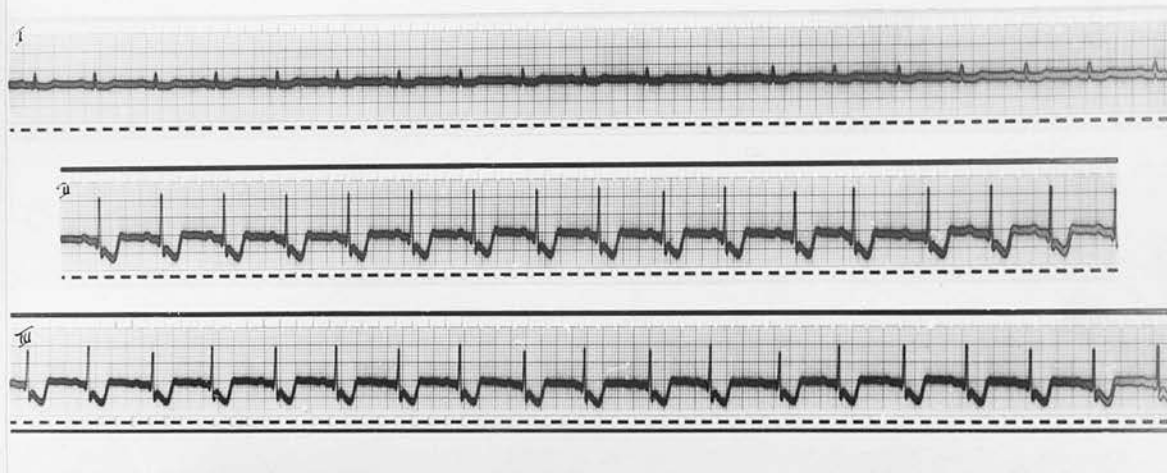


Fig. 73. (Fifteen minutes after atropine).

Fig. 74 was recorded four hours after the atropine was administered. By this time its effect has worn off and one sees a return to the A-V dissociation described previously under Figures 70 and 71 but the R-R intervals are approximately equal and no auricular beats appear to be conducted to the ventricle. The auricle is again contracting faster than the ventricle, the rates being 60 and 48 respectively. The record thus shows complete heart block.



Fig. 74. (Four hours after atropine).

Fig. 75 was recorded four days after all digitalis was stopped and here normal sinus rhythm is seen with a heart rate of approximately 43 per minute, sinus arrhythmia being present. The P-Q interval measures 0.21 second. At times, however, the sinus rhythm gives place to a simple A-V dissociation, the P wave being seen to approach the QRS complex, for example at the end of Lead II, and in the central part of Lead III it is seen as a small upright wave on the descending limb of the inverted T wave.

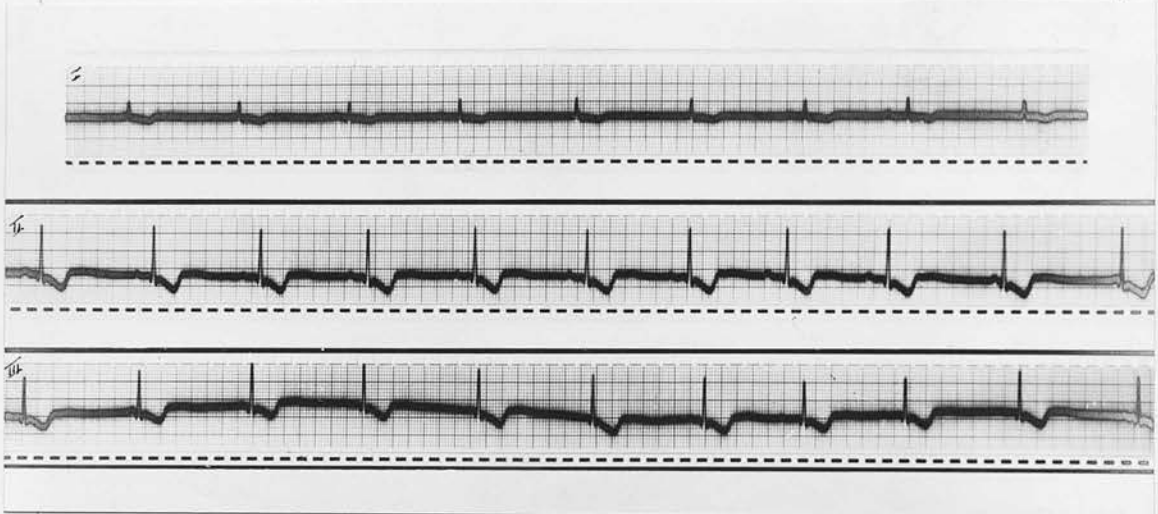


Fig. 75. 8--7--40

A similar transition between sinus rhythm and simple A-V dissociation is seen in Fig. 76, and a lesser degree is shown in Fig. 77, these records being recorded 7 and 12 days respectively after the digitalis was withheld. The T waves are returning to their upright form and this is also illustrated at a later stage in Fig. 78. In this last record sinus bradycardia with a heart rate of 37 beats per minute is seen and no transition to A-V dissociation is present.

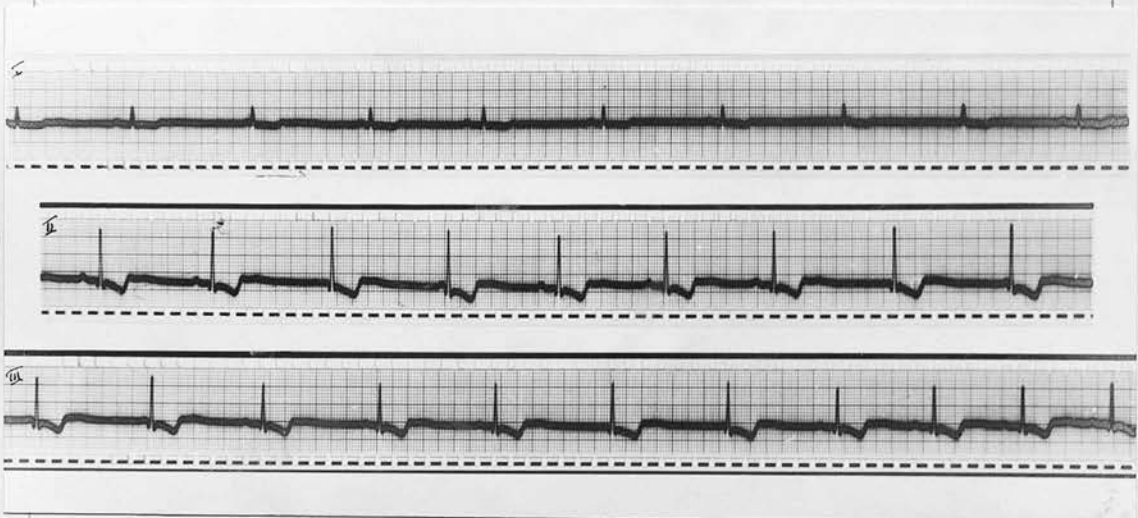


Fig. 76. 11--7--40.

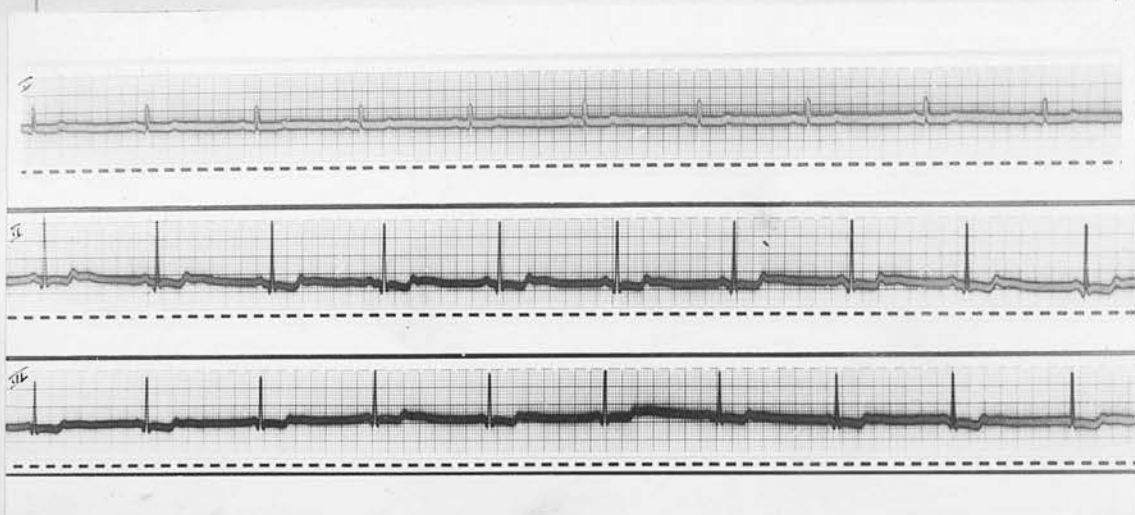


Fig. 77. 16--7--40.

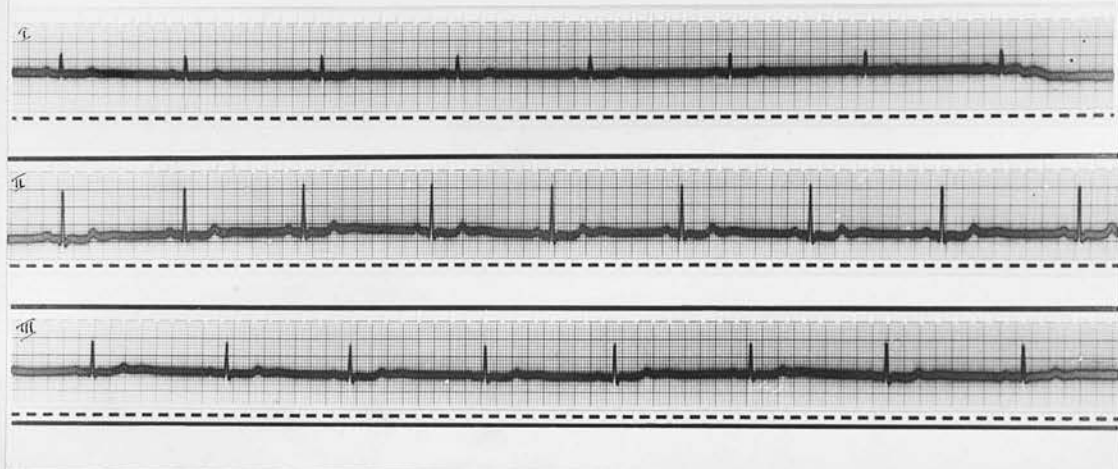


Fig. 78. 22--7--40.

The administration of large doses of digitalis has therefore produced a very striking sequence of events in this case. Various grades of heart block have been described together with examples of A-V dissociation with and without interference. Atropine was specific in relieving temporarily the conduction defect produced by digitalis. Slight degrees of simple A-V dissociation persisted for at least a fortnight after all digitalis was stopped.

Another observation made and controlled by means of the electrocardiograph was the effect of reflex vagal stimulation during the early action of atropine according to the method employed by Wilson and discussed on page 16. The patient appeared to me to be a very suitable subject in view of the spontaneous occurrence of A-V dissociation described early in this case. The

observations were repeated on two occasions.

Carotid sinus pressure alone or together with a forced inspiration, was carried out on several occasions without atropine having been given, and Lead II of the electrocardiogram was simultaneously recorded. Neither right nor left sided pressure produced any change in the tracing from normal sinus rhythm. Ocular pressure was not attempted.

On the first occasion that the drug was given, $\frac{1}{50}$ gr. of atropine sulphate was administered subcutaneously. Records were then taken on Lead II every $\frac{1}{2}$ to 1 minute, and either right or left sided carotid sinus pressure was applied with or without deep inspiration. The beam of the electrocardiograph was carefully watched throughout the whole procedure but it was not possible to distinguish any alteration in the position of the auricular deflection. The results of these procedures are reproduced in Fig. 79. Five strips of film taken on Lead II are illustrated; these records were taken $2\frac{1}{2}$, 5, $6\frac{1}{2}$, 7 and 8 minutes after the injection and have been lettered "A", "B", "C", "D" and "E" respectively.

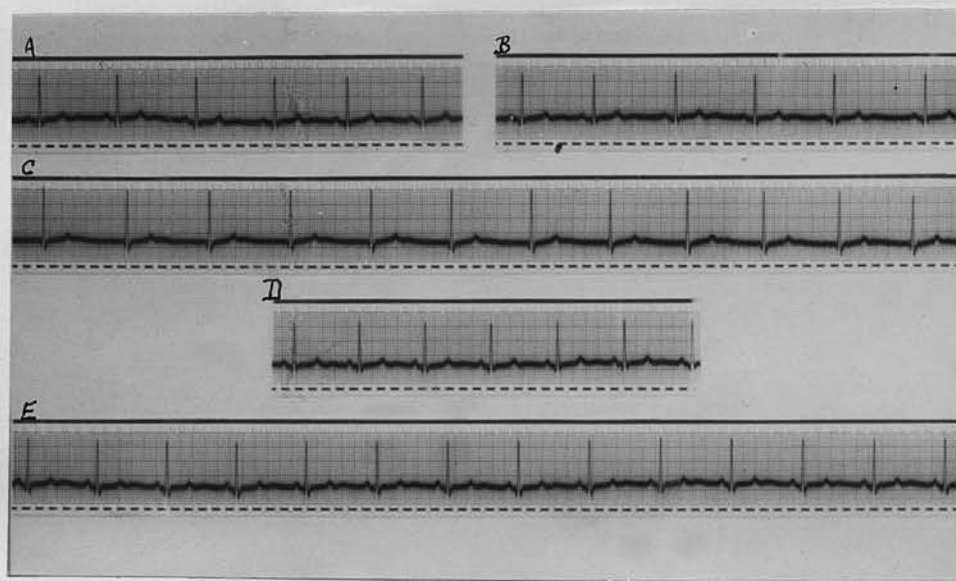


Fig. 79. 12--8--40. (Lead II only).

Strips "A" and "B" show a sinus rhythm, the upright P wave being followed after an interval of 0.20 second by the QRS complex; the rhythm is slightly irregular, the rate being 47 - 52 per minute. In strip "C", taken during right carotid sinus pressure with deep inspiration, no P waves are visible, the diastolic line being unbroken. The R-R intervals decrease gradually from the beginning of the strip to its end and the ventricular rate consequently gradually increases from a rate of 45 to one of 48 per minute. A slight decrease in the ventricular rate has thus taken place as compared with strips "A" and "B". Another striking feature is the increase in the amplitude of the R waves in strip "C" when compared with strips "A", "B", "D"

and "E", this increase representing some two to three millimetres. This increased amplitude is probably associated with the slower heart rate.

Sections "D" and "E" again show normal sinus rhythm with a rate of 55 beats per minute.

Reflex vagal stimulation has thus resulted in the production of A-V nodal rhythm of the second variety described on page 14, this change occurring $6\frac{1}{2}$ minutes after the atropine was given. Records were taken regularly for 30 minutes, but no change occurred from the normal sinus rhythm apart from this isolated instance.

On the second occasion when this procedure was carried out, $\frac{1}{10}$ g. of atropine sulphate was given subcutaneously. Reflex vagal stimulation was exerted in a similar manner and the electrocardiogram was again recorded on Lead II at $\frac{1}{2}$ to $1\frac{1}{2}$ minute intervals for 11 minutes and thereafter at 3 minute intervals. In Fig. 80 three of these records have been reproduced, "A" being recorded 8 minutes, "B" at $9\frac{1}{2}$ minutes and "C" at 11 minutes after the injection.

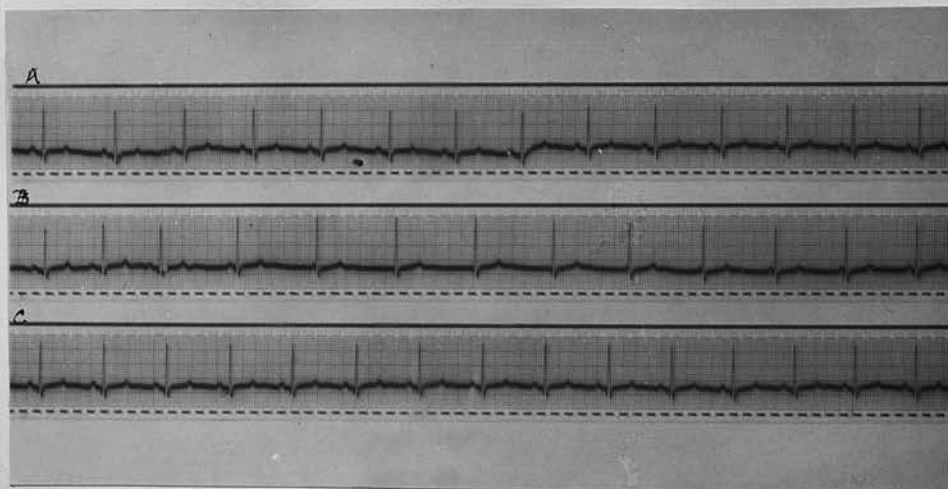


Fig. 80. 19--8--40. (Lead II only).

Sections "A" and "C" again show normal sinus rhythm the heart rate being 55 and 60 per minute respectively. In section "B", however, a temporary A-V dissociation is seen, the P wave gradually approaching the QRS complex, becoming merged in it and then gradually re-appearing before the QRS complex towards the end of this section. This dissociation is accompanied by a marked slowing of the heart rate; at the beginning of section "C" the R-R interval measures 0.93 second (corresponding to a rate of 64 per minute); then there is a sudden slowing of the heart rate, the R-R interval becoming increased to 1.20 seconds (corresponding to a rate of 50 per minute); finally the R-R interval decreases in size and the heart rate again quickens. As in Fig. 79 there is noticeable increase in the amplitude of the R wave associated with the slowing of the heart rate and as this rate gradually increases, the amplitude of the R wave is seen to gradually diminish.

Following the recording of Fig. 80 "C" no change in the cardiac mechanism could be produced by any of the methods of reflex vagal stimulation employed.

Discussion.

The case just described is a particularly interesting one owing to several very unusual features. First of all there is the extreme severity of the diabetic condition on admission to hospital, the severe dehydration, the signs of meningeal irritation and the absence of free flow of cerebro-spinal fluid with the negative intrathecal pressure. Indeed it is surprising that the patient made such an excellent recovery from the coma.

Secondly there is the unexpected development of A-V dissociation described in Figures 60 to 62 and transitions between this and sinus rhythm persisted for at least a week as revealed by daily electrocardiograms. This occurrence is of particular interest since it was discovered more or less accidentally whilst other observations on the changes occurring in the T waves were being made. This accidental finding, in a case where there is no indication in the usual course of events for electrocardiographic study, suggests that A-V dissociation may occur more frequently than is at present generally supposed; and its rarity is probably mainly due to the absence of any indication for electrocardiographic investigation, since it is by this means alone that the condition can be recognised.

The arrhythmia was of short duration and the patient experienced no symptoms during either the transitions to or from normal sinus rhythm or whilst the dissociation was present.

The A-V dissociation is obviously related to the bradycardia. The patient's pulse rate varied between 40 and 60 per minute during the whole of his stay in hospital and was frequently slightly below 40 per minute. Presumably there was some degree of increased excitability of the A-V nodal tissues when A-V dissociation was present, raising its period and so accounting for the ready transition between this dissociation and sinus rhythm. Otherwise one would have expected the arrhythmia to become manifest at other times, but for many weeks no such change occurred until digitalis was administered. Following the observations with this drug a short period of A-V dissociation occurred but thereafter the sinus node always controlled the whole heart. One frequently meets with slight shortening of the P-R interval in cases of sinus bradycardia and there is no doubt a tendency in these cases for A-V dissociation to occur.

The effect of toxic doses of digitalis is of interest and this case provides a perfect example of the production of A-V dissociation as described in Part II and of various grades of heart block by this drug.

Additional confirmation of Wilson's method of producing A-V rhythm and A-V dissociation is shown by the effect of vagal stimulation during the early

stages of atropine action. This method has been fully discussed on page 16. There is one point to which I might draw attention, however, Section "C" of Fig. 79 can be regarded as an example of the second variety of A-V nodal rhythm described on page 14. No P waves are to be seen and the picture corresponds in all ways to that description. But we know from previous records that a complete retrograde heart block exists in this case for in no instance has retrograde conduction to the auricle appeared. (See also page 21.) The picture always presented previously was one of A-V dissociation and Fig. 80 "B" shows this condition produced by a similar means to Fig. 79 "C". Several of the complexes of Fig. 80 "B" also have the characteristics of the second variety of A-V nodal rhythm. Fig. 79 "C" is therefore an example of A-V dissociation, the auricle and ventricle beating independently but at equal rates, and not of A-V rhythm. This distinction between these two conditions is of academic interest, but it is well to recognise that a similar picture can result from A-V dissociation and the second variety of A-V rhythm, and that in the absence of an inverted P wave and altered P-R relation a diagnosis of A-V nodal rhythm is particularly uncertain.

Summary.

A case of Diabetes Mellitus, admitted in coma, is described. It presents several unique features, notably a negative intrathecal pressure.

A-V dissociation was discovered accidentally in this case, favouring the view that that condition may be more common than is generally supposed.

No symptoms occurred during the periods of A-V dissociation or during the transitions to and from sinus rhythm, and the condition could not have been recognised without the aid of the electrocardiogram.

The A-V dissociation was temporary from minute to minute, the arrhythmia persisting in all for only a week.

The effect of toxic doses of digitalis in producing simple A-V dissociation and the various grades of heart block is described and illustrated by electrocardiograms.

Reflex vagal stimulation during the early stages of atropine action produced A-V rhythm and A-V dissociation and thus provides additional confirmation of Wilson's observations.

The distinction between the second variety of A-V rhythm and A-V dissociation where auricle and ventricle contract independently of each other but at identical rates is considered.

My interest in the conditions which I have been considering prompted me to look through some 2000 old records taken during the previous fourteen years at the Leicester Royal Infirmary. Some half a dozen of these showed temporary changes due to the conditions of the character described, but only one of these is, I think, worthy of consideration.

Case 4. A-V Dissociation.

H. C. Male; aged 59 years. Manager.

The patient was admitted to the Leicester Royal Infirmary on 11--8--27, and he died a week later.

For five years previous to this time he had suffered from "heart trouble", with praecordial distress and dyspnoea on exertion; a year prior to admission he had an attack of severe pain in the upper abdomen passing into the chest accompanied by increased difficulty in breathing; this lasted for a few days but he was confined to bed for seven weeks and following this he experienced "anginal attacks".

He gradually became more and more exhausted during the five weeks preceding admission and this was accompanied by increasing breathlessness, fainting attacks and occasional palpitation.

On examination he was seen to be well nourished, slightly dyspnoeic at rest and markedly cyanosed.

His radial pulse was regular on admission with a rate of 85 per minute and the vessel was slightly thickened. The apex beat was palpable in the Vth. left intercostal space one inch outside the mid-clavicular line. The heart sounds were faint with a soft systolic mitral murmur.

The blood pressure was not recorded on his case sheet.

There was marked oedema over the lower back and of the legs and feet.

The abdomen was greatly distended and free fluid was present in considerable amount. The liver was palpable 3 inches below the costal margin; the spleen was not palpable.

A few crepitations were present at the bases of both lungs but little else was noted on examination of the respiratory system.

The urine was alkaline, S.G. 1015 and contained a small amount of albumen; no blood, casts or other abnormal constituents were present.

The urinary output rapidly diminished during his stay in hospital.

The temperature remained normal or slightly subnormal.

He was given tincture of Digitalis $\text{m}x$ b.d. on the day after admission and this was increased three days later to $\text{m}xx$ t.i.d.

His condition rapidly deteriorated and death took place on 18--8--27.

Post-mortem examination revealed a hypertrophied and considerably dilated heart weighing 20 oz. Free fluid was present in the pericardium and numerous adhesions existed between it and the heart wall due to recent pericarditis. The myocardium was fatty, the coronary arteries were atheromatous; the aortic and mitral valves were normal and there was some ante-mortem clot in the right ventricle.

The lungs were congested.

The abdomen contained a very large quantity of free fluid; the liver weighed 62 oz. and was "nutmeg" in character; the spleen was congested and hypertrophied, weighing 20 oz.; the kidneys were congested, no infarcts were present and the right organ was cystic and contained a large number of calculi.

Microscopic examination of the heart muscle revealed no fibrosis and no blockage of blood vessels. Sections of kidneys showed an acute glomerular nephritis superimposed on a chronic interstitial nephritis.

An electrocardiogram was first taken on 15--8--27, four days after admission and is shown in Fig. 81.

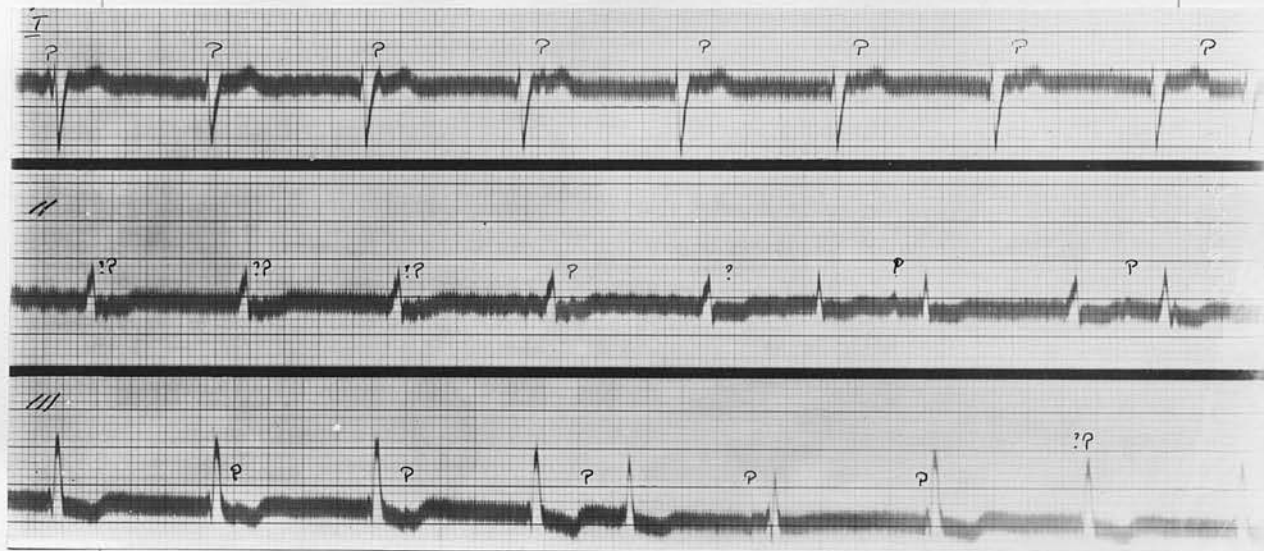


Fig. 81. 15--8--27.

Except for occasional premature beats the heart is seen to be regular with a rate of 66 per minute, but the striking feature is the absence of a P wave before the QRS complex.

On examination of Lead I, one sees a P wave on the S-T interval of the fourth ventricular complex and possibly others occurring at similar places following the next three complexes. A P wave then occurs towards the end of the T wave of the final complex of this Lead and is followed by an early ventricular response. The termination of the S wave of the third complex is also seen to be slurred and

raised above the iso-electric line when compared with the termination of the S wave of the other ventricular complexes and no doubt a P wave has also fallen here. Measurement of these P-P intervals (0.93 second as compared with the R-R intervals of 0.90 second) gives a clue to the position of the P wave of the second ventricular complex and it should have fallen within that deflection; similar measurement shows that a P wave falls just before the first QRS complex of this Lead. Examination of Leads II and III show a similar state of affairs, the auricular impulse giving rise to a second premature ventricular deflection when it falls clear of the refractory period of the junctional and ventricular tissues. I have indicated the positions of the P waves on this record.

This sequence of events is more clearly seen in Figures 82, 83 and 84 which were recorded two days later, one lead only having been taken on each plate. I shall not describe these records in detail as this



Fig. 82. 17--8--27. (Lead I only)

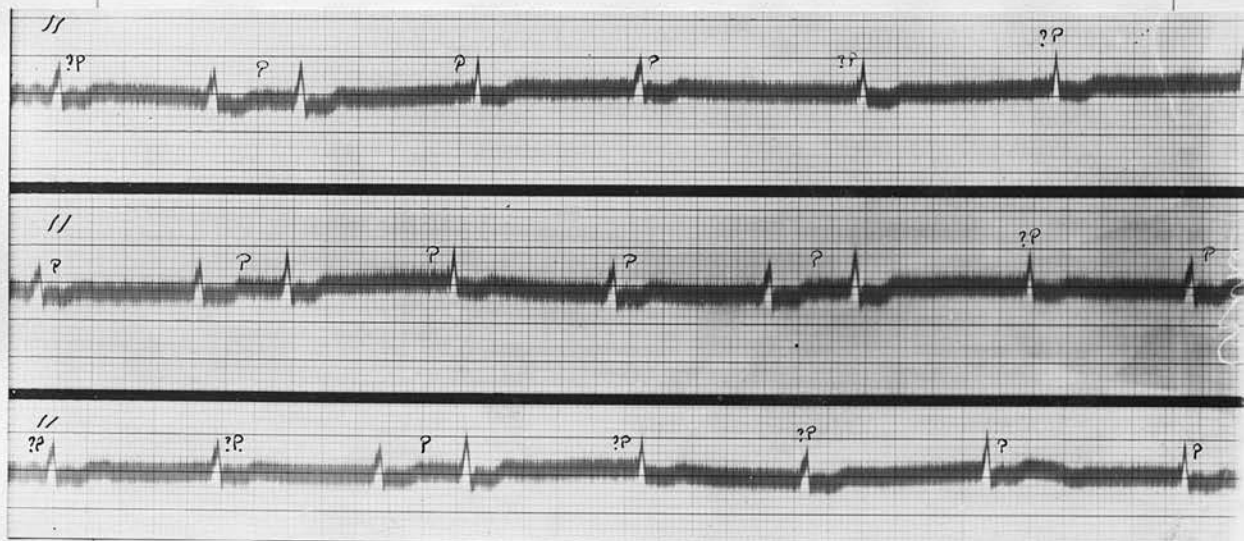


Fig. 83. 17--8--27. (Lead II only.)

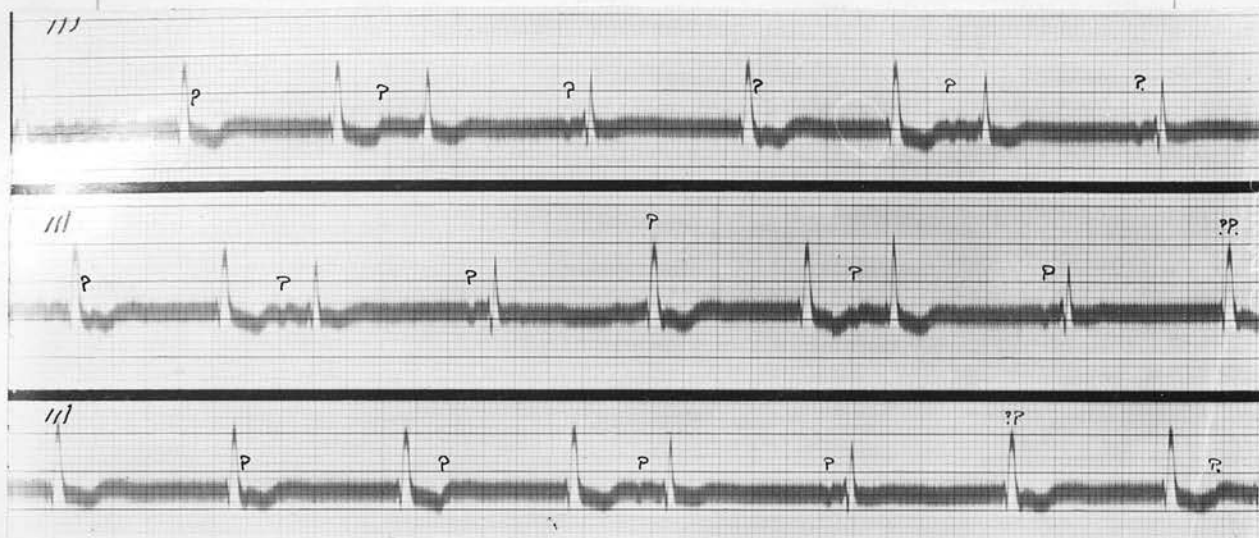


Fig. 84. 17--8--27. (Lead III only).

would simply mean repetition, but dissociation between the auricle and ventricle with occasional interference by the auricular centre is very clearly seen. In each of these three records I have also marked the positions where the P waves were due to appear. The ventricular rate is greater than that of the auricle, the former having an average value of approximately 55 per minute and the latter of practically 50 per minute.

In Lead III (Fig. 84), the P waves are inverted. This inversion is not of significance as inverted P waves commonly occur normally in that Lead.

Discussion.

This case furnishes yet another excellent example of A-V dissociation with interference, the ventricle possessing a rate more rapid than that of the auricle. Were it not for the conducted auricular impulses this difference in rate would not be very great.

The periods of the S-A and A-V nodes are very nearly equal, that of the latter just exceeding that of the former. Complete retrograde heart block accounts for the non-development of the A-V nodal rhythm. The period of the A-V node has in all probability been slightly enhanced by the carditis. There has probably also been some depression of the S-A node to account for its lowered period and the reason for this is a matter of speculation. The administration of digitalis is at once suspect, in spite of the relatively small dosage at first employed. It is unfortunate that no electrocardiogram was taken before the drug was commenced in order to determine what the cardiac mechanism was then. Generally A-V dissociation is produced by large doses of digitalis (c.f. Case 3) but it is possible that the drug even in small doses may at least increase a tendency to S-A nodal depression. Of course there is always the possibility that this

patient may have had much larger doses of digitalis before entering hospital. Atheroma of the coronary vessels had been noted at autopsy but it is very improbable that disease of the vessel supplying the S-A node accounts for its depression; such instances are extremely uncommon and very few cases have been reported where sinus depression was due to this cause.

Summary.

A case of Congestive Heart Failure (discovered amongst old records) showing electrocardiographic features of A-V dissociation with interference is described and discussed.

*

Case 5. "Reversed Rhythm of the Heart".

This case is inserted in order to distinguish it from the form of A-V dissociation already considered.

In 1922 Kahn (81) emphasised the distinction between the reversed cardiac mechanism exemplified by A-V nodal rhythm with its R-P interval and inverted P wave and what might be termed "reversed rhythm of the heart". This term was intended only to express a time relationship where the ventricular complex immediately preceded the auricular complex. It therefore included A-V nodal rhythm in which an inverted P wave followed the QRS complex, A-V dissociation where an upright P wave succeeded the QRS complex, and thirdly cases in which the P-R interval was so lengthened that the P wave fell just after the preceding ventricular contraction. Kahn described a case illustrative of the last condition and the following case is another example and is in many ways similar to Kahn's case.

R.H., a male patient aged 42 years, was admitted to the Leicester Royal Infirmary on 6--8--40.

A month prior to admission he had a severe attack of "gastric influenza"; on returning to work he became progressively more and more breathless and experienced a sense of constriction of the chest. He had no palpitation or oedema of the feet.

He had had no previous illness and there was nothing relevant in the family history.

On examination the patient was found to be well nourished but pale and he did not look well. There was no cyanosis or dyspnoea whilst in bed.

The pulse was regular with a rate of 110 per minute and the blood pressure was 112:55. The heart was slightly enlarged, the apex beat being located in the 5th. left intercostal space half an inch outside the mid-clavicular line. The heart sounds were closed but the second mitral sound was reduplicated. No oedema was present.

The other systems presented no abnormal features on examination.

The temperature on admission was 100.4°F. and it remained fairly constantly elevated with excursions between 98.6 and 101°F. for some four weeks thereafter - gradually returning to normal.

The pulse also remained elevated, varying between 100 and 120 per minute for some five or six weeks, then gradually falling to between 70 and 80 beats per minute as the patient's condition improved.

The heart sounds varied from day to day. The reduplicated mitral sound produced a well marked gallop at times; often this split sound disappeared and occasionally a soft diastolic murmur was heard at the apex. With improvement in the patient's condition the bruit disappeared entirely and the heart sounds became normal.

Blood examination revealed a leucocytosis

of 11,875 per c.m; blood cultures were sterile; and the blood Wassermann Reaction was negative. The blood sedimentation rate gave readings of 69 m.m. in the first hour and 104 m.m. in the second hour.

A trace of albumen only was present in the urine.

X-ray screening of the heart was performed three days after admission. There was considerable enlargement of the left auricle and both right and left ventricle showed increase in size. The appearances suggested mitral stenosis.

The electrocardiographic picture first obtained is shown in Fig. 85.

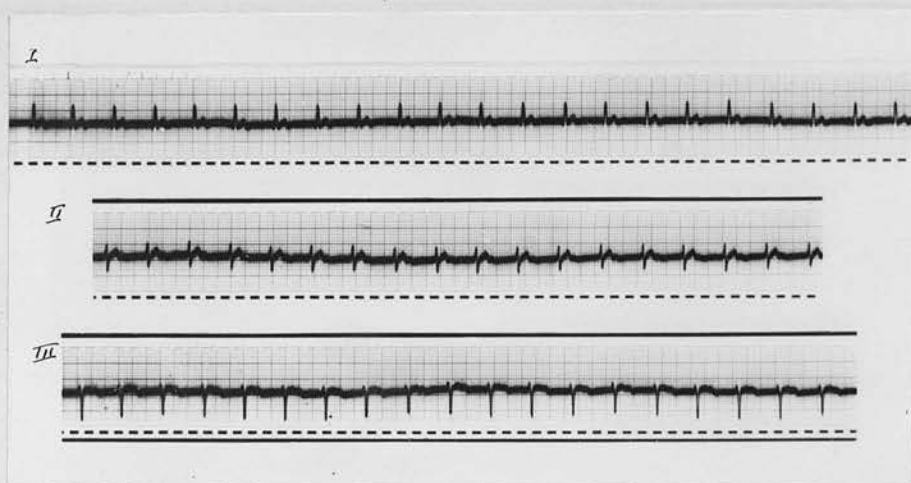


Fig. 85. 10--8--40.

The rhythm is seen to be regular with a heart rate of 100 per minute, but the striking feature is the apparent absence of a P wave before the QRS complex and its changed location to a point immediately following that deflection. At first glance one might regard this record as an example of dissociation of the auricle and ventricle, their respective rates being identical, and thus comparable to the records of that condition shown so clearly in Case 1 (e.g., Fig. 36, lowermost record). Further consideration, however, raises doubts as to this possibility for it is seen that the ventricular contraction could have been in response to the previous P wave, considerable delay being present in conduction of the impulse through the junctional tissues. This P-R interval measures approximately 0.54 second.

Further electrocardiographic study was therefore essential before an opinion could be expressed with certainty on this record.

Fig. 86 shows the type of record next obtained. Here the rate is still 100 per minute and the rhythm is regular. But each ventricular complex is preceded by a well marked P wave, the P-R interval

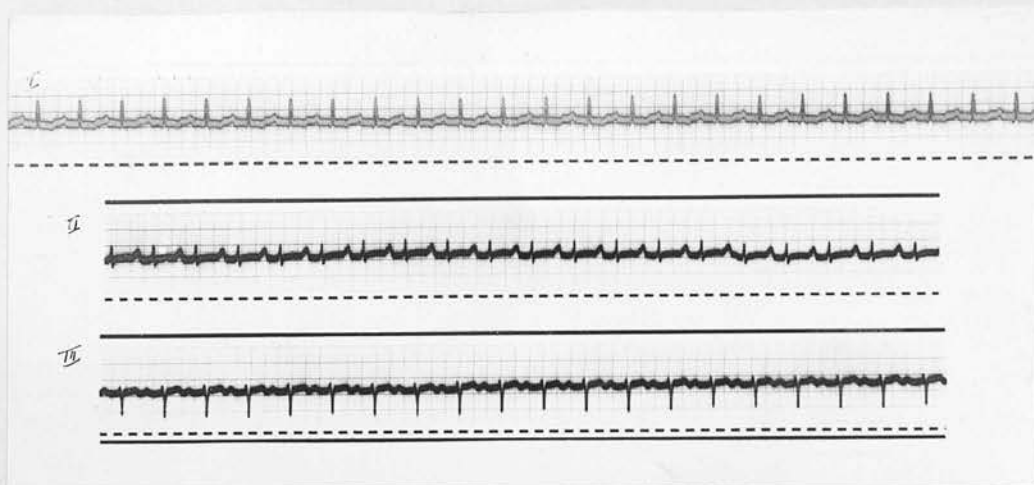


Fig. 86. 12--8--40.

measuring 0.29 second. This record therefore favours the second possibility, atrio-ventricular conduction being less markedly impaired in this record.

Further confirmation was readily obtained. Careful observation of the beam of the electrocardiograph revealed that the position of the P wave in its relation to the QRS complex could be altered from that shown in Fig. 86 to the position shown in Fig. 85 merely by getting the patient to take a deep inspiration and hold his breath. During this procedure a long record was taken on Lead II and Fig. 87 is a continuous section of it.

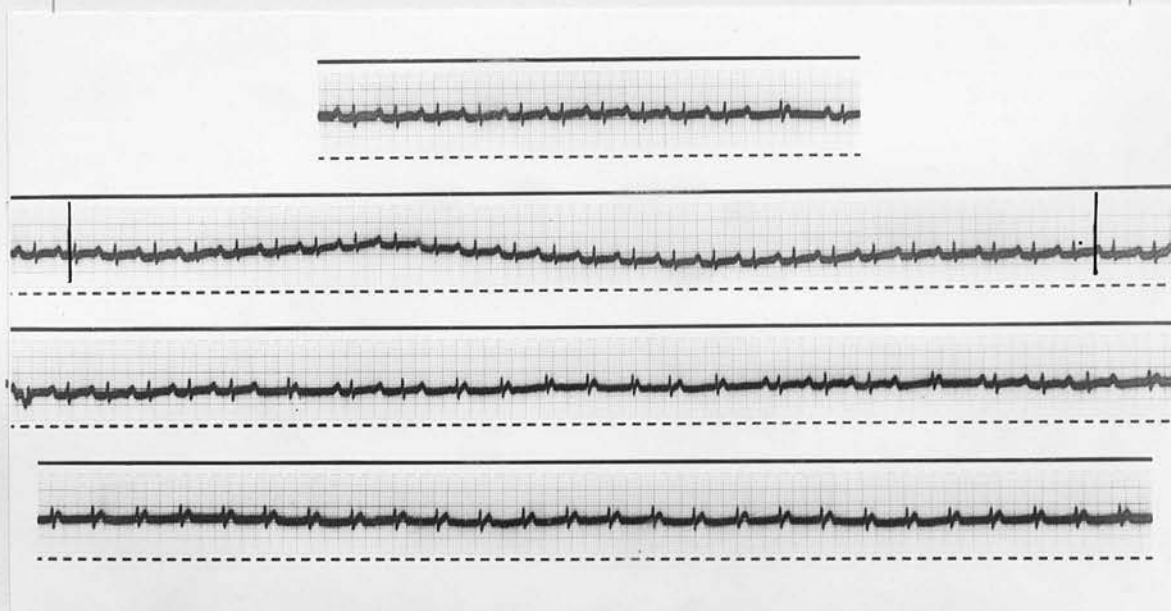


Fig. 87. 14-8-40. (Lead II only; Continuous strips)

A deep inspiration was taken at the first vertical line and was released at the second. In the uppermost section one sees a similar P : QRS relationship to that described in Fig. 86 and this remains unaltered

throughout the period of inspiration until the commencement of the third section, almost immediately after the deep inspiration was released. There is a sudden temporary slowing of the ventricular rate and the P-R intervals become markedly prolonged to 0.55 second. Similar temporary slowing of the ventricular rate occurs further along this section, but the auricular rate remains remarkably constant at 100 per minute. These altered rates of the auricle and ventricle (dissociation) give rise to an altered P : QRS relationship and the P wave is seen to immediately follow the QRS complex, particularly in the central portion of this section. In the lowermost strip (again a continuation of the previous section) the P : QRS relation \simeq observed in the first electrocardiogram taken (Fig. 85) is seen. Here both the auricle and ventricle contract at 100 per minute and the P wave immediately follows the preceding QRS complex, the P-R interval measuring approximately 0.56 second (the commencement of the P wave is hidden in the preceding QRS complex so that accurate estimation of the P-R interval is not possible).

This record therefore conclusively proves that the condition is one of partial forward heart block and not a dissociation of the auricle and ventricle.

This record also shows that the cause of the markedly prolonged P-R interval seen in Fig. 85 was due to nervous factors (vagal inhibition) and not mainly to disease of the junctional tissues. It will be noticed towards the end of the uppermost strip of Fig. 87, before the deep inspiration was taken, that temporary slowing of the ventricular rate occurred with dissociation between auricle and ventricle similar to that described in the third section. This increase in the degree of the heart block is also accounted for by vagal stimulation, psychological factors no doubt being responsible as the patient prepared to take the deep inspiration.

Fig. 88 shows the chest leads from this case recorded immediately following a deep inspiration. A record taken previously showed the same characteristics as Fig. 86. Here again the P-R interval has become



Fig. 88. 14--8--40. Chest Leads.

considerably lengthened and the P wave follows the QRS

complex. Slight ventricular irregularity also exists and is associated with lengthening or shortening of the P-R intervals which are of course dependent upon the degree of conduction impairment present at a given moment. The P waves, themselves, occur at perfectly regular intervals and depending upon the relative lengths of the R-R intervals, follow the QRS complexes or are partly merged in them. This variability of the P-R intervals is another point indicating a nervous factor in the impairment of conductivity.

The effect of carotid sinus pressure was later investigated, but by this time the characteristic prolongation of the P-R interval seen in Fig. 85 was no longer present and could not be induced by deep inspiration.

A continuous record was taken on Lead II and RIGHT carotid sinus pressure was applied, the onset being marked by the vertical line in the first section of Fig. 89 and the withdrawal of pressure is indicated by the vertical line on the third strip.

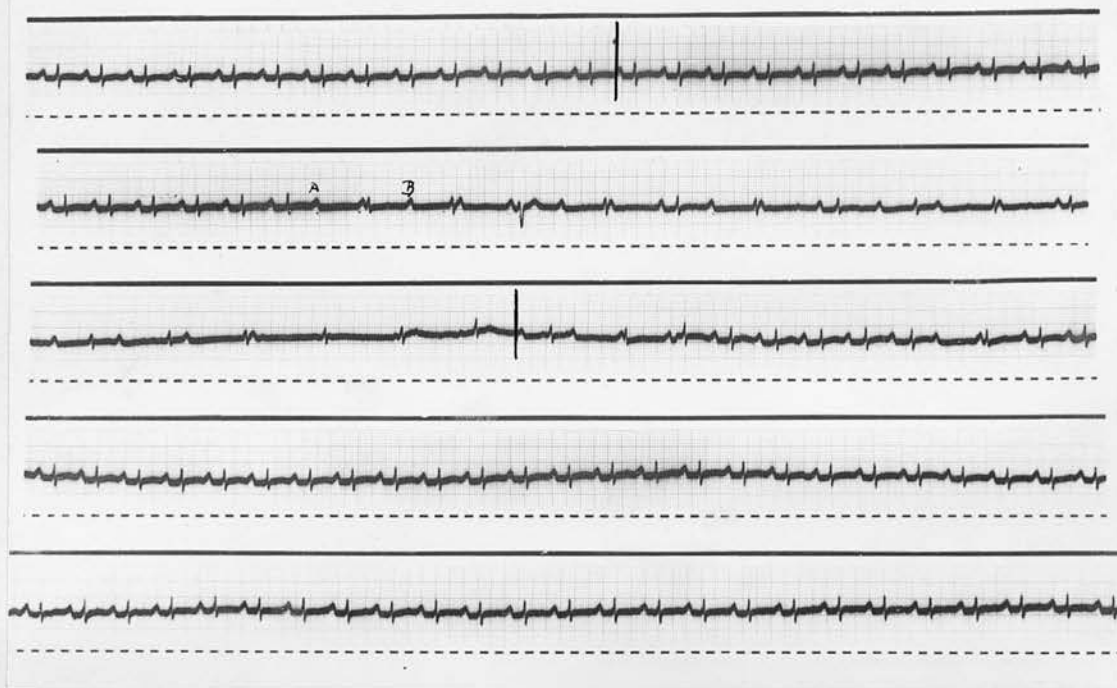


Fig. 89. 15--8--40. Continuous record on Lead II.

The effect is seen commencing in the second strip where the ventricular rate suddenly slows to nearly half its previous value. The auricular rate also slows (P-P interval at beginning of strip = 0.66 and at end of strip = 0.86 second), and many auricular impulses fail to excite a ventricular response. The R-R intervals, marked "A" and "B" of the first two slow ventricular beats equal that following the ventricular extrasystole and the remaining R-R intervals have a very nearly similar value, so that one can here assume

an idio-ventricular rhythm with a rate of 50 per minute; complete heart block exists in this section of the record.

A similar state of complete block is present in the first part of the third section until very shortly after the release of the pressure over the carotid sinus. Then both auricle and ventricle rapidly regain their previous normal sequence and rate, the P-R interval returning to its previous value of 0.26 second.

Fig. 90 shows the effect of LEFT sided carotid sinus pressure and complete heart block is

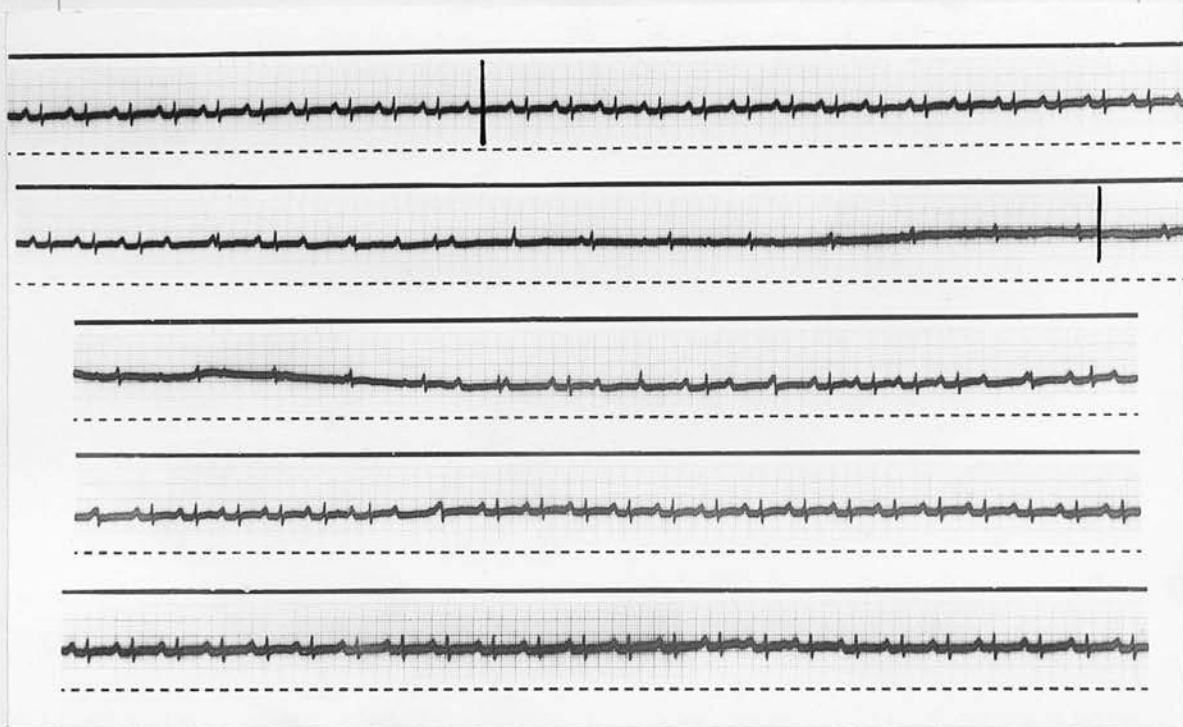


Fig. 90. 15--8--40. Continuous records on Lead II.

again produced. The picture is similar to that shown in Fig. 89. The ventricular rate is 52 per minute and the auricles contract at 66 per minute, whereas the previous heart rate was 91 per minute.

The shape and particularly the size of the P wave is altered in this record and at times it is almost diphasic. This is probably due to dislocation of the pacemaker from its normal position in the head of the sinus node to a lower auricular level.

With the withdrawal of carotid sinus pressure there is a rapid return to the previous normal auriculo-ventricular sequence but blocking of a few isolated auricular impulses occurs from time to time.

Reflex vagal stimulation has thus produced a profound effect upon the condition of conductivity in the junctional tissues in this case.

Discussion.

This case is interesting because the first electrocardiogram obtained closely resembles that form of A-V dissociation discussed in Part II. A "reversed cardiac rhythm" is present. The ventricle-auricle sequence illustrated in Fig. 85 has been shown to be mainly due to nervous influences, particularly vagal effects upon the junctional tissues, -a very important point in the case, since it proves that organic disease of the conducting system is not wholly responsible.

This case was not under my personal care but came to my notice when electrocardiographic examination was requested. For this reason further investigation, such as the effect of drugs or exercise, upon conduction were not performed. Digitalis had been administered to the patient but this drug was discontinued when I pointed out the precarious state of the conducting tissues. At the time the first record was taken only small doses of digitalis had been given (m. viiss of the tincture t.i.d. during the preceding two days) but it is possible that the prolonged P-R interval of Fig. 85 was caused by the additional action of the drug.

The length of this P-R interval (0.54 second) is of interest, for it is not common to have such a long interval. In Figures 89 and 90 very long P-R intervals could be assumed were not careful measurements made of the P-P and R-R intervals so demonstrating the presence of complete heart block. Zeissler (79) regards the longest P-R interval recorded as being 0.75 second, although longer intervals have been reported. He gives the following amusing paragraph in his discussion of this point. "The question has frequently been raised as to how long the P-R intervals may be. Barker and Bridgeman state that there is no upper limit to the possible length of the P-R; this statement is unquestionably wrong for there can be no doubt that if an auricular impulse is not conducted say within one hour it will not be conducted at all, so that the P-R can never be greater than one hour"!

This case also furnishes an excellent example of the frequent necessity for repeated electrocardiographic examinations before an accurate and considered opinion can be given and it also demonstrates the value of such procedures as reflex vagal stimulation in assessing the condition of the conducting system.

The case was regarded as being one of myocarditis following influenza. It is possible that the occasional reduplication of the second mitral sound may in reality have been simulated by a third heart sound due to the contraction of the auricle immediately after the ventricle. This possibility was not considered at the time when the lengthened P-R intervals occurred and consequently was not confirmed.

Summary.

A case of "reversed cardiac rhythm" is described with its electrocardiographic features.

The mechanism is a prolongation of the P-R interval so that the P wave immediately succeeds the QRS complex.

Vagal hypertonia was probably the main cause of this prolongation which could be induced by deep inspiration, but organic disease was also partly responsible, the P-R interval never having a value less than 0.26 second.

The value of the electrocardiogram in both treatment and in diagnosis is emphasised.

*

The following series of short cases illustrate changes occurring in the DYING HUMAN HEART.

It recently occurred to me that since asphyxia occasionally produced A-V rhythm or A-V dissociation, these conditions might also accompany the asphyxia occurring in death and I therefore decided to record electrocardiographic changes in cases at the point of death.

Since commencing this series of observations, I have found several articles in the literature in which changes in the electrocardiogram were observed at and following clinical death and in several instances "nodal" rhythm has been reported.

Many minor difficulties were encountered whilst attempting to secure these records. I was able to obtain the co-operation of the Sisters and Nursing Staff in the wards and they would let me know when a patient was in extremis. Unfortunately I was not always able to secure the co-operation of the patient and he frequently forestalled me by departing this life before I was able to convey the portable electrocardiograph to his bedside! In spite of many difficulties I was, however, able to record some twenty-five such cases and a few of the tracings taken are shown here.

In each case the electrocardiogram was taken on Lead II and records were made when any change appeared to take place in either the rate or form of the deflections whilst carefully watching the electrocardiograph beam. Many long reels resulted and as their value would have been reduced by cutting them into strips suitable for mounting, selected portions only have been photographed. In some instances I was able to secure a three-lead electrocardiogram shortly before death took place.

The great variety of changes occurring in the QRS complex at the time of death is of much interest. I do not, however, intend to discuss these features, but will confine myself to alterations in the shape and location of the P wave.

The cases were not, of course, selected and patients dying from any cause were included. For this reason I shall not give any details of the clinical condition before death, except where relevant, other than indicating its cause. I shall also first describe these records and then discuss them as a whole.

"Clinical death" is the term employed in these cases to indicate the point at which the patient "died" on ordinary physical examination. It usually coincided with the last gasping respiration, the pulse being imperceptible and the heart sounds inaudible. That is all signs of life had apparently ceased. Electrocardiographic examination, however, revealed cardiac contractions persisting generally for a few minutes only, but occasionally the heart beat was recorded as long as half to three quarters of an hour

after clinical death. The time in relation to the occurrence of clinical death (both before and after) was noted when small records were taken.

Case 6. D. 4. Female; aged 60 years.
Died: 26--7--40. Carcinoma of Bladder.

Fig. 91 comprises three strips on Leads I, II and III respectively and was recorded 13 minutes before clinical death.

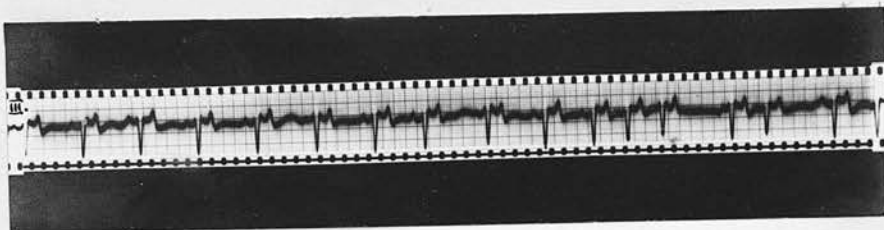
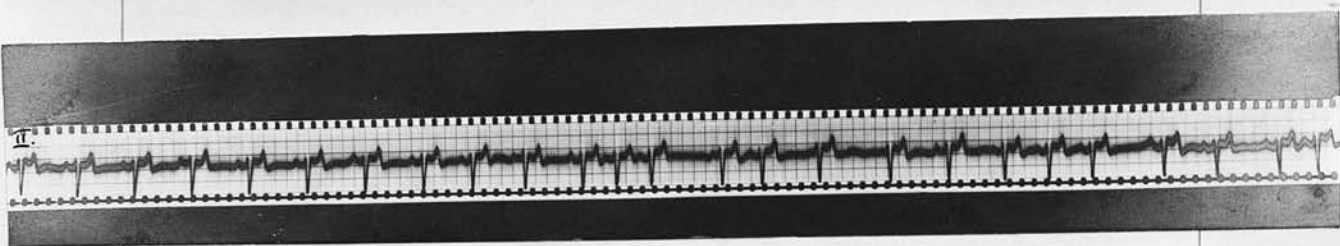
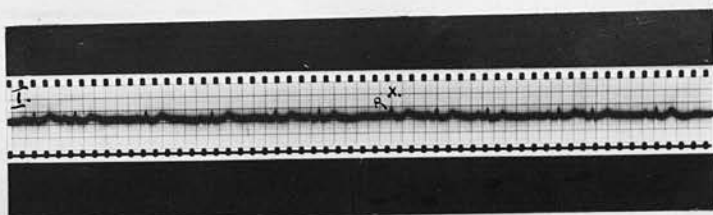


Fig. 91. 13 minutes ante mortem.

The rhythm is seen to be irregular. In Lead I all complexes are preceded by normally shaped upright P waves, the P-R intervals having a fairly constant value of 0.20 second. At the beat marked "X" occurring in the centre of the record after an unusually long pause the ventricle has escaped and the P and QRS complexes occur almost simultaneously, there being a P-R interval of 0.04 second. This tracing appears to show sinus arrhythmia.

In Lead II a more striking irregularity is seen. The first eight beats occur regularly and are of sinus origin. Then irregularity appears and changes in the shape and position of the P wave which, however, remains upright, are apparent. This irregularity is due to auricular extrasystoles and similar irregularity from the same cause is seen in Lead III, but in many instances the P of the premature beat is small and inverted with a P-R interval of 0.18 second.

Fig. 92 was recorded on Lead II 6 minutes before clinical death. Similar irregularity to that

occurring in Leads II and III of Fig. 91 is seen, many premature auricular beats occurring. But changes

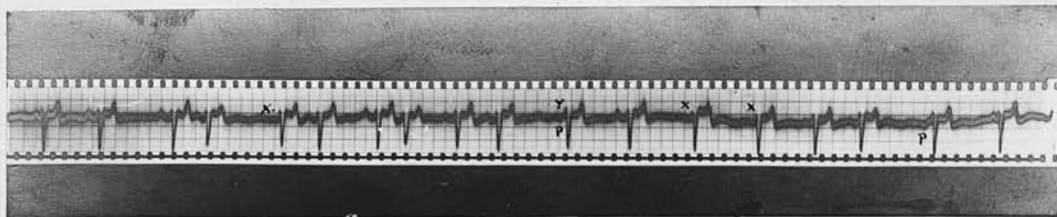


Fig. 92. 6 minutes ante mortem.

commonly appear in the shape and position of the P waves following these extrasystoles. At the three places marked "X" no auricular wave is seen and the ventricle appears to have responded to an A-V nodal impulse liberated in the long compensatory pause. At "Y" an inverted P wave is present with a P-R interval of only 0.10 second. The R-R interval of this cycle measures 1.22 seconds and corresponds with the cycles marked "X" which measure 1.30, 1.13 and 1.12 seconds respectively, in that order from the beginning to the end of the strip. Except for the second cycle of this strip which has an R-R interval of 1.28 seconds, all cycles between normal upright P waves are considerably shorter than these intervals. An inverted P wave also occurs before the second last complex, again following a similar long pause and has a P-R interval of 0.13 second. These complexes with absent or inverted P waves may consequently be regarded as A-V nodal beats, although in the case of the latter the interpretation may be open to some doubt as a low position of the pacemaker in the auricle, with possible aberrant conduction of the impulse through that chamber, might also account for the inversion and shortened P-R interval.

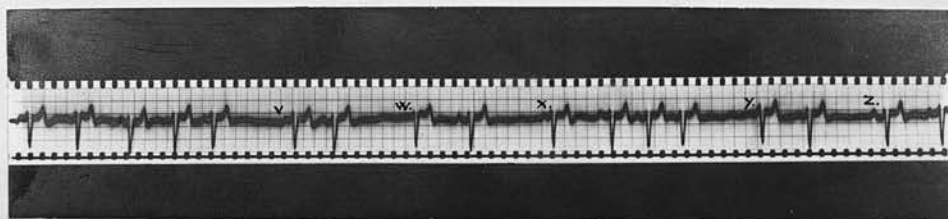


Fig. 93. 4 minutes ante mortem.

Fig. 93 was recorded four minutes before clinical death and a similar picture is seen. Changes in the shape of the P wave are well marked throughout the record. At "V" the P wave is diphasic with a P-R interval of 0.18 second and the R-R interval is 1.44 seconds. At "W" the P wave is absent and the cycle length again measures 1.44 seconds. At "X" the P wave is upright with a P-R interval of 0.14 second and a similar cycle length precedes it. At "Y" the P wave is inverted with a P-R interval of 0.13 second and the cycle length measures 1.40 seconds. At "Z" the P wave is a well formed upright deflection with a P-R interval

of 0.20 second and this cycle measures 1.36 seconds.

This record thus shows a changing location of the pacemaker in the auricle with one idio-ventricular beat and a possible second where the preceding P wave is inverted and at a short interval before the QRS complex.

In Fig. 94 taken one minute before clinical death, fewer extrasystoles are seen and in the latter two-thirds of the record, the rhythm is regular with a rate of 59 per minute. In this instance, however, fewer

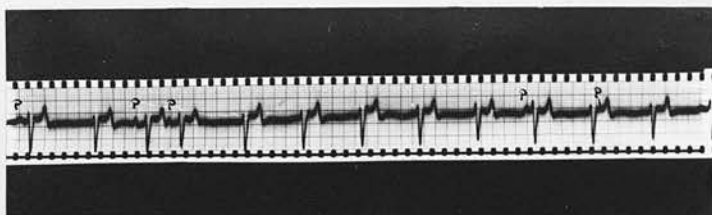


Fig. 94. 1 minute ante-mortem.

P waves are seen and none are inverted. In the second last complex a P wave causes a small hump on the S-T interval. All visible P waves have been indicated in the reproduction. The P wave seen before the third last complex is upright but occurs at a short interval of 0.14 second and together with the next P wave occurring on the S-T interval appears to indicate an A-V dissociation. The complexes other than those at the beginning of the record with upright P waves at normal P-R intervals, thus appear to be of A-V nodal origin. Complete retrograde heart block can be assumed to be present in the absence of any inversion of the P waves.

In Fig. 95, taken during clinical death, the heart rate has become much slower. A normally shaped P wave is present before four complexes in the latter half of the record, the P-R intervals measuring 0.22 second. A deeply inverted P wave occurs 0.12 second before the third ventricular complex and may be assumed to arise in the A-V node. The visible P waves have again

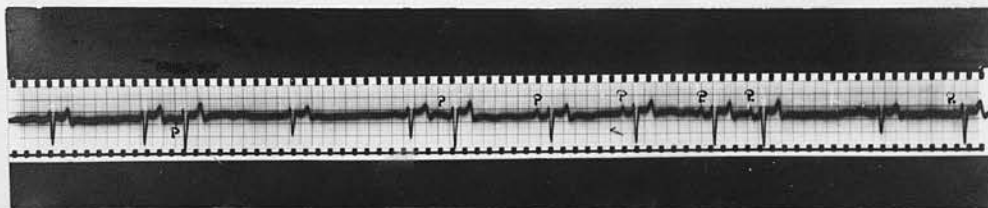


Fig. 95. During Clinical Death.

been marked in the record; many idio-ventricular beats are present.

Figures 96 and 97 were taken immediately following clinical death and show a fairly regular idio-ventricular rhythm with a rate of 30 beats per minute. No evidence of auricular activity is seen.

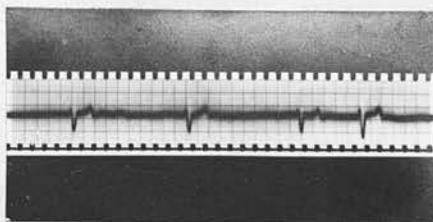
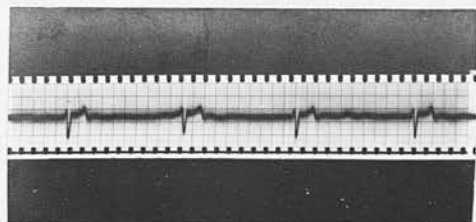


Fig. 96.

Fig. 97.

Taken immediately following clinical death.

Records were taken at short intervals for five minutes after clinical death. Progressive changes took place in the ventricular complex but no P waves appeared. The rhythm changed to a ventricular flutter and finally the beam became stationary with complete standstill of the heart.

This case therefore illustrates auricular extrasystoles, changes in the location of the pacemaker in the auricle, A-V nodal beats, A-V dissociation and idio-ventricular rhythm occurring before, during and after clinical death.

*

Case 7. D.G. Female; aged 46 years.
Died: 27--7--40. Empyema.

Fig. 98 is a reproduction of a three-lead electrocardiogram taken three-quarters of an hour before clinical death.

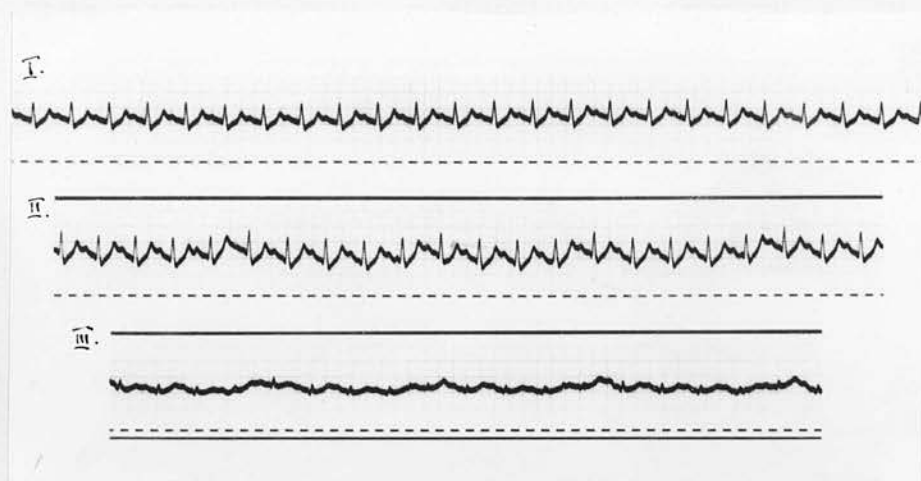


Fig. 98. 45 minutes ante-mortem.

Normal sinus rhythm is present with normal A-V conduction time. Changes due to myocardial damage are also present.

Fig. 99 was recorded four minutes before clinical death. The rhythm is irregular and each ventricular complex is preceded by an inverted P wave with a varying P-R interval of between 0.24 and 0.20 second. This relatively long P-R interval excludes the

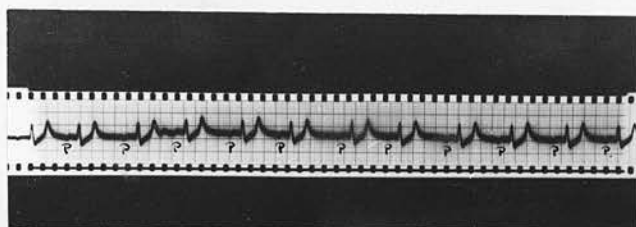


Fig. 99. 4 minutes ante-mortem.

possibility of A-V nodal rhythm being the cardiac mechanism present. The altered shape of the P complex is probably due to a downward dislocation of the auricular pacemaker or altered pathway of conduction in the auricle.

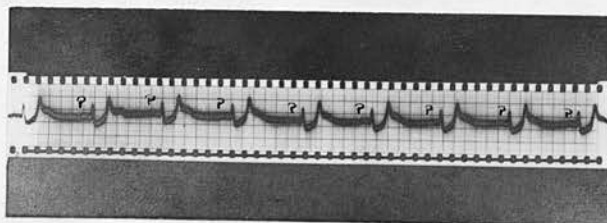


Fig. 100. 2 minutes ante-mortem.

Fig. 100 was taken two minutes before clinical death. The P waves are now seen to be upright before each ventricular complex although of very low amplitude. A further change in the auricular centre appears to have taken place.

Fig. 101 was recorded during clinical death. The rhythm is irregular with an average rate of 85 per minute. Very few P waves, all upright, can be seen and their position has been indicated in the figure. The majority of the ventricular contractions appear to have originated independently of the auricular pacemaker. At the four places where P waves can be identified the

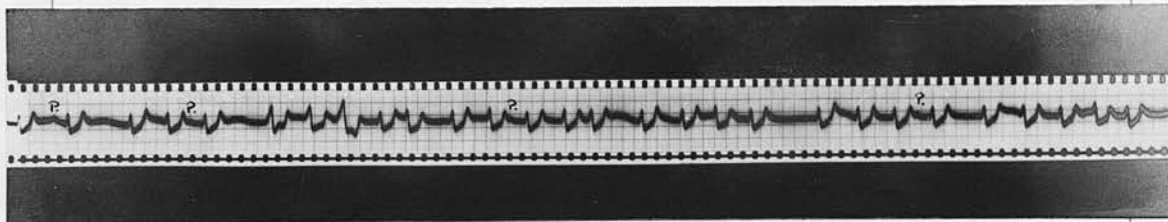


Fig. 101. During clinical death.

respective P-R intervals are approximately of the same duration (0.28 second) and it is possible that they have given rise to the succeeding ventricular deflections but there is no prematurity of these ventricular complexes if one excludes the first instance in which the heart rate is slower than elsewhere in the record.

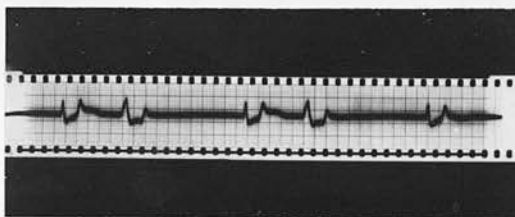


Fig. 102. $\frac{1}{2}$ minute post mortem.

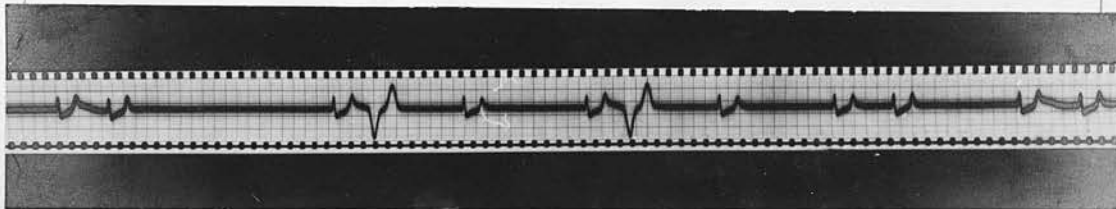


Fig. 103. 1 minute post mortem.

Figures 102 and 103 were recorded half and one minute after clinical death respectively. There is a conspicuous slowing in the heart rate and there is no evidence of auricular activity throughout the records. Coupled ventricular beats are seen in both these records; in the case of Fig. 102 the second ventricular complex of the couplets differs in shape from the first complex and is probably deformed by aberrant conduction in the ventricle. In Fig. 103,

however, these coupled beats are entirely similar (excluding of course the definite ventricular extrasystoles) and they both appear to have originated from the same centre. Thus the A-V node would appear to be forming impulses at different rates. Retrograde heart block is complete.

Further records showed varying ventricular rates with no evidence of auricular contraction and finally a short period of ventricular fibrillation occurred, cardiac standstill resulting three minutes after clinical death.

Records taken preceding, during and after clinical death in this instance thus provide evidence of change in the location of the auricular pacemaker, dissociation of auricle and ventricle with apparent absence of P waves and finally cessation of auricular activity appears to result, the ventricles responding to impulses from the A-V node.

*

Case 8. D. 7. Female; aged 68 years.
Died 31--7--40: Carcinoma of Ovary.

Fig. 104 was recorded four hours before death and shows a simple sinus rhythm, the upright P waves preceding the QRS complexes by 0.17 second.

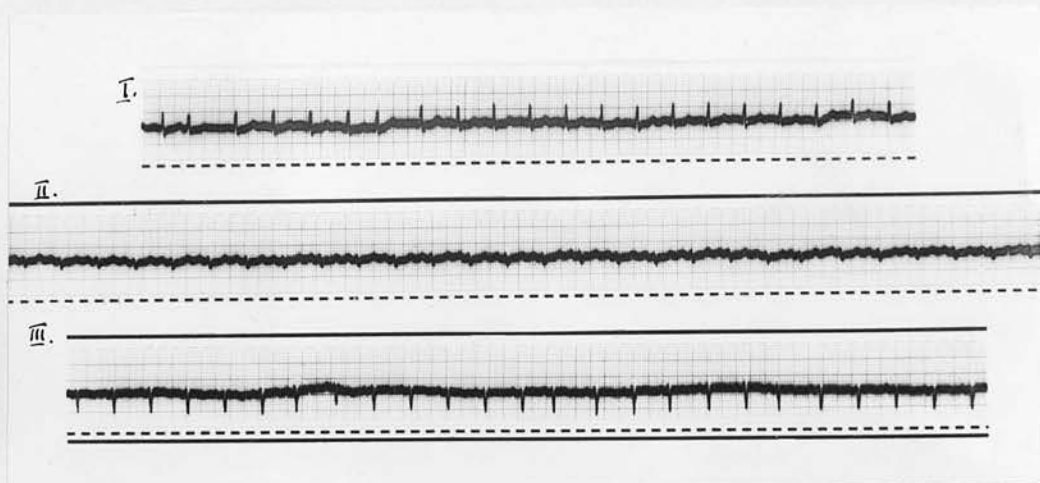


Fig. 104. 4 hours ante-mortem.

Fig. 105 was recorded fifteen minutes before clinical death, the patient being deeply unconscious, cold and breathing regularly and shallowly. A very marked change is seen. The heart rate has become

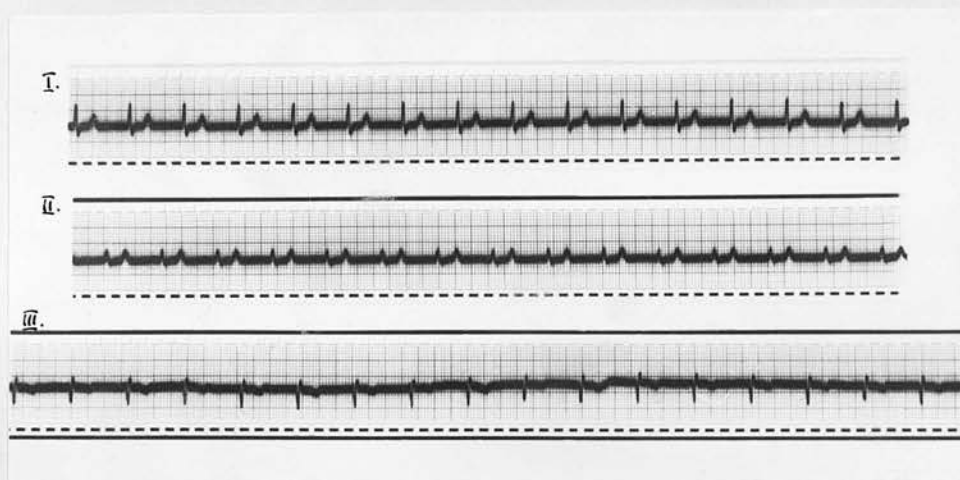


Fig. 105. 15 minutes ante-mortem.

a little slower but there is no evidence of any P wave throughout the record. The diastolic line is smooth and unbroken and there is no distortion of the S-T interval or T wave. This record consequently illustrates the second variety of A-V nodal rhythm described on page 14.

Fig. 106 was recorded one minute before clinical death. The heart is contracting slowly and irregularly and P waves are again visible and have been indicated on the photograph. The P wave appears before

the first two ventricular beats as a small upright deflection 0.24 second before the QRS complexes. Thereafter the P wave precedes the QRS complex by shorter and varying intervals and in the case of P-5 and P-8 the P-R interval is so short (0.06 second) it appears unlikely that the auricular impulse has given rise to the ventricular contraction. P-6 is seen as a small hump on the S-T interval of the ventricular complex and P-7 appears at the end of the T wave and provides further evidence of dissociation between auricle and ventricle. The P-P intervals are unequal

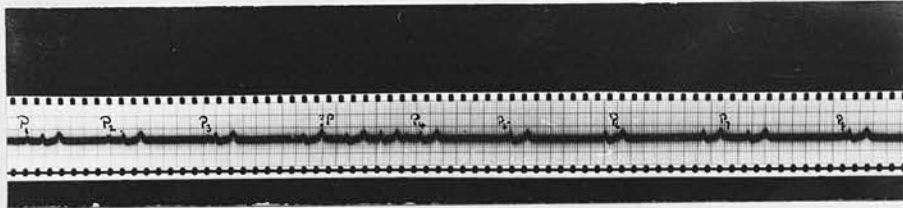


Fig. 106. 1 minute ante-mortem.

even where successive P waves are visible but their average length is less than that of the R-R intervals indicating a slower rate of auricular contraction compared with that of ventricular contraction. (Average values are: auricular rate 37, ventricular rate 48 per minute).

Fig. 107 shows very marked slowing of the ventricular rate (average 27 beats per minute) and was recorded during clinical death. Auricular waves are still present and, excluding the more rapid ventricular beats at the beginning of the record, precede each ventricular contraction by an interval of 0.32 second. Again the P-P intervals vary in duration, the shortest interval between P-4 and P-5 measuring 1.48 seconds and the longest interval between P-1 and P-2 measuring 3.6 seconds. In this record, therefore, dissociation of auricle and ventricle is not marked, each auricular

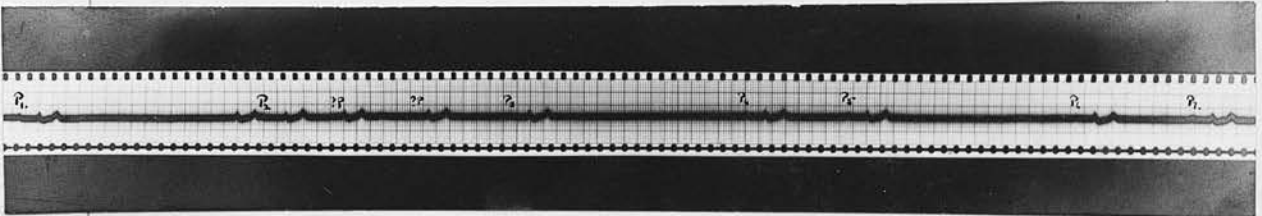


Fig. 107. During clinical death.

impulse giving rise to a ventricular response. Even before the short run of more rapid ventricular complexes towards the beginning of this record there are faint oscillations of the iso-electric line where P waves might be expected to fall and which have an interval corresponding to the above P-R duration. No such oscillation precedes the first of these beats which is due to an A-V nodal impulse.

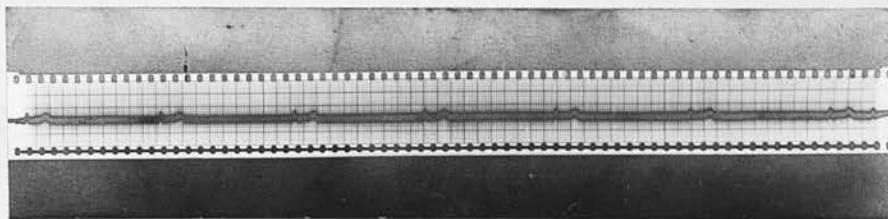


Fig. 108. 1 minute post mortem.

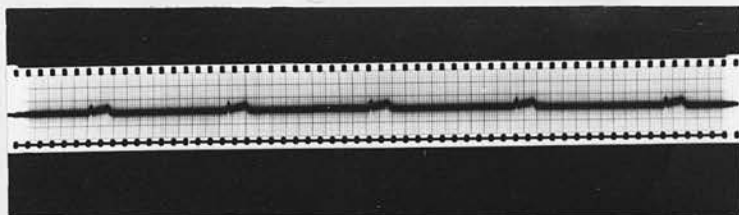


Fig. 109. 3 minutes post-mortem.

Figures 108 and 109 taken one and three minutes after clinical death show no evidence of auricular activity, an idio-ventricular rhythm with rates of 30 and 27 per minute respectively being present.

During the remainder of this reel, the heart rate became progressively slower and the ventricular complexes smaller in amplitude, all movement of the electrocardiographic beam ceasing 8 minutes after clinical death.

This case therefore illustrates A-V nodal rhythm of the second variety several minutes before death took place and A-V dissociation occurred at the point of death, then giving place to a normal auricle-ventricle sequence until idio-ventricular rhythm developed.

*

Case 9. D. 8. Male; aged 48 years.
 Died: 5--8--40. "Cardiac Asthma."

Fig. 110 was recorded seven minutes before clinical death. No P waves are visible and the second variety of A.V.Nodal rhythm may be assumed.

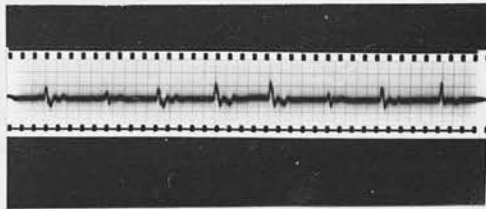


Fig. 110. 7 minutes ante-mortem.

In Fig. 111, recorded one minute later, no P waves are seen during the first part of the record. Then a P wave appears immediately after the end of the fifth T wave and thereafter a P wave is seen on the diastolic line with regular P-P intervals of 1.24 seconds.

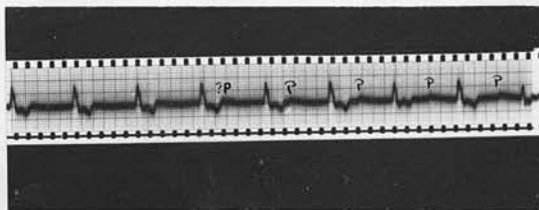


Fig. 111. 6 minutes ante-mortem.

There is no alteration in the rhythmicity of the ventricular complexes (R-R interval = 1.13 seconds) and the auricular impulses are not conducted to the ventricle. Complete forward heart block exists, but with a ventricular rate (54 per minute) greater than that of the auricle (48 per minute).

In Fig. 112, recorded $5\frac{1}{2}$ minutes before death, a similar condition is seen as in Fig. 111. No P waves are to be identified with any certainty associated with the first six ventricular complexes, but thereafter they appear regularly and give rise to

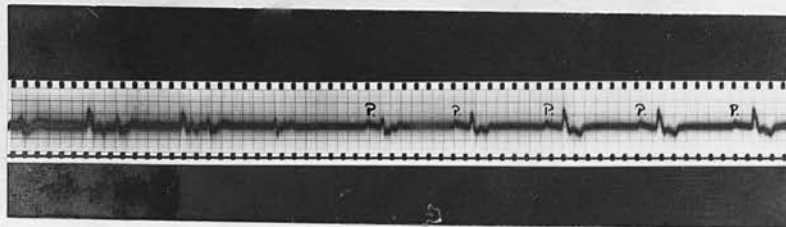


Fig. 112. $5\frac{1}{2}$ minutes ante-mortem.

ventricular responses. Gradual slowing of both auricular and ventricular rates occurs as one proceeds along the record and the P-R intervals also correspondingly lengthen.

In Fig. 113, recorded five minutes before clinical death, it is difficult to be certain of P waves except in the first instance where it precedes the QRS complex by 0.32 second. It is almost impossible

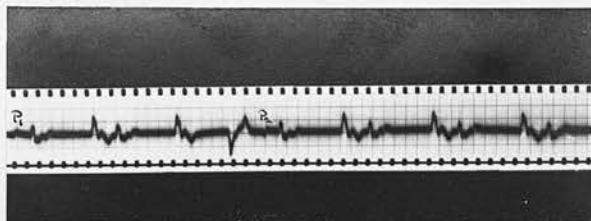


Fig. 113. 5 minutes ante-mortem.

to identify a P wave in the aberrantly shaped ventricular complexes, but except in the first instance already cited no P wave precedes these deflections.

In Fig. 114 inverted or diphasic waves are seen at only two points on the diastolic line and the second of these appears to have given rise to a

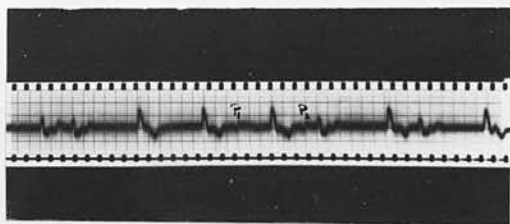


Fig. 114. 4 minutes ante-mortem.

ventricular response after an interval of 0.28 second. Downward dislocation of the auricular centre probably accounts for the inverted form of the wave.

In Fig. 115, taken three and a half minutes before clinical death, inverted P waves are seen at four places, the first two preceding ventricular complexes

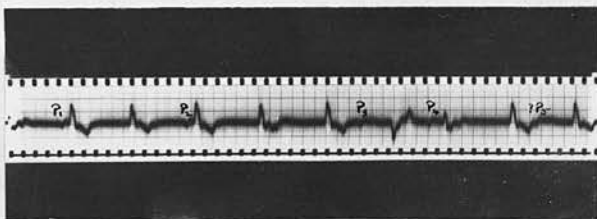


Fig. 115. $3\frac{1}{2}$ minutes ante-mortem.

by P-R intervals of 0.16 second. Similar inverted or diphasic P waves occurring at irregular intervals are seen in Fig. 116, recorded three minutes before death.

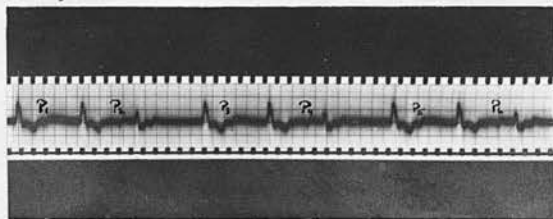


Fig. 116. 3 minutes ante-mortem.

P-2, -4 and -6 appear to give rise to ventricular responses after intervals of 0.31 second. Similar changes in the P waves are seen in Fig. 117, P-1 and -3 apparently producing ventricular responses. Fig. 118 recorded one minute before clinical death shows similar P waves at regular P-R intervals of 0.50 second and a like condition is seen in Fig. 119, recorded one minute after clinical death, but with lengthening P-R intervals. P-3 is upright. Finally, in Fig. 120, recorded one and a half minutes after clinical death, no P waves are seen and a slow idio-ventricular rate of 21 beats per minute has developed.

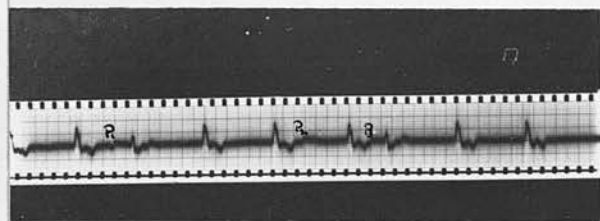


Fig. 117.
2 minutes ante-mortem.

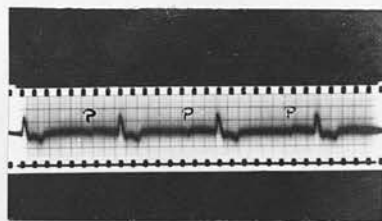


Fig. 118.
1 minute ante-mortem.

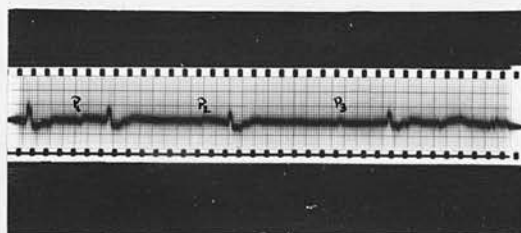


Fig. 119. 1 minute post-mortem.

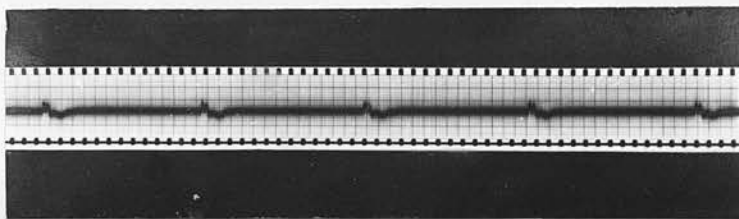


Fig. 120. 1½ minutes post-mortem.

Further records showed ventricular slowing, decrease in amplitude, a short period of ventricular fibrillation and finally cardiac standstill four minutes after clinical death.

This record, therefore, also illustrates the second variety of A-V nodal rhythm, A-V dissociation and later a dislocation of the pacemaker in the auricle downwards with varying degrees of forward heart block. Retrograde block was again complete.

Case 10. D.9. Male; aged 57 years.
Died: 7--8--40. Duodenal perforation
fourdays previously.

Fig. 121 was recorded approximately two hours before clinical death. It shows normal sequential rhythm occurring in all three leads, the P-R interval being 0.17 second.

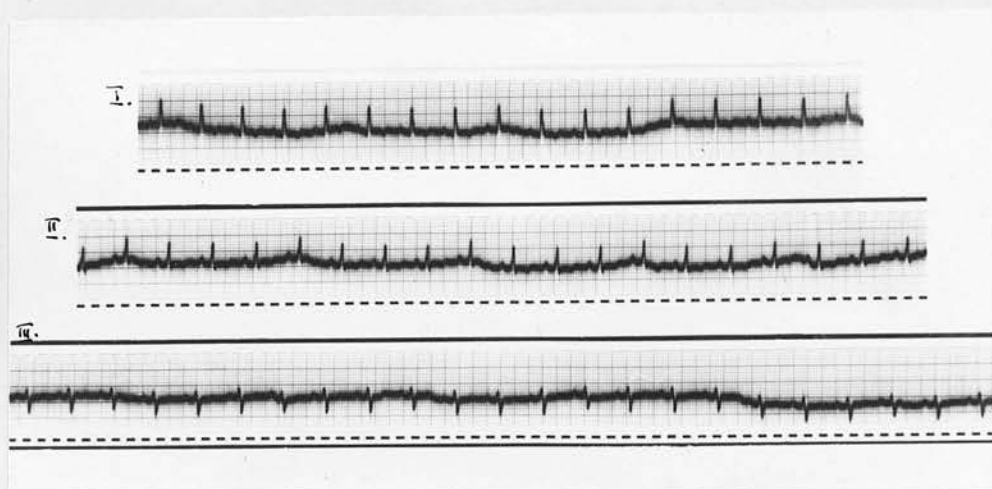


Fig. 121. 2 hours ante-mortem.

Fig. 122 was recorded three minutes before clinical death. Normal sinus rhythm is again seen, the P-R interval measuring 0.20 second. Towards the end of Fig. 123, taken half a minute later, A-V dissociation is well seen, the P wave approaching and becoming merged in the QRS complex. The ventricular rate does not alter at all at this point.

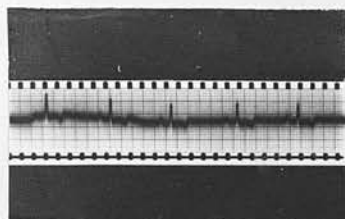


Fig. 122.
3 minutes ante-mortem.

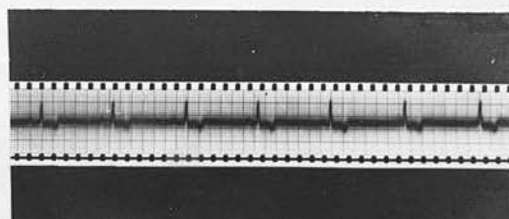


Fig. 123.
2½ minutes ante-mortem.

Fig. 124, taken 2 minutes before clinical death, shows normal sinus rhythm throughout the record, the P wave being a low amplitude but upright and preceding the QRS complex by 0.20 second.

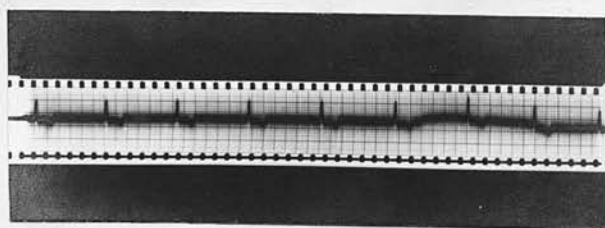


Fig. 124. 2 minutes ante-mortem

In Fig. 125 taken half a minute later, the P wave is now inverted, but of too small an amplitude to be clearly shown in the reproduction. The P-R interval, however, is only slightly shortened to 0.18 second.

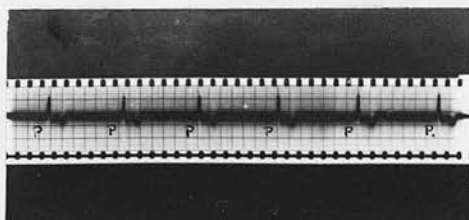


Fig. 125. 2 minutes ante-mortem.

Fig. 126 was recorded half a minute before clinical death and shows a marked change in the location of the P wave which throughout the record remains inverted, but small in size. In the first three complexes it appears on the S-T interval at gradually increasing R-P intervals. Then a couplet appears and the interval following the second ventricular complex is equal to the preceding R-R intervals. The inverted

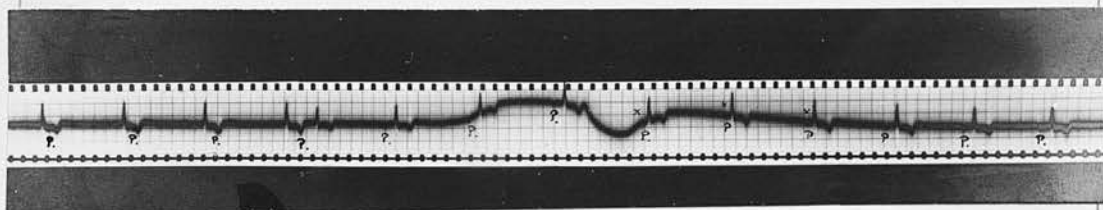


Fig. 126. $\frac{1}{2}$ minute ante-mortem.

T wave between these coupled ventricular beats is much more sharply pointed than any other T wave in the record and the peaking is presumably due to a superimposed P wave. Here, then, is the picture of reciprocal rhythm! The couplet is preceded by increasing retrograde block and when finally the inverted P wave follows the QRS complex by a suitably prolonged interval it gives rise to a second ventricular response. Can this interpretation be the correct one? One must study the rest of the record before expressing such an opinion. Following this coupled beat the P wave precedes the QRS complex by an interval of 0.20 second - too long for the impulse causing it to have arisen in the A-V node and passed back to the auricle. But in other places (marked "X") the P-R interval is very short, measuring 0.10 second and in these instances the impulse could undoubtedly have arisen in the upper portion of the A-V node. One cannot be certain of the state of the conducting system at the point of death and it appears reasonable to assume that conduction to the ventricle might be impaired (as is illustrated in preceding cases) so that an impulse arising in the upper part of the A-V node might reach the auricle considerably before reaching the ventricle and produce a prolonged P-R interval in spite of A-V nodal rhythm being present. Varying degrees of interference with conduction both in

a forward and a retrograde direction would therefore explain not only the prolonged R-P interval but also the lengthened P-R interval. This explanation is, of course, purely speculative. Undoubtedly the simpler and probably the correct interpretation of this record with the bigeminal contraction is that of A-V dissociation, the impulse for auricular contraction arising low in the sinus node or in one of its ramifications and producing an inverted P wave; and the relative rates of auricle and ventricle would account for the changed location of the P wave in relation to the QRS complexes and for the bigeminal beat, which is therefore an example of Interference Dissociation.

In Fig. 127, recorded during clinical death, further examples of coupled beats, here alternating regularly with single beats, are seen and their relationship to interference dissociation is at once apparent. Between the first couplet of this strip is an

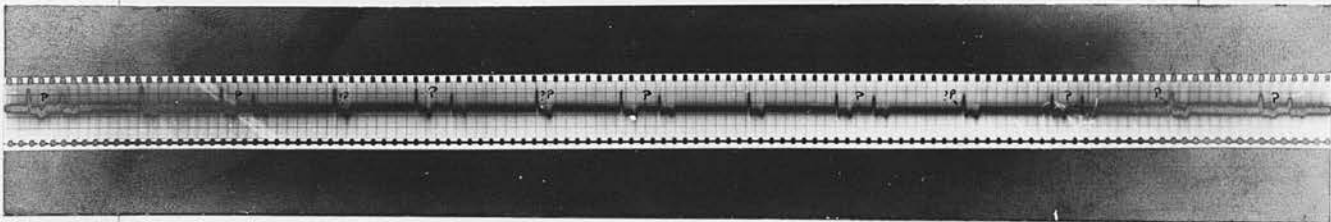


Fig. 127. During clinical death.

inverted P wave similar in character to those seen in Fig. 126, the P-R interval being 0.28 second. A small P wave is seen between the next couplet and in this case is upright. No P wave then appears until between the third couplet where it is visible as a definite upright deflection. P waves are thereafter upright and appear only between the bigeminal beats, except in the case of the last single complex where it occurs at the commencement of the R wave. The P-P intervals are apparently very long and increase towards the end of the record (average P-P interval = 4.16 second), but it is possible that P waves are hidden in the intervening ventricular complexes and careful examination of these deflections reveals occasional slight humping either of their commencement or of the S-T interval at approximately half the above P-P duration. When the P wave falls clear of the QRS complex the impulse is conducted to the ventricle after a prolonged interval and produces its contraction. Assuming the P-P interval to be approximately half the above duration the auricular rate would be roughly 28 per minute, while the ventricular rate has an average value of 48 per minute due to the multiple coupled beats. This record is therefore an excellent example of A-V dissociation with interference.

In Fig. 128, recorded $1\frac{1}{2}$ minutes after clinical death, long periods of cardiac standstill are seen, but each of the three ventricular complexes is preceded by an upright P wave with a P-R interval of 0.39 second. A similar state is seen in Fig. 129, but

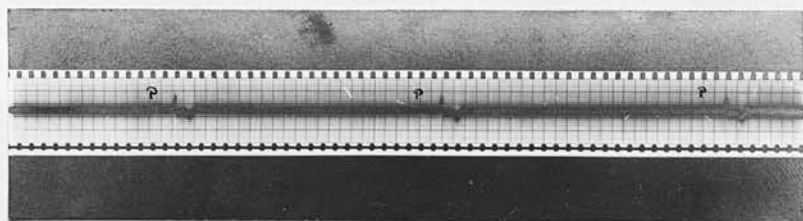
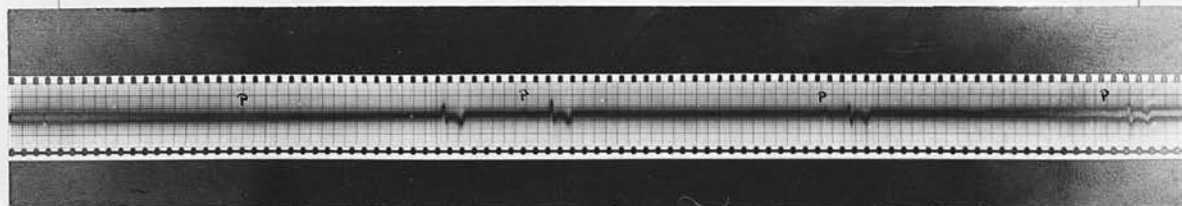
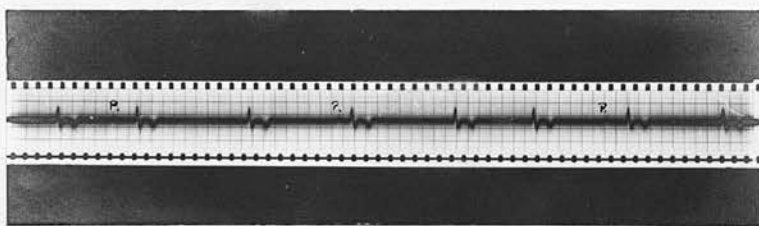
Fig. 128. $1\frac{1}{2}$ minutes post-mortem.

Fig. 129. 2 minutes post-mortem.

the initial steady iso-electric line is broken in its centre by an upright P wave which has not been followed by a ventricular beat and the first QRS complex is an A-V nodal one. The remaining three ventricular contractions are preceded by upright P waves, the P-R interval being 0.44 second. The P-P and R-R intervals are very long, the longest measuring 5.24 seconds, corresponding to a heart rate of 11 beats per minute!

In Fig. 130, recorded $2\frac{1}{2}$ minutes after clinical death, the heart rate has quickened and upright P waves are seen before several of the ventricular complexes. The P-P interval diminishes considerably as

Fig. 130. $2\frac{1}{2}$ minutes post mortem.

one proceeds along the record and the auricular impulses give rise to early ventricular beats interrupting the regularity of the idio-ventricular rhythm.

Finally in Fig. 131 a regular idio-ventricular rhythm has developed with a rate of 36 per minute

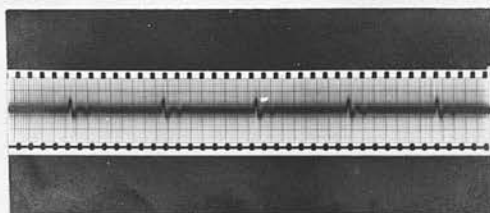


Fig. 131. 3 minutes post-mortem.

and no evidence of auricular activity is seen.

In remaining records the heart rate progressively slowed, the amplitude decreased and finally complete cardiac standstill resulted four minutes after clinical death.

This case furnishes a unique example of A-V dissociation with a faster ventricular rate than that of the auricle and in which interference dissociation is particularly well seen. The differentiation between reciprocal rhythm and interference dissociation ("pseudo-reciprocal rhythm") also occurs and points in favour of the latter have been stressed, a change in the location of the auricular pacemaker probably accounting for the inversion of the P wave.

*

Case 11. D. 13. Female; aged 62 years.
Died: 21--8--40. Intestinal Obstruction.

The first three-Lead electrocardiogram only is reproduced and is shown in Fig. 132. It was recorded two and a half hours before death.

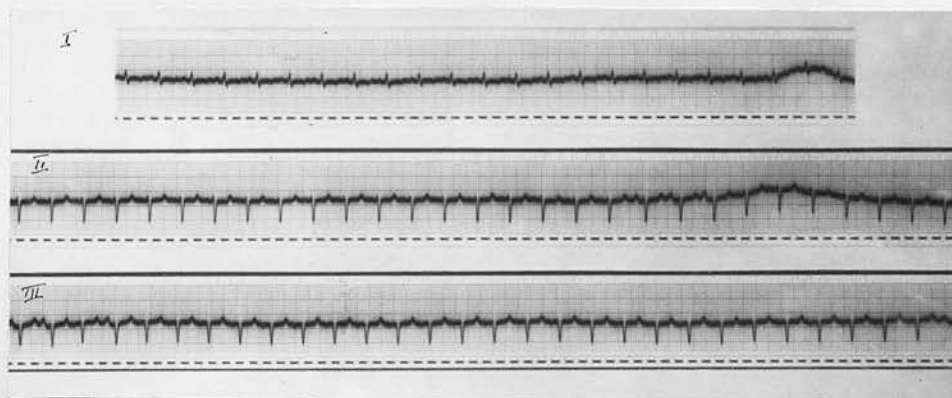


Fig. 132. $2\frac{1}{2}$ hours ante-mortem.

The main feature of interest lies in the shape of the P wave in Leads II and III. In lead II they occur as very small diphasic waves difficult to see in the photographic reproduction. They consist of a small upward deflection, a downward deflection, followed by another small upward movement, the three components being of equal size. In the latter third of Lead II a series of three beats with well marked upward P waves of normal shape is seen and this again occurs at the beginning and end of Lead III where the intervening P complexes are similar to those described in Lead II. The P-R intervals of the small diphasic P waves measure 0.14 second, whereas the P-R intervals of the upright and normally shaped P waves measures 0.18 second.

The small diphasic P waves with their shortened P-R intervals illustrate a downward dislocation of the pacemaker in the auricle, temporary return to the neighbourhood of the head of the sinus node occurring when the P waves assume their normal shape. An A-V nodal origin of these small beats is unlikely in view of their diphasic character (inversion not being definite), the P-R interval of 0.14 second is rather on the long side, and the abrupt transition to normal contour.

*

Discussion of Cases 6 to 11.

Six cases illustrating the mechanism occurring in the dying human heart are described electrocardiographically. These particular cases have been selected from several examples to show the occurrence of A-V nodal beats and A-V dissociation at this time. A-V nodal rhythm of the second variety appears in several of these cases but its occurrence was only temporary, often lasting for only a few seconds. No examples of undoubted A-V rhythm of the first and third varieties described on page 14 were observed in any of these cases and the apparent occurrence of the third variety in Case 10 has been discussed and considered to be an example of A-V dissociation. Later records in this case confirm this interpretation and also furnish a good example of interference dissociation.

Apart from the occasional appearance of A-V nodal beats preceded by inversion of the P waves at shortened P-R intervals (and even in their case this interpretation of the mechanism is open to doubt) inversion of the P waves, generally of small amplitude, has been attributed to a shift in the position of the auricular pacemaker from its normal position in the head of the S-A node. As has been pointed out on page 19 such a downward shift in the auricle towards the region of the A-V node results in an inversion of the P wave, as a rule. Possibly aberrant pathways of conduction through the auricle may also be responsible for the change in location and shape of the auricular complex. All these cases illustrated this phenomenon.

Relatively few electrocardiographic studies of the dying human heart have been reported in the literature and of these a fair proportion showed A-V nodal rhythm but mainly of the second variety. Robinson (61) in 1912 appears to have been one of the first to describe a series of such cases; in 1933 Hanson, Purks and Anderson (26) could collect from the literature only 70 cases illustrating electrocardiographic changes at death and these authors described a further 25 cases; Sigler, Stein and Nash (69) reported 20 further cases in 1937, six of which contained tracings of A-V nodal rhythm.

Changes in the auricular activity, its appearance and disappearance, have been noted in these previously reported cases (69). The absence of P waves in many of the records here reproduced is presumptive evidence of cessation of auricular contraction, as in these records it appears unlikely that the P waves are merged in the ventricular complexes. X-ray screening, the only certain evidence of auricular activity in view of negative electrocardiographic findings, is obviously impracticable at the point of death. During idioventricular rhythm no P waves are visible presumably due to non-contraction of the auricle; complete retrograde block accounts for the non-excitation of

that chamber by the ventricular impulse. One of my cases, recorded too late for insertion here, shows long periods of cardiac standstill lasting 15 to 20 seconds or more, later interrupted by idio-ventricular beats and finally P waves re-appear with following ventricular responses - i. e., sinus rhythm was again restored. But electrocardiographic evidence strongly suggests that the auricle ceases to contract long before the ventricle.

These cases further illustrate very clearly the change from one pacemaker centre to another, particularly the change from the head of the sinus node to some lower centre in that node or possibly in one of its ramifications, a point to which attention has been repeatedly drawn. When these lower auricular centres fail other automatic centres in the ventricular system assume control of the whole or part of the heart, depending upon whether impulses can pass in a retrograde direction from these centres to the auricle. Generally retrograde heart block was complete in these instances and A-V dissociation appeared instead of A-V nodal rhythm. Case 10 is a unique example of A-V dissociation with interference occurring at the point of death. When these "secondary centres" in the A-V node failed to produce impulses sufficiently rapidly, still lower ventricular centres occasionally assumed control and very bizarre shaped complexes appeared shortly before final cardiac standstill. These changes, however, have not been illustrated, although earlier stages are shown in a few of the records reproduced here. These progressive changes from one centre of impulse formation to another consequently supply a good example of the automatism of the different parts of the specific tissue and their ability to take over the control of the heart. The fact that auricular activity appears to fail some time before the ventricular contraction ceases is explained by this automatism of the lower centres, complete retrograde block preventing auricular activation.

Several instances of A-V nodal beats, temporary A-V dissociation and particularly of altered shapes of the P wave occur in my remaining examples of electrocardiographic changes at death but the number of cases with which I have dealt is too small to be of any value as an incidence percentage.

*

CONCLUSION.

An intensive study of Atrio-ventricular Nodal Rhythm, Atrio-ventricular Dissociation (with and without Interference) and Reciprocal Rhythm together with a consideration of Retrograde Heart Block in their production has been made.

Clinical cases exhibiting these conditions have been fully considered and electrocardiograms reproduced, each of which has been fully described, illustrating these different types of rhythm.

These arrhythmias are very uncommon and in their recognition the electrocardiogram is essential; consequently many of the records reproduced are unique, especially those in Case 1. This particular case, as has already been stressed, is most unusual and probably no similar case, showing as it does all the conditions mentioned in the title and lasting for so long, has been described previously. The other cases also exhibit unusual features and illustrate not only the spontaneous occurrence of atrio-ventricular nodal rhythm or atrio-ventricular dissociation but demonstrate the necessity for careful consideration of all electrocardiographic features before a considered opinion can be given. Many difficulties in the interpretation of the records present themselves and are discussed together with the value of such clinical procedures as reflex vagal stimulation and the action of drugs upon electrocardiographic pattern in the elucidation of the arrhythmia present in a given case.

The common occurrence of atrio-ventricular nodal rhythm and atrio-ventricular dissociation with or without interference at the point of death, when cardiac arrest is imminent, is also a point of great interest. Further study in this direction may be worth pursuing.

Each case has been fully discussed and further consideration here would only lead to repetition without the addition of any important point to which attention has not already been drawn.

The subjects chosen for this work have been to me a fascinating study and it is my earnest hope that this thesis may prove of some value and interest to all who read it.

*

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