

## SOME OBSERVATIONS UPON THE ELECTRO-CARDIOGRAPH, WITH NOTES OF CASES.

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AMONGST the recent advances in Medicine an important place must be assigned to the development of instrumental methods of observation in connection with the heart in health and in disease. These methods have opened a new chapter in cardiology, one which has already proved fruitful and which has promise for the future. While we cannot attach too much importance to procedures with which we have long been familiar, to a careful investigation of the whole clinical complex in heart disease, including history, causation, symptoms, and the data afforded by inspection, palpation, percussion, auscultation and radiography, there can be no doubt that the polygraph and the electrocardiograph add new and important facts—facts not otherwise available. By their instrumentality the heart writes its own message, and the cardiac script can be interpreted, not yet, perhaps, perfectly, but still with a certainty and precision which are constantly on the increase. The personal factor is eliminated; we get the phenomena of disease at first-hand: observation is made for us; our task is that of interpretation. In many cases, of which heart-block and auricular fibrillation are good examples, instrumental methods convert a clinical probability into a demonstrated certainty. Incipient or undeveloped lesions which tell a

doubtful story in response to older methods of investigation may reveal themselves unequivocally to the electric current and the recording needle. Physicians have long been in search of some method of observation which would give definite evidence of myocardial changes. Our knowledge of valvular lesions may be regarded as fairly complete, but apart from such gross changes as hypertrophy and dilatation, we have all felt the difficulty of determining myocardial lesions. We have been obliged to rely upon an inquiry into history, causation and symptoms. Physical examination has often yielded doubtful and equivocal signs. In such cases the electrocardiograph gives hope of effective reinforcement of our materials for diagnosis. Though the subject is still far from being completely elucidated, we may affirm that the electric current reacts in a different manner to healthy and to diseased muscle. Further, graphic methods record function, rather than anatomical conditions. As Lewis, to whose writings I am indebted for a large part of my information, says :—“ Graphic work has dealt as severe a blow to the prestige of anatomical pathology as any it has received of late years. Not that I desire to deprecate this line of study; but, clearly, as our prime business is with the living and not with the defunct organism, so the pathology of the wards must take precedence of that of the dead-house. Graphic records are records of function, normal or pervert; it is of pervert function that our patients complain. Graphic work sharpens our perceptions; it provides facts which are intensely satisfactory as a basis for argument. The records are clear messages writ by the hand of disease, permanent and authentic documents, which silence dogma.” I am far from denying that the electrocardiograph is a very complex instrument. Its re-

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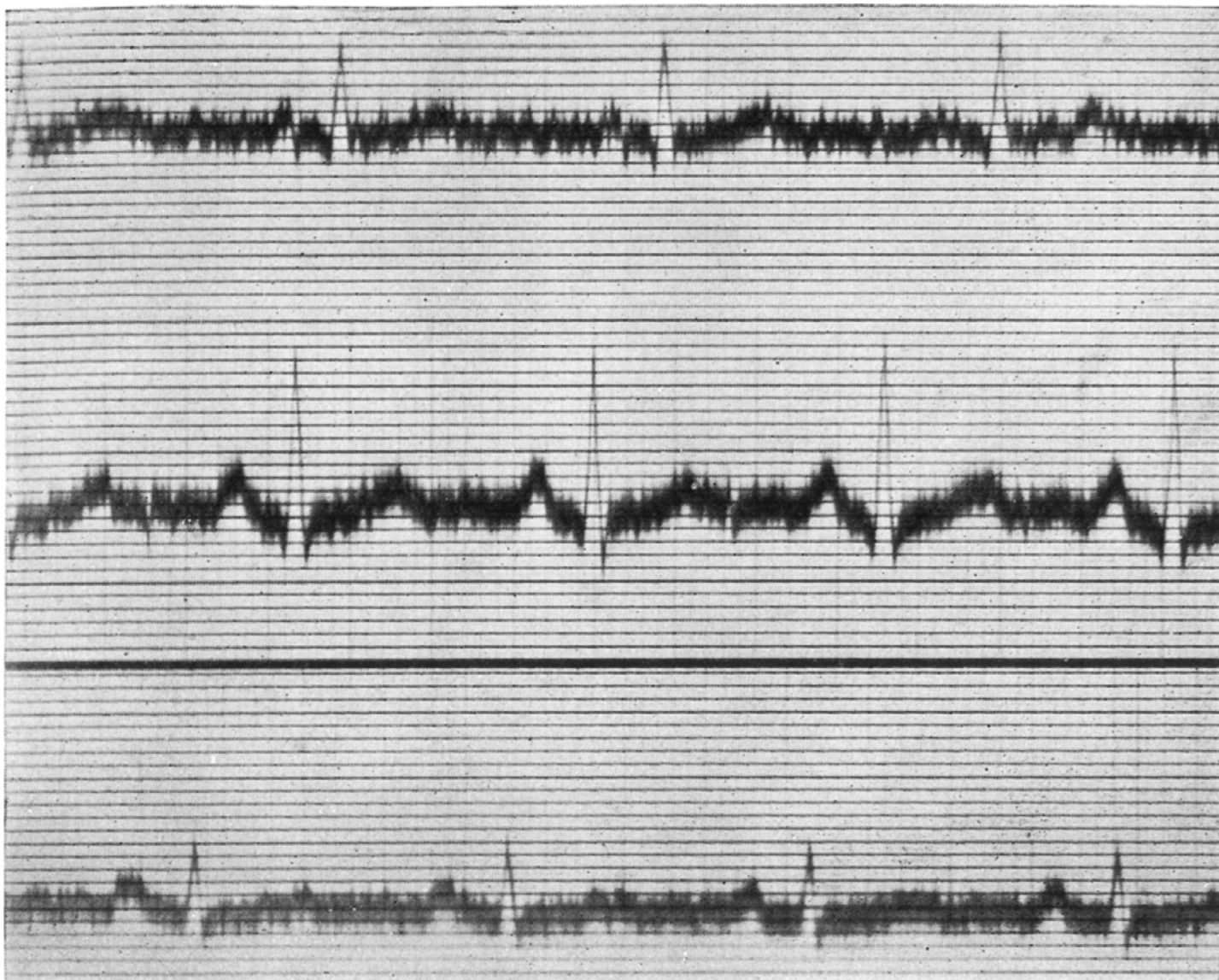


FIG. 1.

Normal Cardiogram.

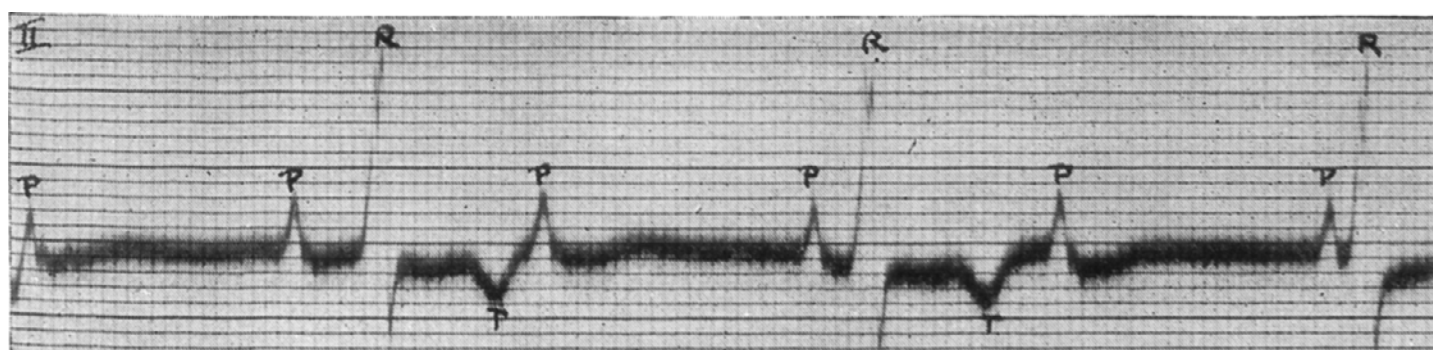


FIG. 2.

Complete Heart Block.

cords are not always clear. Much remains to be determined, and it is possible to ask many questions which do not at present admit of a precise answer. My own experience of the instrument is limited to a period of a little over a year, and, while the number of cases investigated has been large, I feel myself an explorer in a difficult country; I am very dependent upon the path hewed out and the landmarks erected by previous explorers, and I desire this communication to be regarded as strictly preliminary, and any opinions which I may express beyond the range of elementary and admitted facts are to be regarded as tentative and provisional.

*History of Electrocardiography.*—The fact that the heart-beat is accompanied by an electric discharge was first demonstrated by Köl liker and Müller in the year 1856. They laid the nerve of a nerve-muscle preparation upon the beating ventricle and noticed that at each contraction of the ventricle the nerve became excited. This is the foundation fact upon which the new science of electrocardiography rests. Waller was the first, I believe, to perceive that these electrical discharges were capable of graphic representation, while we owe to a Dutchman—Einthoven—the invention of a string galvanometer sufficiently delicate to give adequate records. This instrument “consists essentially of a powerful electro-magnet, the poles of which are closely approximated; and of an extremely delicate conducting fibre of silvered quartz or glass which is stretched in the narrow gap between the two magnetic poles. If minute currents are led through this fibre, as it lies in the magnetic field, the fibre moves in response to the tested current in a plane at right angles to the lines of magnetic force across the gap. The magnified shadow of the fibre is vertical, and is projected by means



of an optical system and powerful light on the horizontal slit of a camera; the shadow moves at right angles to and across the slit, and the movements are photographed upon its sensitive plate which travels behind the slit" (Lewis). The subject of electrocardiography has been studied by Kraus, Nicolai, Strübell, and Samojloff, and in this country by Lewis, Parkinson and others. The excellent works of Lewis, which constitute the most convenient accessible literature, have done much to popularise the subject. In Belfast we are much indebted to the labours of my colleagues, Dr. MacIlwaine and Professor Milroy.

*Mode of Employment of the Electrocardiograph.*—I must refer you to the works of Lewis for a full account of the mode of employment of the electrocardiograph, and shall content myself with a brief statement. The patient is connected by wires with the galvanometer, and the actual contacts are made when the limbs are immersed in salt water and through porous pots containing zinc sulphate. Three "leads" are employed—viz., right arm and left arm, right arm and left leg, left arm and left leg. Precautions are taken to neutralise the current derived from the skin. A standardiser is employed to standardise the string excursion and to secure that all electrocardiograms may be comparable, one with another. The resistance of the string must be large compared with the resistance of the body. Strings having resistance of from 5,000 to 10,000 Ohms are suitable.

*Electrical Phenomena of the Normal Heart.*—Electrocardiography rests on the principles that electrically active muscle is relatively negative to inactive muscle, and that the direction which the excitation wave takes governs the form of the resulting curve. The excitation (electric)

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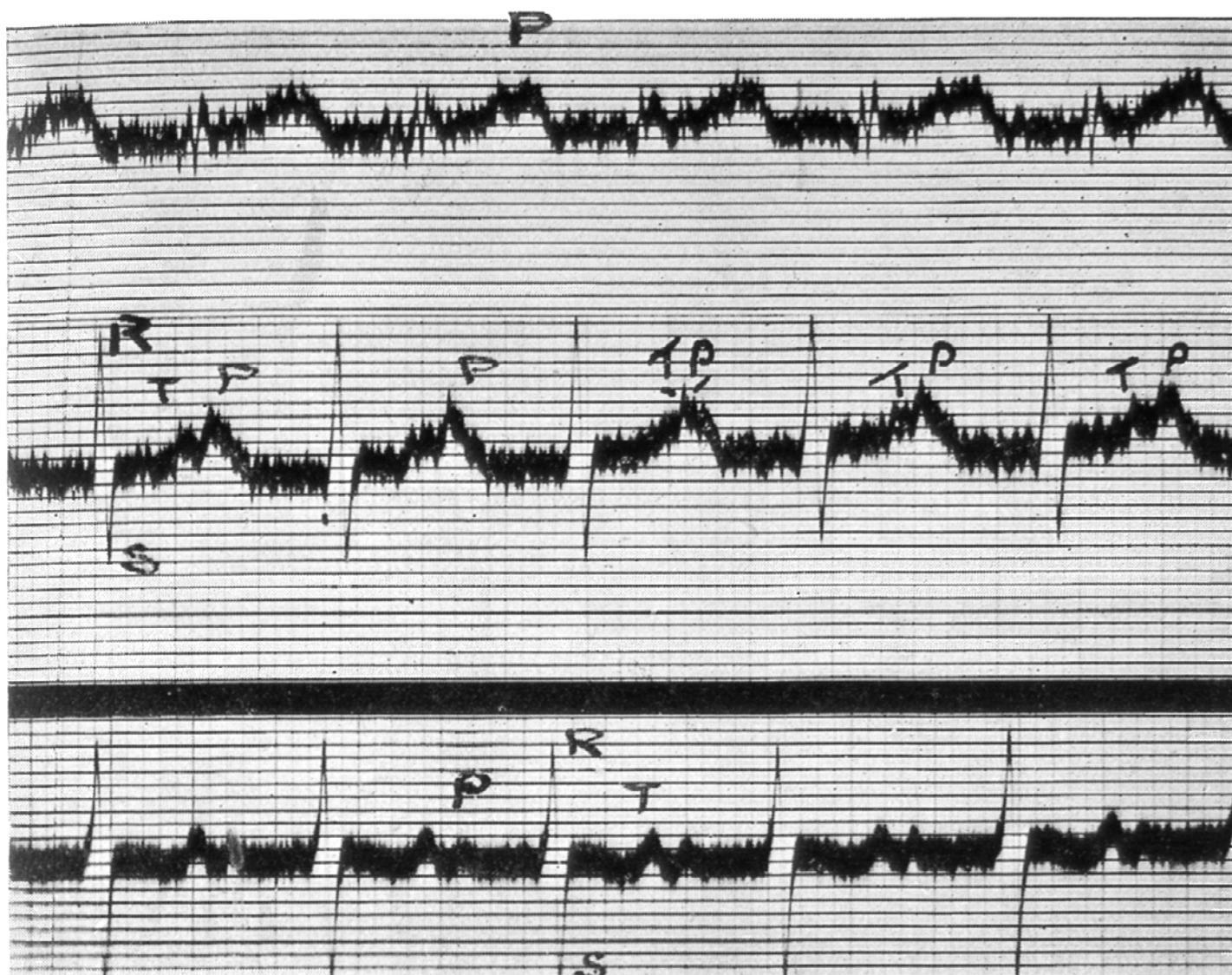


FIG. 3.  
Partial Heart Block.



FIG. 4.  
Auricular Fibrillation. Myocardial Degeneration.

wave is not identical with the contraction wave. It precedes it by an extremely short interval. Both waves are joint effects of a common cause—*i.e.*, certain chemical or physico-chemical changes which take place in the heart muscle. The excitation wave, like the contraction wave, takes origin at the sino-auricular node, in the angle between the superior vena cava and the right appendix. This node has been named by Lewis the “pace-maker” of the heart. From it arise the impulses which regulate the normal cardiac contractions, and many forms of cardiac arrhythmia are due to the fact that this regulating centre is disturbed in its function either by causes extrinsic to the heart or intrinsic to the organ. From this node also arises the excitation (electric) wave. From this point the excitation wave spreads radially in all directions, running down the *tænia terminalis* into the tip of the right appendix, along the inter-auricular band to the tip of the left appendix, down the septum and into all the veins—caval, coronary, and pulmonary—against the blood-stream. The excitation wave passes up the superior vena cava and flows along it to a point well outside the pericardium; it ends where the heart muscle ends and the venous muscle begins. The rate of transmission is approximately 1,000 mm. per second. From the auricles the excitation wave passes to the ventricles through the auriculo-ventricular bundle—the bundle of His. The precise mode of transmission of the excitation wave through the ventricles has not yet been completely made out, and the subject awaits further elucidation. The wave does not follow the anatomical arrangement of the cardiac musculature. The superficial area which passes earliest into a state of excitation seems to be those portions of the conus of the right ventricle which join the inter-ven-

tricular groove, while the latest region is the upper wall of the conus directly below the pulmonary valve. In the left ventricle the earliest area to feel the excitation wave is the extreme apex; the remaining portions of the chamber are affected almost simultaneously, while the last part to feel the wave is the basal attachment. A hundredth of a second measures the interval between the excitation of the apex and that of the other portions of the ventricle. Experiment would seem to show that conduction in the ventricles is much more rapid than in the auricles. It is highest and approaches or surpasses 2,000 mm. per second where the muscle is thinnest. It is lowest and approaches 400 mm. per second where the muscle is thickest. This principle is important, as it throws light upon certain electrocardiograms. The progress of the excitation wave is to be measured, not by distance, but by the nature of the tissues through which it must pass. Lewis sums up this subject as follows:—  
“ Distribution of the excitation wave in the auricle is expedited by the central position of the sino-auricular node and by a relatively high conduction rate—a relatively simple plan. The muscle of the ventricle conducts slowest because its function of distribution is a minor one; on the other hand, this, the driving chamber, is provided with a special system of distribution, clearly arranged to provoke almost simultaneous contraction; this special system is endowed with conduction powers of the highest order.”

*The Normal Electrocardiogram.*—Let us now see what is the nature of the message which the normal heart sends to us when consulted by the electrocardiograph. I show you several tracings of the normal heart. It writes a strange hieroglyphic, and one which could be interpreted only by



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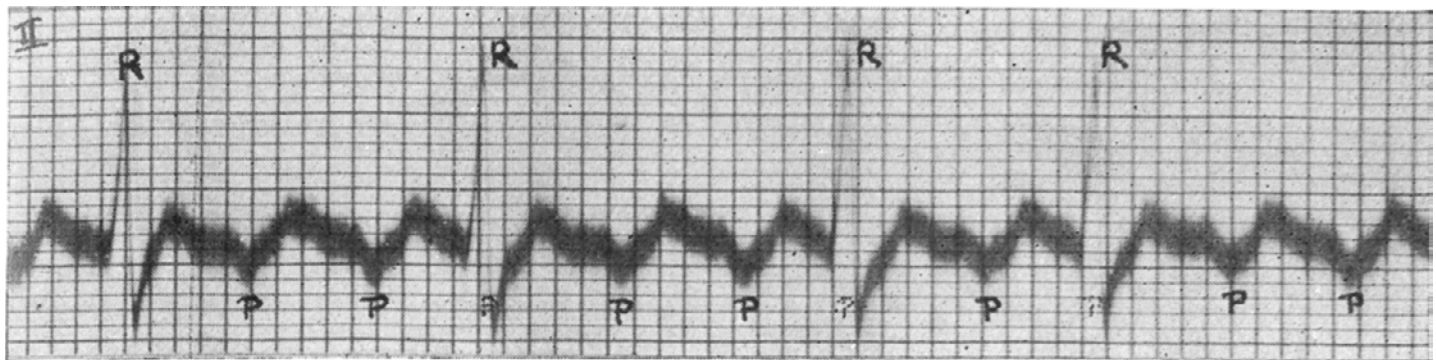


FIG. 5.

Auricular Flutter.

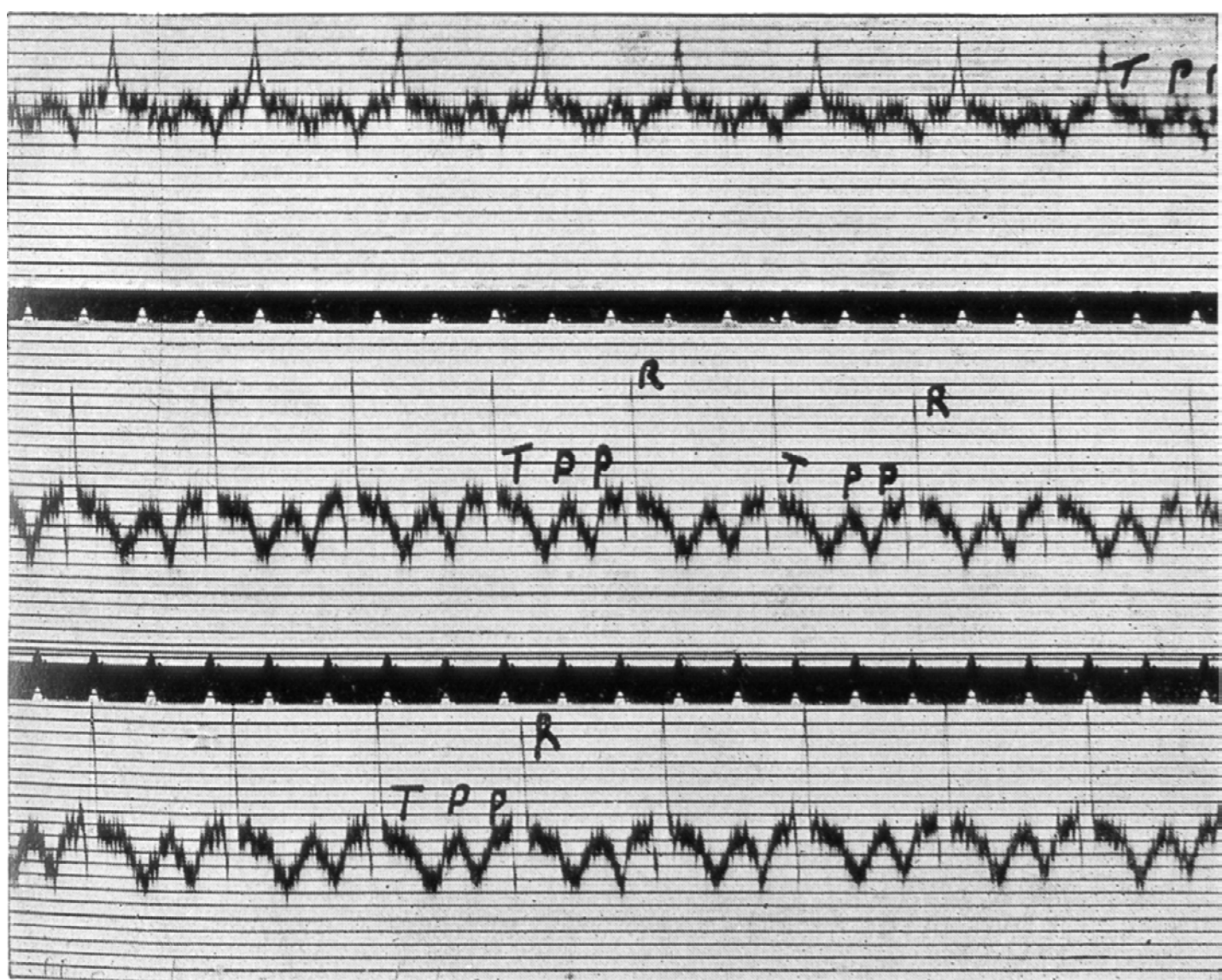


FIG. 6.

Auricular Flutter.

experiments upon the heart of the lower animals. It records the activity of the auricles and of the ventricles. The heart, with its different muscular-walled chambers, shows a series of electrical variations corresponding to the phases of activity in the various chambers. The string galvanometer responds to the electrical variations by moving to one or other side of the position of equilibrium of the string. In the electrocardiogram all movements above the line are due to the base of the heart being electro-negative to the apex, and all movements below the line to the reverse state of affairs. When we examine the photograph of the string movements we observe a series of waves, "curves," or "deflections," which are repeated regularly, each series representing the cardiac complex with the intervening pauses. There are five "curves," to which the letters P, Q, R, S and T have been assigned. These letters are simply labels, and have no significance in themselves. In each group of waves there is first a small rounded wave, "P," which is auricular in origin. Following this elevation the string is quiescent for a short period, and then there is a marked elevation above the line of very short duration. This immediately precedes the ventricular form change and is termed the "R" wave. In some, but not in all tracings, there intervenes between "P" and "R" a slight movement below the line which is termed the "Q" wave. The significance of this wave is not understood, and it seems to be of relatively small importance. Following the "R" wave there is in many tracings a slight movement below the line, which is termed the "S" wave. Although of minor importance, this wave throws light upon some of the phenomena of disease. After a short period the "S" wave is followed by a wave



above the line, termed the "T" elevation, which has great significance. It corresponds to the period of active contraction of the ventricular muscle, and with its conclusion the iso-electric period or the period of quiescence begins.

The precise mode of causation of these deflections has not been fully made out; but depends, no doubt, upon the principles already enunciated. The interpretation of the "curves," so far as this has been made out, has been established in two ways—viz., by experiments upon the hearts of animals in which the form changes and the electrical phenomena are simultaneously recorded; and, secondly, by the simultaneous employment of the polygraph and the electrocardiograph whereby the relations of the arterial and the venous waves to the electric waves are registered.

Of the five "curves" or "waves," "P," "R," and "T" are present in all normal hearts; "Q" and "S" are often absent. "T" sometimes varies in direction. It is always upright in healthy individuals in lead II, and its reversal in this lead has great significance. "R" and "S" show variations in apparently healthy subjects, probably dependent upon the relative preponderance of the musculature in the right and the left ventricle respectively. These variations are accentuated in disease. The "curves" are modified by age, the chief change being a decrease in the amplitude of "T" as the subject becomes older. Exercise causes an increase in the amplitude of "T." The variations in the normal electrocardiogram are many, and add much to the difficulty of the subject. We have no precise "norm," but this is only to be expected from the nature of the case. No two hearts are structurally identical, and no two hearts can, therefore, give quite the same response to the electrocardiograph.

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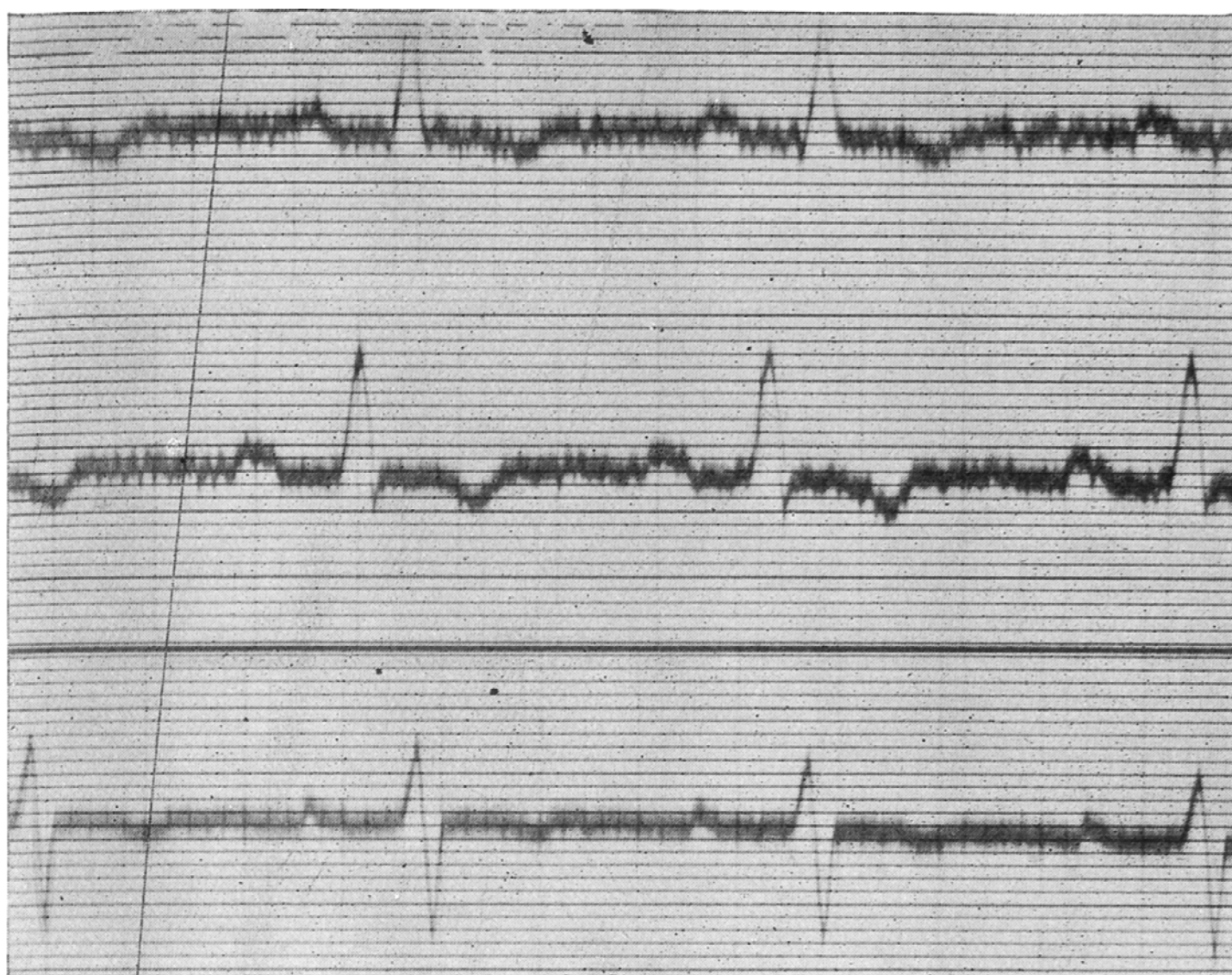


FIG. 7.

Partial Heart Block. Myocardial Degeneration.

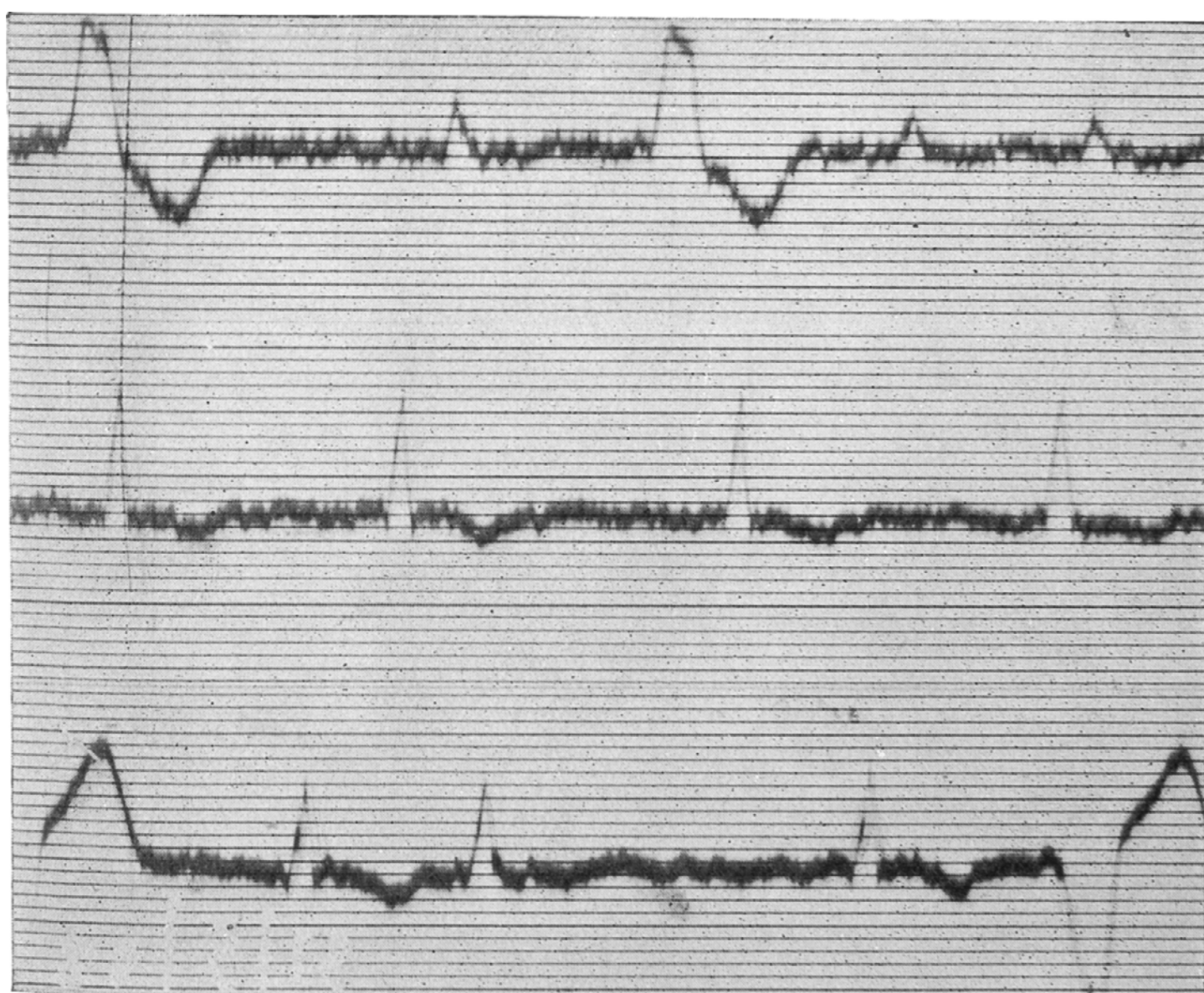


FIG. 8.

Auricular Fibrillation. Myocardial Degeneration.

*Relation of the Heart Sounds to the Electrocardiographic Curves.*—The first sound of the heart begins about  $\frac{1}{50}$  sec. after the curve “R”—*i.e.*, this curve precedes the systole of the ventricle by a very brief interval. The second sound is usually co-incident with the end of the “T” curve, but may precede or follow the end of this curve by an interval which does not exceed  $\frac{1}{50}$  sec.—*i.e.*, we may take the end of “T” as for practical purposes synchronous with the closure of the semi-lunar valves.

*The Electrocardiograph in Diseased Conditions of the Heart.*—I propose now to pass in review the principal morbid conditions of the heart in which the electrocardiographic tracings give definite information of proved value and importance. I shall confine myself to conditions of primary importance in which the value of the instrument admits of no question. Let us consider the following conditions, viz. :—

1. Heart block.
2. Auricular fibrillation
3. Auricular flutter.
4. Myocardial degeneration.
5. Extra systoles—auricular and ventricular.
6. Hypertrophy of the ventricles.

1. *Heart Block.*—The first clear recognition of heart block is to be attributed to two eminent Dublin physicians, and under the title of the Stokes-Adams syndrome has long been familiar to students of Medicine. It was recognised as a clinical entity, and many theories, which are now obsolete, were propounded as regards its pathology. We now know that it is due to disease of the auriculo-ventricular bundle—the bundle of His—and that the symptoms are dependent upon interruption of the auricular stimulus to the ventricles. In its florid or fully-developed

form the disease is easily recognised—the combination of bradycardia, syncopal or epileptiform seizures and respiratory abnormalities constituting a very definite clinical picture. In its milder forms, however, diagnosis can seldom rise above the level of probable conjecture. Both the polygraph and the electrocardiograph throw important light upon cases of heart block, either partial or complete. The former instrument shows a prolongation of the “ A-C ” interval, the latter a prolongation of the “ P-R ” interval. This interval occupies normally .18 sec. If it exceeds .2 sec. the condition is pathological. I show you a number of tracings in which this interval amounted to more than 1-5th sec. In complete heart block the auricle and the ventricle beat with their own rhythm—the former at a rate of 70 or more, the latter at a rate of 30 to 40 per minute. In one of the tracings which I show you the auricular rate is 74 and the ventricular 38 per minute—*i.e.*, practically a 2 to 1 heart block, in another tracing you will observe that there is a 4 to 1 heart block, the auricles beating four times to each ventricular contraction. Prolongation of the “ P-R ” interval is the first sign of commencing heart block. In one of the tracings you will notice that this interval exceeds 1-5th sec. As the condition progresses, this interval is further prolonged. After a time there arise occasions when the ventricle fails to respond to some of the auricular systoles, and we get what is somewhat inaptly styled “ intermission ” of the pulse. I show you a cardiogram illustrating this phenomenon of “ intermission ” or “ dropped beat.” At a still later stage, as I have already pointed out, there is complete interruption of the auricular stimuli to the ventricle, and auricle and ventricle act independently, each preserving its own rhythm.

Heart block is due to lesion or temporary incapacity of



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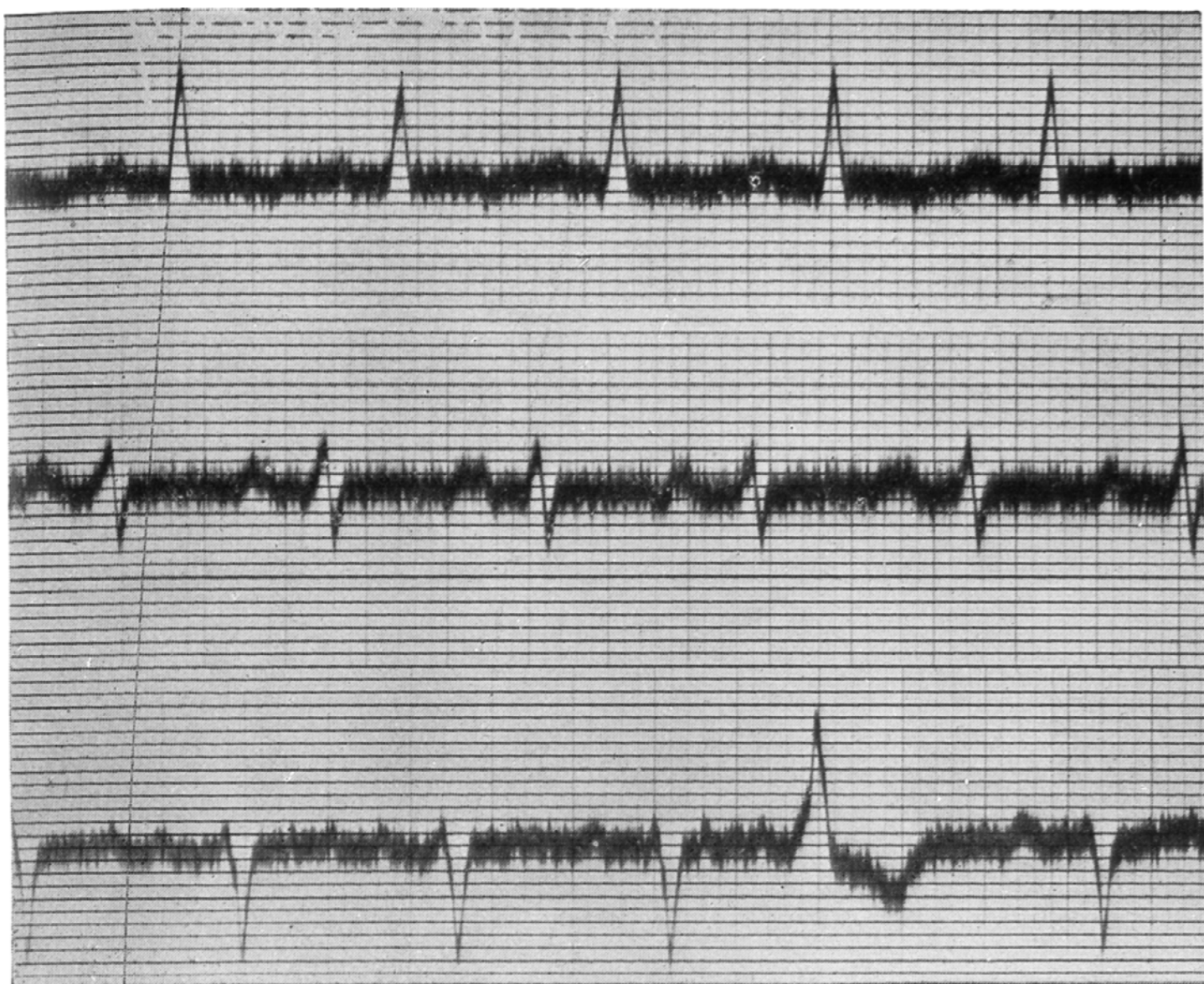


FIG. 9.  
Left Ventricular Hypertrophy. Extra-systoles.



FIG. 10.  
Right Ventricular Hypertrophy. Mitral Stenosis.

the A-V bundle. It is most often due to degenerative changes in the bundle, often arterio-sclerotic in type. Syphilis is an occasional cause. Toxic causes may operate as in diphtheria. Rheumatic endocarditis may be accompanied by various degrees of heart block. Digitalis, if pushed beyond a certain point, will cause heart block. It is important to remember that this drug, and the other cardiac tonics of allied nature, are contraindicated in this disease.

2. *Auricular Fibrillation*.—In this condition the auricles no longer contract. They are distended in diastole, and their surfaces can be seen to present irregular, tremulous, flickering movements. Their function of propelling the blood is in abeyance, but they continue to send forward to the ventricles irregular stimuli, exciting them to frequent irregular contraction, and causing an extreme type of arrhythmia. Auricular fibrillation may arise in any form of failing heart, but is most typically seen in mitral stenosis and in certain forms of myocardial degeneration. I show you cardiograms exhibiting auricular fibrillation in mitral stenosis, mitral reflux, and myocardial disease. The cardiogram is quite characteristic. The deflection “P” has disappeared, and is replaced by a series of wavy lines of low elevation.

Auricular fibrillation is commonly regarded as a serious condition, usually persistent when once established, and involving a grave prognosis. Our experience in Belfast throws some doubt upon these affirmations. We have found auricular fibrillation present in some cases, probably of toxic causation, where it was not expected, and where cardiac symptoms were slight or absent.

Auricular fibrillation usually persists when disturbed compensation has been restored.

Auricular fibrillation is an indication for the use of digi-



talís, which has often an excellent effect. It is an interesting question how the drug acts—whether by increasing the muscular tone of the auricles and ventricles, or by producing partial heart block, and so checking the irregular auricular stimuli to the ventricles. It will not be forgotten that when the remarkable influence of digitalis upon the heart was first established, the drug was called the “ opium of the heart.” Later views rejected this doctrine in favour of the theory that digitalis is essentially a cardiac tonic. It will be curious if the electrocardiograph causes a reversion to the earlier view. I do not feel justified in expressing any positive opinion upon this point, which I content myself with throwing out for discussion.

3. *Auricular Flutter*.—In this condition, which has only been recently recognised, the auricles contract at an extremely rapid rate, the ventricles beating in response to each second, third or fourth auricular contraction. I show you two cardiograms of this condition. In one the auricles are beating twice as often as the ventricles, and partial heart block is present. In the other the auricular rate is 304 and the ventricular approximately 120. This condition is most common in the elderly, and the heart’s action, while extremely rapid, continues regular. The cardiogram is quite characteristic. The “ P ” wave is well marked, and is repeated several times before the ventricular phase begins. Partial heart block exists, the ventricles refusing to respond to all the auricular stimuli, in most cases responding to each alternate stimulus. Syncope attacks are common. Lewis suggests that paroxysmal tachycardia may in some cases be due to the ventricles taking on the auricular rhythm in the subjects of auricular flutter. The question awaits further elucidation. Mackenzie holds that tachycardia is due to a dislocation of the seat of rhythm from the sinus centre to the A-V node.

4. *Myocardial Degeneration*.—I have already remarked upon the difficulty of diagnosing myocardial changes, except in advanced cases, by the ordinary clinical methods. Any addition to our materials for diagnosis in these cases would be welcome. I show you four cardiograms of cases where myocardial disease was diagnosed. The most constant change in the tracings is an inverted “ T ” in the second lead. If further experience strengthens our reliance upon this sign, the gain to clinical medicine will be great.

5. *Extra-systoles—Auricular and Ventricular*.—Extra-systoles are premature contractions, either auricular or ventricular, probably explained as due to stimuli arising at some point in the cardiac musculature other than the sino-auricular node. They may also be due to causes extrinsic to the heart, such as an excess of accelerator action. Extra-systoles have many causes—organic change, toxic conditions, neurosis, &c.—and hence many varying degrees of importance. They are often of slight gravity, and may occur in conditions of perfect health. The cardiograms are easily recognised. I show you two examples. In the one upon the screen auricular fibrillation is also present.

6. *Hypertrophy of the Ventricles*.—A study of tracings in ventricular hypertrophy shows that in right ventricular hypertrophy we find in lead I a small “ R ” and a prominent “ S,” while in lead III we get a small “ S ” and a prominent “ R.” In left ventricular hypertrophy the conditions are reversed. As Lewis points out, the former are the curves which are found in the heart of the new-born child, in whom there is a relative preponderance of the right ventricle. Right ventricular hypertrophy is best studied in leads I and II, left in lead III. I show you several cardiograms in which these points are illustrated.

*The Electrocardiograph and Valvular Lesions.*—It is evident from the very nature of the case that the electrocardiograph cannot be expected to throw any direct light upon valvular lesions. Its message is from the musculature of the heart, not from the valves. We may have important lesions of the valves with a normal electrocardiogram. The claim that with a normal tracing of the electrocardiograph we can dismiss the existence of serious heart mischief is one which cannot be sustained. On the other hand, valvular lesions, sooner or later, and often sooner rather than later, involve important consequences for the cardiac muscle, and these consequences will, clearly or obscurely, write their story upon the electrocardiograph. Further, a good many cases of valvular defect are accompanied by some degree of heart block, and the detection of this important complication is one of the most valuable aids which we may expect from the instrument. It is true that valvular lesions, thanks to the labours of generations of clinicians, amongst whom the names of Stokes and Corrigan stand high in the roll of honour, are for the most part capable of ready recognition by the ordinary clinical methods, which may seem hardly to require re-inforcement by the newer instrumental procedures. But in recent times we have come more and more to recognise that the patient's fortunes stand or fall by the condition of his heart muscle, and that valvular defects owe their significance and importance to their effects upon his heart muscle. Any method which promises information regarding the condition of the cardiac musculature will be welcome, but we must never forget that the electrocardiograph speaks a language of its own—a language of which the alphabet is composed of electric waves—and that the relation of electrocardiographic tracings to cardiac effi-

ciency or inefficiency involves a process of interpretation sometimes easy but often difficult.

It cannot be said that any of the valvular lesions have a characteristic cardiogram. The nearest approach is seen in the case of mitral stenosis. In this lesion there is usually a well-marked " P " wave which is often broad, flattened or bifid. Of this latter condition I show you an example. Auricular fibrillation is relatively frequent in mitral stenosis, and most of these cases show some degree of right ventricular preponderance. Mitral regurgitation has no characteristic cardiogram, nor has aortic disease. Left ventricular preponderance is, of course, common in these lesions and will affect the tracings.

*The Electrocardiograph and the Cardiac Arrhythmias.*—The time is not remote when the cardiac arrhythmias constituted one of the most obscure and perplexing fields of clinical medicine. That they are now capable of classification and interpretation we owe largely to the polygraph and the electrocardiograph, Mackenzie's work, in particular, having rendered much former observation obsolete. Several forms of arrhythmia have been already considered, viz.—those depending upon auricular fibrillation, heart block and extra-systoles. Let us consider some of the remaining types.

(a) Sinus arrhythmia.

In this variety there is a variation in the diastolic period, the systolic period remaining constant. Each beat is propagated from the normal pacemaker, the sino-auricular node, and the electric curve is formed of the usual complexes, the irregularity being evidenced only in the disposition of the beats. The size of the pulse waves remains constant. The irregularity diminishes or disappears with increase of the pulse-rate. It is much in-

fluenced by respiration. The causes of this type of arrhythmia are extrinsic to the heart, and depend upon variations of vagal tone. The condition is of little importance, and no special treatment is required. I show you an example.

(b) *Pulsus alternans*.—In this variety the rhythm is regular, but the beats are alternately large and small. This condition is not usually perceptible to the finger. It is readily recognised in the cardiogram. It is a serious condition, indicative of serious exhaustion of the heart muscle, and calls for prolonged rest and treatment.

*Concluding Remarks*.—The electrocardiograph is the most complicated instrument ever introduced into clinical medicine, and its routine employment in ordinary practice presents great difficulties. It is a marvel of ingenuity, and I feel that with my limited experience I should speak with the utmost caution and diffidence. The little that I know on the subject has been learnt mainly from the labours of others and a study of the literature, which is still scanty. The electrocardiograph, even more than the polygraph, has profoundly affected the study of cardiology. It has compelled us to think out the old problems from a new angle. It has helped to fix attention upon the cardiac musculature, rather than upon the cardiac valves. It has enabled us to differentiate auricular from ventricular action. It has rendered obsolete the age-long controversy between the neurogenic and the myogenic theories of the cardiac contraction. It has afforded a ready means of disentangling the maze of the cardiac arrhythmias and of easily recognising such conditions as heart block, auricular fibrillation, and *pulsus alternans*. But I should be the first to deprecate any exclusive reliance upon instrumental methods in the study of heart disease. There are lesions

regarding which the electrocardiograph is silent. A normal electrocardiogram is no guarantee of a normal heart. The final test of cardiac sufficiency or insufficiency is the appeal to experience. Clinical observation in the broad sense of the term is in the long run more trustworthy than any form of mechanical or instrumental record, but the two should supplement, not supplant, each other. Science, it has been well said, is essentially measurement, and to the measurement of the complex phenomena of cardiac disease instrumental methods make an important contribution.

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PROFESSOR THOMPSON referred to the numerous difficulties in the employment and interpretation of the method, but expressed the belief that time would elucidate the majority of these. He pointed out that while the P—R distance is important, the “T” wave is even more so, as showing whether ventricular contractions were dropped or not. A large amount of experimental work had been done in Belfast by Dr. Gibson and Professor Milroy with particular reference to this “T” wave. The electrocardiograph was, however, essentially a clinical instrument, and it was noteworthy that its employment in the hospital in Belfast preceded the laboratory work. Every hospital would have to provide itself with the apparatus in the near future. He inquired whether the large number of tracings shown were the work of the President.

THE PRESIDENT, in reply, said that while the tracings shown were not entirely his own work, practically all had been obtained in the Victoria Hospital, Belfast. He was not a devotee of instrumental methods, which could never replace trained clinical observation, but they had one most important quality—namely, the elimination of the personal factor.