An Address

ON

MITRAL STENOSIS.

DELIVERED AT THE OPENING OF THE WINTER SESSION,
POST GRADUATE COURSE, MOUNT VERNON HOSPITAL
FOR CONSUMPTION AND DISEASES OF THE CHEST.

BY

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[AFTER some introductory remarks, Sir James Barr stated that his address was based on his own previous work on the subject brought up to date. He considered the subject much too large for a single address, so he would confine his attention chiefly to the debatable points in the clinical manifestations of the disease.]

The significance of the characteristic murmur of mitral stenosis was first clearly recognized by Fauvel, and by him designated *presystolic*, but it was the late Sir William Gairdner who clearly depicted the clinical signs of the disease and their pathological importance, so that when the murmur, which he termed *auricular-systolic*, or briefly the A.S. murmur, is present, the disease becomes one of the most easily recognized affections of the heart. Sir William Gairdner's first contributions on the subject were published in his *Clinical Medicine* in 1862, and there has since been a slow but gradual evolution in knowledge of the subject; but, compared with the great amount of literature which has been devoted to its exposition, the real additions to knowledge are comparatively trivial, and the value of some of those additions an unknown quantity. It should be clearly understood that the disease is easily diagnosed apart from any murmur, but such diagnosis is very imperfect unless it takes into account the extent of the lesion and its effects. There is still much to be done in the way of prevention and in retarding the evolution of the disease.

ETIOLOGY AND PATHOLOGY.

Of all the causes or exciting conditions of endocarditis and pericarditis, rheumatism holds the first place. The fibrous tissue seems to be specially vulnerable to the rheumatic poison, but the myocardium may be involved as well as the whole endocardium and pericardium in the inflammatory process. The valvular lesion is determined by the violent collision of the vulnerable valves, and this view of causation has a most important bearing on prevention and treatment, as by relieving the laboured action of the heart in the early stages of endocarditis the mischief can be prevented or mitigated.

When the rheumatic poison, whether it be animate or inanimate, sets up endocarditis, the myocardium is, in the majority of instances, more or less involved. The systole of the ventricle is slow and laboured to overcome the high intra-cardiac pressure which is set up by increased peripheral resistance. As compared with the temperature the pulse in these cases is not very frequent, and may not exceed 90 even with a temperature of 103° F. The pulse is slow, full, and moderately strong, and the tension is well maintained. The blood pressure is much higher than it is in typhoid fever, pneumonia, or diphtheria. Among the earliest signs of endocarditis is a dull first sound and a delayed radial pulse, so that the former can be heard an appreciable interval before the latter is felt. By careful attention to these signs, endocarditis can usually be diagnosed some days before any murmur is heard. The much more frequent occurrence of valvular disease in the left heart than in the right is due to the much greater strain and more violent collision to which the valves are subjected. When the mitral valve is involved we get a beaded row of vegetations on the auricular surface of the valve about $\frac{1}{4}$ in. or $\frac{3}{8}$ in. from the margin where the cusps come into most violent apposition; and when the aortic valve is affected the damage occurs on the ventricular surface at the angle of the cusps, which are brought into forcible collision during their closure. The vegetations arise from proliferation of the cellular elements in the sub-endothelial layer of the endocardium. These groups of cells burst through the endothelium, and fibrin is deposited

on the rough surface. This has a most important bearing on treatment, as by keeping the blood pressure extremely low in rheumatic fever, endocarditis can often be prevented. Unfortunately the mischief has often occurred before we see the patient, and when the valve has been once damaged there is a marked tendency for the mischief to be maintained and developed, even under the ordinary action of the heart; it is much aggravated by violent collision of the cusps during palpitation, or from high intra-cardiac pressure from any cause, perhaps from the meddlesome interference of the physician with that much-abused drug, digitalis. When free mitral regurgitation takes place, the blood-pressure falls, and the pulse increases in frequency.

Children are very liable to rheumatism, especially those with a hereditary tendency to the disease, but the joint affection may be so slight as to escape notice, and in many cases endocarditis is the only gross expression of the rheumatic affection. Following this endocarditis, which may even not have been detected, mitral stenosis is not an infrequent sequence. Many writers have asserted that mitral stenosis is essentially a disease of early life, and some believe the disease to be frequently congenital. While not denying the occasional congenital origin of the lesion, I think it must be extremely rare, as the affection is very seldom detected under 5 years of age. It is very common in youth, but may occur at any age.

When it is directly associated with acute rheumatism the edges of the cusps which are principally affected become gradually united so that the funnel form of the lesion is eventually established. Frequently these cases begin with incompetence, pure and simple, but from fibrous contraction of the auriculo-ventricular orifice and agglutination of the edges of the valve segments, they finally end in stenosis either with or without regurgitation.

Mitral stenosis is frequently associated with chorea, and here the mechanical determination of the disease is very apparent. It may arise in cases of protracted anaemia associated with high blood pressure and frequent emotional excitement, but it does not arise in cases of exophthalmic goitre in spite of the violent palpitation, because the blood pressure is low and the lime salts, which are another determining factor, are deficient. It is not uncommon in chronic Bright's disease, and in these cases mechanical strain plays a most important part in its causation. In such cases the orifice is not usually much contracted, but the whole segments of the valve are much thickened, and may be atheromatous or contain calcareous nodules consisting of lime salts or sodium urate. The musculi papillares are much hypertrophied and the chordae tendineae thickened. The insertions of the chordae tendineae are spread out over the greater part of the cusps, so when there is long-continued high intracardiac pressure the whole valve becomes very much thickened, and there is a great increase in the fibrous tissue, which eventually leads to puckering or contraction of the segments and the diaphragmatic or button-hole variety is produced. Syphilis has also been set down as a cause, but if so, it must, in my opinion, be a very rare one. Dr. Byrom Bramwell thinks that in some cases large calcareous nodules in the walls of the ventricle—causing obstruction—are syphilitic gummata which have become calcified.

Mitral stenosis is more common in females than in males, for the simple reason that rheumatism and chorea occur more frequently in girls than in boys, and anaemia and all emotional disturbances have a special predilection for the female sex. However, men are much more liable to this disease than is generally supposed; and, in fact, the disease is much more common among both sexes than is usually recognized. This frequently arises from the fact that it is often overlooked when associated with mitral regurgitation. When associated with tricuspid stenosis I have seen as many cases of the double lesion in men as I have in females. Mitral stenosis is frequently associated with pericardial adhesions, and this arises from the fact that pericarditis is almost as common as endocarditis in children.

The disease is, as a rule, slowly progressive, and although sooner or later it leads to the death of the individual, yet under proper care and treatment it is very slow in its progress, and is quite compatible with a fairly long existence. I have known many cases of mitral stenosis of twenty to thirty years' standing. In some cases of

tricuspid stenosis associated with mitral disease I have looked upon the former as a conservative lesion which saved the heart and lungs from many strains to which they would otherwise have been subjected if the mitral lesion had existed alone.

In mitral stenosis occurring in early life the orifice usually assumes the funnel form. This arises from the fact that these cases are generally of rheumatic or choreic origin, and the margins of the cusps are primarily affected. The relatively high intracardiac pressure and violent collision of the cusps causes their edges to get cemented gradually together, and taper down into the ventricle as a hollow cone. In the experience of Sansom, Hilton Fagge, and Hayden the button-hole variety almost replaces the funnel form in the adult, but this scarcely accords with my experience. I have found that while the button-hole variety is scarcely known in children, it is not much more common in the adult than the funnel form. It is true that the orifice at the end of the funnel is often a slit, but that scarcely constitutes a different variety. The characters of the orifice and valves depend, perhaps, more on the age of the lesion than on the age of the patient, and also on the causes which gave rise to the disease. If there be much fibroid thickening of the whole valve and of the auriculo-ventricular ring, or if there be much atheromatous degeneration with calcareous deposit, then more or less puckering is produced, and the orifice assumes the button-hole variety. These conditions occur more readily in adults, and in them the lesion is frequently of long standing. In some cases the mitral cusps are so thickened and contracted that they merely form a transverse septum with a narrow slit between the auricle and ventricle. In such cases the chordae tendineae are frequently thickened and matted together, and the muscoli papillares are in such a fibroid condition, that it would seem impossible for a first sound to be generated by the mitral valve. This, however, is the exception and not the rule; even in cases in which the orifice is extremely small and its edges much thickened, the valve curtains are usually in a sufficiently vibratory condition for developing sound. The insertions of the chordae tendineae are spread over the greater part of the cusps, and the muscoli papillares are usually hypertrophied so that tension is vigorously applied to the whole valve. If the muscoli papillares be pulled, it will often be found that the only part not rendered tense is the thickened fibrous ring. The relatively small quantity of blood in the left ventricle does not muffle the first sound, which is directly conducted to the chest walls through the chordae tendineae, muscoli papillares, and the part of the heart causing the impulse. The small hypertrophied left ventricle, the thick muscoli papillares, and the high intracardiac pressure produce a loud thumping or booming first sound unless the valve be so contracted as to form a septum. The character of the first sound at the apex affords valuable evidence as to the condition of the mitral cusps.

In the evolution of mitral stenosis any excess of calcium ions in the blood plays a very important part. The so-called "good healing flesh" simply means that there is an excess of calcium cement in the blood and tissues. Under certain circumstances this may be very beneficial, but whenever there is any tendency to sclerotic changes in the body, Nature's attempts at repair are apt to be far in excess of the requirements. In the case of mitral stenosis these excessive calcium ions may be the determining factors in the production of the disease. They raise the blood pressure, increase the force of the cardiac contraction, give rise to hypertrophy of the muscoli papillares, cause violent collision of the mitral cusps, increase the formation of the fibroid tissue, and gradually cement and unite the edges of the cusps together. I shall have more to say on this subject when we come to speak of prevention and treatment.

DIAGNOSIS.

When we hear at the mitral area a murmur immediately preceding the first sound, or even a murmur during the long pause, it is a very simple matter to recognize the fact that there is some obstruction to the flow of blood from the auricle to the ventricle, but such an observation cannot be properly called a diagnosis. We want to know the nature of the obstruction, the size of the orifice, and the effect on

the circulation. Any observer can recognize a presystolic murmur, but it requires some training to interpret its significance. A great many men base their diagnosis of the lesion on the presence of the characteristic murmur, and as it is absent in a large number of cases, they thus fail to recognize the disease, even in the very extreme and most urgent cases.

In a large number of cases in which the murmur is well pronounced the interference of the physician is uncalled-for; but in many cases in which the murmur is absent judicious treatment may be of vital importance. In many cases the only murmur heard is a mitral systolic, due to regurgitation. Now, in my opinion, the treatment of these two affections is in many respects essentially different, and the failure to recognize the underlying condition of mitral stenosis may be fraught with great danger to the life of the patient.

The characters of the murmur and of the first sound may help us to estimate the nature of the orifice and the condition of the cusps, but it is only by an examination of the pulse, and by a careful study of the effects of the obstruction, that we can arrive at the far more important calculation of the size of the orifice or the amount of obstruction.

Of all the signs of mitral stenosis, the murmur is the most obtrusive, and, therefore, has perhaps received undue attention, to the neglect of other more constant, and to my mind more important, signs. The characters and varieties of the murmur have been so well studied and depicted by numerous writers, that very little new can be said on the subject, but, nevertheless, the intensity of the murmur prevents our passing it over in silence in an address dealing with a lesion in which it plays such a prominent feature. There is, perhaps, no cardiac murmur about which such a conflict of opposing opinions has been waged. Even the very rhythm of the murmur has been disputed, but at last we have arrived at an almost unanimous opinion that the murmur occurs prior to the systole of the ventricle. Sir William Gairdner happily designated it "auricular systolic," which implies a theory as to causation as well as rhythm. It has been objected to this name that the auricle is often so thin and dilated as to be incapable of any effective contraction, and the objectors substitute the theory of elastic recoil of the auricle, forgetting that under such circumstances there can be no recoil of the auricle, and under no circumstances can the auricle be compared to the aorta or to an overstretched india-rubber ball. The atrium may be so thin and dilated as to be incapable of any forcible contraction, but it is very rare for this to happen with the auricular appendix, and the current induced by its contraction may be sufficient to give rise to a murmur. When the muscular contraction of the auricle is so weak as to be incapable of giving rise to a murmur through the narrow or roughened orifice, it is not an imaginary recoil which can do so. Under these conditions there is no murmur, or it occurs at an earlier period owing to the suction action of the ventricle. When you get a rough, rasping, low-pitched murmur immediately preceding the first sound, it must be due to the contraction of the auricle or of the auricular appendix, and is, therefore, auricular systolic.

A murmur may arise under any conditions which are capable of giving rise to a *fluide veine*—hence, it is not at all surprising that it does frequently arise before the auricular systole from the blood rushing through a narrow orifice during the active dilatation of the ventricle. The suction power of the ventricles is a matter of ancient history. It was maintained by Brown Langrish, and afterwards by the illustrious Haller, but it was not until 1878 that the force was expressed in millimetres of mercury pressure by Goltz and Gaule.

The suction power of the ventricle is much aided by the high intrapulmonic blood pressure. Sir William Gairdner recognized and described the murmur as occurring at different periods, and even during the whole period between the second and first sounds. These different varieties of murmur were named by the late Dr. Bristowe *early diastolic*, *mid-diastolic*, *late diastolic*, and *entire diastolic*. The late diastolic corresponds to the *presystolic* of Fauvel and the *auricular systolic* of Gairdner. The *early diastolic* may be purely mitral in origin; but I am convinced that it is often confounded with a short, soft, blowing, diastolic murmur, which not infrequently occurs

in this disease at the moment of closure of the pulmonic valve, and which arises from regurgitation through the pulmonic orifice into the right ventricle owing to high pulmonic tension and dilatation of the pulmonary artery. This murmur is usually short, but I have known it to be prolonged well into the long pause and nearly up to the first sound. The occurrence of the *early diastolic* and *mid-diastolic* mitral murmurs depends on high intra-pulmonic and auricular blood pressure, a narrow orifice, and the aspirating force of the left ventricle. The size of the orifice and the nature of the valve segments will largely influence the character of the murmur, as it occurs at any part of the diastolic period.

At a very early stage of mitral stenosis, when the further progress of the disease may be very largely modified if not arrested, the characteristic murmur is usually absent, or there may be only a mitral systolic murmur. Again, the murmur may be absent in the very late stage, when much can be done for the comfort of the patient, and when it is most important to diagnose between mitral stenosis and mitral incompetence. I think, therefore, we should endeavour to recognize the disease independently of any murmur.

Enlargement of the Left Auricle.

One sign to which I attach considerable importance is an extension of the cardiac dullness in the direction of the left auricle. Under normal conditions a line drawn from the centre of the suprasternal notch to the nipple, or a point on the left fourth costal cartilage where the nipple should be, and which for convenience I call the supra-sterno-mammillary line, should mark the left outer and upper border of the heart. Any extension of the cardiac dullness beyond this line in the direction of the outer part of the infraclavicular region should raise a strong suspicion of mitral stenosis. This portion of the heart is usually well overlapped by lung, and so it requires very delicate percussion to elicit the extreme margin.

I may here premise that the whole deep cardiac area should be carefully mapped out; we want to know the size and position of the whole heart and of its individual parts. The anterior surface is to a greater or lesser extent overlapped by lung, and so in every case the percussion note of the deep cardiac area is only relatively dull; and in order to get the first shade of dullness, we should, in my opinion, percuss *very gently* from without inwards. In this delicate percussion I think it is a mistake to interfere with the slight vibrations of the chest walls, and therefore I prefer an ivory pleximeter to the finger. When you wish to bring out the slight dullness or impaired note of the lung in the very early or hyperaemic stage of pneumonia, then the vibrations of the chest walls should be stopped by the whole left hand laid firmly on, and the middle finger percussed. In this way you avoid the confusion arising from the resonance of the vibrating chest walls, and you obtain the further information of the resistance to the stroke. In the case of the heart, however, it is not a question of resistance or even dullness, but of variation in the percussion note. It is a very good exercise to percuss out the cardiac dullness in the cadaver and compare that with the actual area occupied by the heart. The superficial cardiac dullness gives you some information about the position of the anterior margin of the left lung, but, so far as the heart is concerned, it is of no practical value. The cardiac dullness is usually given much too small in standard textbooks; if you compare these pictures with the areas occupied by the heart in the *post-mortem* room, and under the *x* rays, you will be much struck with the difference. Turn the lungs aside and you will find the anterior surface of a normal heart is as large as many illustrations of extreme hypertrophy. In none of Sansom's plates of cases of mitral stenosis is there any extension of the cardiac dullness beyond what I have termed supra-sterno- (or simply sterno-) mammillary line. This, I believe, is not because it was not there, but because it was not marked out. This careful differentiation of the cardiac dullness has yielded valuable results in my hands, and I hope that others will find it worthy of accurate observation. One authority on the heart, who does not believe in the possibility of accurately mapping out the deep cardiac dullness, says that when he sees anyone attempting to do so he inquires if the percussor is trying to map out the heart in systole or in diastole. No doubt

this appears very smart to the authority in question, but he should learn that there is very little difference in the size and position of the heart between systole and diastole—when one part of the heart is emptying itself another part is filling, and the whole heart always occupies the same position in the mediastinum between the two lungs. The total size of the heart is very much more affected by even quiet respiration than it is by its own systole or diastole. In Müller's or Valsalva's experiment the space occupied by the heart may be reduced by at least a half, but when you are percussing out the heart the respiration is very quiet, and therefore it is a heart full of blood which you are mapping out. Not only is it possible to map out the deep cardiac dullness by percussion, but, where the costal cartilages are fairly pliant, with a little practice you can palpate out the deep area with your eyes shut. The enlargement of the left auricle can be made out both by percussion and palpation, and is one of the commonest phenomena in obstructive mitral disease, but in some cases of associated mitral and tricuspid stenosis I have noted its absence. Here the comparatively small amount of blood passing through the narrowed tricuspid orifice was carried on without causing great distension of the left auricle.

The *pulmonic second sound* is accentuated. The intensity of this sound at the pulmonic cartilage largely depends on the amount of lung intervening between the artery and the chest walls. Frequently the sound is better heard over the conus arteriosus or right ventricle. In a certain number of cases there is a short, soft, blowing diastolic murmur (to which I have before alluded) in the pulmonic area, due to slight regurgitation through the pulmonic orifice. This is especially apt to happen when the right ventricle is dilated and hypertrophied, and does not completely empty itself during systole. At the end of ventricular systole, the high tension in the pulmonic artery drives a certain amount of blood back through the closing valves into the unemptied ventricle, or the pulmonary artery may be dilated, and the cusps not quite sufficient to close the orifice; in this case the regurgitation is freer and the murmur longer, so that it may occupy nearly the whole diastole. Some think this explanation of the murmur unwarranted, as the valve is usually found competent at the autopsy, but there is a remarkable difference between the pressure of 1 in. or 2 in. of water and the pulmonic tension in a case of mitral stenosis.

Doubling of the second sound of the heart is a very common phenomenon in mitral stenosis. It is not by any means a pathognomonic sign, as some have supposed it to be, but merely an exaggerated expression of a normal doubling, which can be heard in almost every healthy heart at the end of inspiration or commencement of expiration, and, like the normal doubling, the second element of the double sound is invariably pulmonic.

The duplication undoubtedly arises from asynchronous closure of the aortic and pulmonic semilunar valves, and this does not directly arise, as is often assumed, from variations in blood pressure in the aorta and pulmonary artery respectively, but is due to asynchronism at the completion of the left and right ventricular systoles; a relatively large quantity of blood in the ventricle, and heightened blood pressure in its artery, necessarily protract its systole, and so delay the recoil of its artery with closure of its valve. In normal doubling and in cases of mitral stenosis the right ventricle is overloaded and the resistance in the pulmonic artery is increased, hence the right ventricular systole is protracted, and the closure of the pulmonic valve occurs appreciably after that of the aortic valve. Moreover, the muscle of the right heart more closely resembles involuntary muscular fibre than that of the left, and consequently its contraction is not so brisk, but for the same reason it is more easily stimulated to contract. Doubling of the second sound is an important fact, and its interpretation in any individual case is usually very easy, if you will content yourself with the simple intelligible theory which I have enunciated. In many cases of mitral stenosis this phenomenon is absent where it might be expected to be present. This is especially apt to be the case where the right ventricle is failing, free tricuspid regurgitation taking place, or the ventricle not emptying itself during systole. Under such circumstances the right ventricular systole is not protracted beyond that of the left, and so there is no doubling.

Its absence, therefore, may be of more grave significance than its presence. We should therefore not view it as a certain sign of mitral stenosis, nor fail to recognize that lesion when that sign is wanting.

The fact that the double second sound is frequently more marked over the right ventricle than at either the pulmonic or aortic cartilages has been urged against the theory of its asynchronous origin. But the site of the greatest intensity of the normal second sound is also very variable; in at least 50 per cent. it is also loudest over the right ventricle. If the pulmonary artery is uncovered by lung, even the normal second sound appears very accentuated, and the closure of the valve may be felt as a distinct snap, but a good padding of elastic lung tissue interferes very materially with the conduction of the cardiac sounds. The mitral first sound may be well conducted to the parietes through the impulse, even when the point of impact has been entirely formed by the right ventricle; but then the second sound occurring at the beginning of diastole is apt to be absent at this point owing to the impact of the dilated right ventricle not being well sustained against the chest wall. The facts of each individual case should be examined in the light of the conditions present, and not by the theoretical considerations of the examiner. The sound, whether single or double, is best heard at the point of the chest through which it is best conducted by some solid media. Frequently, with one bell of a differential stethoscope at the aortic and the other at the pulmonic cartilage, a double second sound can be heard when only a single sound is heard at either point.

A double first sound is not an infrequent, nay, it is a common, event in mitral stenosis. It is not put down as a sign in our textbooks, nevertheless it is a fact. It is very difficult to account for this, as it must have been heard hundreds of times by every experienced auscultator. The only explanation which I can offer of this want of recognition of a matter of daily occurrence is the fact that this doubling of the first sound in mitral stenosis is often accompanied by a rolling or tumbling action of the heart which renders the sounds very complex and difficult to analyse. When the heart is working steadily there may be slight dissociation of the tricuspid and mitral first sounds, which is appreciated by the ear, but there may be not complete separation of the two elements. In these cases the right ventricle invariably initiates the contraction, and the tricuspid element comes first, but before it is completed the mitral element is heard. This *quasi* doubling, or in many cases true doubling, may be followed by a single or a double second sound. Frequently the right ventricle, which is better supplied with blood, gets so far ahead of the left that it starts contraction before the latter is half filled, and so you get a tumultuous or rolling action of the heart. There is a strong pulsation felt over the right ventricle, and this is accompanied by a loud, clear, tricuspid first sound; this wave of contraction is propagated to the left ventricle, and this is accompanied by a short, sharp, mitral first sound. If this occur very soon after the preceding effective left ventricular systole, when there is very little blood in the left ventricle, the aortic semilunar valves may not be opened, and in this way you may have twice as many cardiac contractions as pulsations at the wrist. When there is some blood in the left ventricle the semilunar valves may be opened, and you get an early abortive systole, and you may even have five or six of these small systoles shown in a sphygmogram before the lever reaches the base line. What, then, is the cause of these small pulsations in the down stroke, as the action of the heart (or rather of its right side) may be so powerful as to shake the præcordium? It is, in my opinion, undoubtedly due to the overloaded right heart trying to get rid of its extra charge of blood, and so acting in advance of the left. In the sphygmogram a strong, vigorous, pulsation, starting from the base line, corresponds to a quiet, even, synchronous systole of both ventricles; this may be followed by a tumultuous rolling and apparently forcible action of the heart, but the pulsation at the wrist may be barely perceptible to the fingers, and only recorded in the sphygmogram as an abortive systole, or, as it is nowadays called, an "extra-systole." There may be one, two, three, four, five, or six of these extra-systoles before perfect synchronism between the two ventricles is restored, and then you get a full, complete systole, or, as it

is frequently now called, a "compensatory systole." If the cardiac sounds associated with this tumultuous rolling action of the heart and with each abortive pulsation are carefully analysed, the following result will be obtained, and, for the sake of clearness of explanation, I shall at first discard the consideration of any murmur which may be present:

There will be heard a clear, short, sharp, but not very loud, first sound (which I believe to be tricuspid in origin).

This is quickly succeeded by a dull, low-toned, short sound (which I consider of mitral origin).

Then, after a short but appreciable interval, there may be a dull, feeble sound (which I ascribe to the aortic valve), and this sound may be absent or coincide with a fourth sound, by which it is quickly followed.

This last sound is the loud, accentuated pulmonic second sound.

All these phenomena are often heard over the right ventricle, close to the ventricular septum, or the double second sound may require to be analysed at the aortic and pulmonic cartilages. In these cases, when there is an auricular systolic murmur, it is usually absent during the extra-systoles, or it may occur as a slight rumbling noise between the two elements of the double first sound. When there is a mitral systolic murmur, it invariably succeeds the second element, and, like the sound, is short and feeble, as it arises from the abortive contraction of a half-filled ventricle.

The rolling action of the heart is felt over the right ventricle, but as the two ventricles again assume their synchronous action the impulse is transferred further to the left, and the first sound becomes loud, sharp, clear, and banging, quite distinct from the short, sharp, clear sound previously associated with the tricuspid valve.

The absence of the auricular systolic murmur with the extra-systoles shows that the wave of contraction is not propagated from auricle to ventricle. In 1886 I advanced the view which I had long previously held that in these cases of abortive systoles the wave of contraction is not propagated from the left auricle, which in many cases is so dilated as scarcely to contract at all, but from the right to the left ventricle. In all obstructive cardiac lesions the effect tells backwards in the course of the circulation; therefore in mitral stenosis the cavities chiefly affected are the left auricle and right ventricle, which tend to become hypertrophied and dilated. There is also engorgement of the right auricle, of all the viscera, and of the whole venous system. On the other hand, the left ventricle remains a comparatively small cavity, always provided that there is no aortic lesion nor any free mitral regurgitation, and consequently can only throw a small quantity of blood into the aorta at each systole. This small supply to the arterial system does not demand a great holding capacity, and so all the systemic arteries become contracted, and thus the arterial tree is diminished, and the arteriolar contraction raises the arterial blood pressure so the capillary velocity is increased, and, notwithstanding the venous engorgement, you do not get oedema. We have thus high pressure in both circuits, but it is relatively greater in the pulmonic circuit in proportion as the obstruction is comparatively greater and the area smaller.

Again we have a comparatively large right ventricle and a small left; the former contains more blood, and therefore tries to discharge more at each systole, but, of course, in a given time no more blood can pass through the right ventricle than that which leaves the left; therefore, the extra effort of the right is used up in maintaining high pulmonic tension, which, with the aid of the left auricle, drives the blood forcibly through the narrowed mitral orifice during diastole. The very high pulmonic pressure and overloading of the right ventricle often tends to prolong the contraction of the right ventricle beyond the short, sharp, and effective systole of the left, and thus we get asynchronism in the closure of the two arterial valves, with consequent doubling of the second sound. The large distended right ventricle does not completely empty itself during systole, and frequently the discharge is so slight that it is again quickly distended, and then initiates contraction, which is propagated to the left ventricle before it is full. This contraction may get so far ahead of the left ventricle that the systole of the latter may be induced before it contains much more blood than is sufficient to raise the aortic valve, and thus we may get one or more

abortive pulsations in the down stroke. This goes on till the right ventricle has disposed of its superfluous charge of blood, and then the rhythm may become quite regular until it is again over-distended. This over-distension of the right side, with initiation of contraction in advance of the left, in some cases takes place in a regular rhythm, so that we get the so-called *pulsus bigeminus*, *trigeminus*, etc.

On auscultation of the heart this asynchronism at the commencement of ventricular systole may be so slight that the mitral first sound becomes merged in that of the preceding tricuspid sound, and thus we only get a long first sound; or the asynchronism may be so great that we get a regular tumbling action of the heart, and there may be two first sounds with one or two second sounds for a carotid pulsation as I have before explained. This peculiar action is most easily observed when the cycles are infrequent.

The sequence of events may be briefly described as follows: Starting with a forcible contraction of the left ventricle, which is evidenced by a strong apex impulse, loud mitral first sound, strong pulse, and well-marked aortic second sound, this full discharge well fills the contracted arterial tree, keeps the arteries full between the beats, and produces a very gradual down stroke in the sphygmogram. The contraction of the right ventricle which accompanies this complete systole of the left may only partially empty its distended cavity; its first and second sounds are synchronous with those of the left side, but less pronounced. The partially emptied right ventricle is quickly recharged, initiates contraction which is propagated to the left ventricle, while the latter is only partially filled. In this case the systole of the right ventricle is more powerful, its impulse stronger, and sounds louder than those of the left. This may only occur as an occasional irregularity, or, on the other hand, the right systole may keep in advance of the left for several cardiac cycles, and you may have an equal number of beats, or so-called extra-systoles, recorded in the sphygmogram before the lever reaches the base line. What is felt in the pulse as an intermission, or an irregularity in force and rhythm, or is recorded in the sphygmogram as one or more abortive pulsations, is represented on auscultation by an irregular tumbling action of the heart, or a loud thump followed by one or more irregular rolling motions. When the mitral orifice is very much contracted, you may have a tricuspid first sound, then a mitral first sound, followed by a single second sound; or this may be resolved into aortic and pulmonic elements, for one carotid pulsation. This peculiar rhythm of the heart, with corresponding irregularity of the pulse, is increased by the lime salts, by digitalis and caffeine, and is lessened by decalcifying agents, by nitroglycerine, and atropine. It is also relieved by such agents as lessen the venous engorgement.

Although this peculiar action is very pronounced in mitral stenosis, it is by no means limited to that disease. It may arise when the innervation and balance of blood-pressure in the two sides of the heart is disturbed from any cause. It is frequently associated with dilatation of the right side of the heart, as occurs in emphysema, with fatty degeneration of the heart, and atheroma of the coronary arteries. It is not uncommon in the infiltrated or degenerated fatty hearts of elderly people affected with an acute blood poison, such as erysipelas, septicaemia, or diphtheria. It may occur in gout, either active or latent, but, as a rule, in these cases there is usually a true intermission; the whole heart comes to a standstill for one cycle. In a case of Stokes-Adams disease, which I published in the *BRITISH MEDICAL JOURNAL* in 1906, when the patient took a very deep breath and held his chest expanded, the frequency of the contractions of the right side of the heart was increased, but after a couple of beats the left ventricle came to a standstill and an epileptic seizure was induced; this continued until the large intrapulmonary vascular cavity was repleted. In many cases the peculiar rhythm arises from the fact that the right side of the heart is usually more susceptible to stimuli than the left.

It is not sufficiently recognized that the heart is not a single organ, but two organs—each of which has got its own definite work to perform—linked together for mutual assistance in cases of stress or difficulty.

All parts of the heart can be excited to contraction by various stimuli, except during the refractory period; but the right auricle is the most sensitive part of the heart, and responds to stimuli for some hours after the rest of the heart has become quiescent in death. The two auricles are intimately linked together by a community of muscular fibre, and, although the wave of contraction may, and I presume usually does, commence in the right auricle, it is quickly propagated to the left, and consequently their contractions are simultaneous. When the auricles have driven a sufficient amount of blood into the ventricles to raise the diastolic pressure and stimulate contraction the ventricular systole begins, and it is rapidly propagated over both ventricles. The right ventricle is usually more sensitive than the left, or is better supplied with blood, as when you get doubling of the first sound the first element is almost invariably associated with the right ventricle. Although the right ventricle usually initiates ventricular contraction, it is often slower in completing its work than the more powerful left ventricle, because when you get doubling of the second sound the final element is frequently pulmonic. In Müller's experiment and in cases of *pulsus paradoxus* the systole of the left ventricle may be delayed or abolished for one or more beats, owing to defect in the diastolic tension. All parts of the heart act rhythmically; but even in perfect health the rhythm is constantly liable to considerable variations, which are readily detected if you will take the trouble to measure the various periods of activity and rest, not in fifths of a second, but in fiftieths or hundredths of a second.

The length of ventricular systole depends on the amount of blood to be driven, the power of the ventricle to drive it, and the resistance in front. If, then, the commencement of systole depends on distension, and its length on very varying factors, it would be very strange if the two sides of the heart were incapable of acting to some extent independently. When the balance of blood pressure in the two sides of the heart is disturbed, it would be a very extraordinary provision in Nature if one ventricle had to wait on the other, or prolong its contraction, not in accordance with the work it had got to do, but in accordance with the necessity of its fellow. Although in mitral stenosis the right ventricle invariably initiates the contraction, yet in many other conditions the left ventricle acts in advance.

[Sir James Barr exhibited numerous tracings showing extra-systoles in mitral stenosis and other cardiac affections, and also the effects of respiration on the circulation.]

These views on the myogenic function of the heart, and on the production of extra-systoles are not those which are generally accepted in the present day. If you wish to get up-to-date information on the subject, I can strongly recommend you to Dr. James Mackenzie and Professor Wenckebach. These are very able men and very careful observers, whose writings will repay perusal whether you agree with them or not. Their facts are, as facts always are, extremely valuable, but I do not wish you to accept the superstructure which they have raised on these facts without due inquiry. They have already too many disciples who have swallowed everything, and often belch forth the work as if it were their own, without, in my opinion, due acknowledgement. One recent writer even produces Wenckebach's trotting horse to illustrate the myogenic function of the heart, and the rider to represent the control of the nervous system. It is really too bad of Wenckebach to give us such crude similes, but when his disciples trot them out it becomes rather more than a joke. From the physiological side there have been numerous writers, but personally I prefer the work of Gaskell, because he makes no attempt to draw deductions which are not warranted by his facts. The myogenic function as given by Wenckebach and Mackenzie may be briefly stated as follows:

The cells of the cardiac muscle possess not only the properties of *excitability* and *contractility* which they have in common with voluntary muscles, but also those of *stimulus production* and *stimulus conduction*.

All the muscle cells of the heart are supposed to possess the property or function of manufacturing a stimulus to contraction, but this function exists in a special degree at the junction of the great veins with the auricle, or at a point which has been described and designated by Keith

as the sino-auricular node. As this stimulus, whatever it may be, is most readily produced and in greatest quantity at the sinus or sino-auricular node, the time of cardiac contraction is set there. From this point the stimulus is conducted over both auricles, and in its wake there follows the muscular contraction. From the auricle it is conducted along the bundle of His to the ventricles, and here the propagation is slower. According to Mackenzie the *a-c* interval, which includes the contraction of the auricle, the propagation of the stimulus along the auriculo-ventricular bundle, and the presphygmic period of the ventricular contraction, occupies in normal hearts about one-fifth of a second. It is supposed that the period occupied by the first and third events is fairly constant, but the transmission of the stimulus along the bundle of His is very variable, as sometimes the *a-c* period occupies two-fifths of a second. When the stimulus reaches the ventricles it is conducted along the muscle cells and rapidly followed by the ventricular wave of contraction. The muscular contraction is supposed to destroy the stimulus material, and the cells immediately start to manufacture a fresh supply, and by the time the refractory period is over this is ready for future use. When there is any block or interference with the orderly progression of this stimulus wave from the great veins to the auricles and ventricles then any other part of the heart may start a rhythm of its own, and hence extra-systoles arise.

Dr. Mackenzie holds that when the ventricle takes on its own rhythm the systoles are fewer than those arising from a propagation of the sinus or auricular rhythm, hence on some occasions the auricles and ventricles may be contracting simultaneously. It is also held that when an extra-systole occurs, whether it arise from the auricle or ventricle, it renders the muscle refractory and incapable of responding to the ordinary physiological stimulus when it arrives from the sino-auricular node. Consequently we get a long compensatory pause after the extra-systole, and after this long rest the ventricle readily responds to the second physiological stimulus, and we then get a large compensatory beat. As this physiological stimulus is supposed to be given out in a regular rhythmical manner it is necessary to assume that the time occupied by the last physiological beat and extra-systole up to the compensatory systole should be equivalent to two pulse periods, but all the observers hitherto have never been able to stretch the time out so long, hence it is assumed by way of explanation that during the long rest the muscle cells become charged with stimulus material, and their excitability is increased, and so the muscular contraction occurs a little too soon. In many cases you may have a good many extra-systoles between the physiological beats, and then the pulse periods are made to fit in the same way. The bundle of His, which is supposed to transmit the physiological stimulus from the auricles to the ventricles, seems to be of a peculiar pale, muscular constitution, or according to some a neuro-muscular band, consisting largely of sarco-plasm enclosed in a fibrous sheath and almost devoid of striation, and according to Retzer is 18 mm. long, 2.5 mm. wide, and 1.5 mm. thick.

This theory is very nice and plausible, and deserves to be true, but like a good many other theories, it has not been considered necessary to establish the truth of the premisses; not one scintilla of evidence has ever been adduced to show that the muscle cells, or any node or set of cells, generate any stimulus which excites contraction, and there is no information as to the nature of the stimulus. I said in 1906, and I say still,

that the so-called myogenic stimulus, or the production of a stimulus of contraction as a function of the cardiac muscle is, so far as I know, purely an inference, possibly a figment of the imagination which exists in the brains of certain writers rather than in the cardiac muscle. Of course there may be such a stimulus, but before believing in it I should like to know what it is. If it were a salt of potassium, or sodium, or calcium, or an alkaloid like strychnine, or some difference in electrical potential, we might form some conception of its nature and action.

Regarding the propagation of the stimulus there is no evidence, but it is assumed that it does travel and that often it is very much delayed in its transmission along the bundle of His; often taking more than one-fifth of a second to travel 18 mm., whereas, according to Leonard Hill,

the rate of propagation of the contraction wave in the heart is so fast, reaching 5 metres a second or more, that, for all practical purposes, we may say that the contraction of the whole ventricle is synchronous.

The necessity for this theory seems to have arisen in the brains of certain individuals from the fact that the hearts of the tortoise, frog, etc., go on beating in a rhythmical manner when removed from the body, and quite free from blood, but I fail to see what that has got to do with the more highly specialized function of the mammalian heart. The heart of the tortoise possesses the function of rhythmic contraction in a very high degree, and all muscular tissue possesses it to some extent, a clonus can frequently be established in the voluntary muscle. In a venous tracing, which I show, there is a regular series of rhythmic waves during the diastolic periods which might be readily mistaken for auricular beats, but which are really due to the involuntary rhythmic impulses of the hand of the individual who was holding the receiver on the vein; in trying to keep the pressure equal on the vein a regular rhythmic contraction was set up in the hand, and this was overcome by the systole and again reappeared during diastole.

I have seen some of Sherrington's experiments on the isolated mammalian heart which he kept beating for hours under the influence of nutritive fluid supplied under a certain pressure through the aorta and coronary arteries. The heart contracted quite rhythmically, and after several systoles there regularly occurred an extra powerful systole of the right ventricle to dispose of the accumulated fluid which had been returned by the cardiac veins to the right auricle, and thus raised the diastolic tension in the right ventricle. If he had depended on any imaginary contraction stimulus to be generated and propagated, rather than on the pressure in the coronary arteries, the heart would have quickly come to a standstill. The living cardiac muscle is irritable and contractile, and can be made to contract by any stimulus, mechanical, chemical, or electrical, but the mammalian heart will only *continue* to beat rhythmically under the stimulus of a certain diastolic tension in its cavities and in the coronary vessels. The right side of the heart is more excitable than the left, and responds to a lower pressure.

The popular myogenic theory also presupposes a regular rhythmic discharge of stimulus material, hence in a normal heart there should be perfect synchronism between the two sides, and the pulse periods should be equal, whereas we know that in a healthy heart there is a doubling of both sounds and great variations in the systolic and diastolic periods with every deep respiration. This theory tends nowhere but to the grave, whereas if you believe that the rhythmic contraction of the heart is maintained by the diastolic tension, you can often save lives by putting your theory into practice.

Many deaths from syncope could be averted by simply hanging the individual up by the feet. This has been long known in chloroform syncope, but it should be firmly inculcated in every ambulance course. Some of my earliest experiments in this direction were conducted before there was any Vivisection Act. After the apparent death of a dog from chloroform, he was resuscitated by hanging him up by the hind legs. In this way you can quickly raise the tension in the right side of the heart, and when it starts to work the left is very likely to follow suit.

The Character of the First Sound in Mitral Stenosis.

The first sound is unusually loud, clear, sharp, abrupt, and banging or thumping. It may be described as a thud, resembling the accentuated pulmonic second sound, only nearly twice its length. Certain writers, thinking that the mitral valve is not in a condition to generate sound, concluded that this more or less characteristic sound is produced by the tricuspid valve. It would have been well if they had made certain of their premisses before arriving at such a hasty generalization. The valve segments are usually in very good condition for generating sound. From the insertion of the chordae tendineae over the greater part of the cusps often the whole valve is readily rendered *taut* with the exception of the thickened and rigid orifice which may permit of free regurgitation. In many cases the valve is so puckered and contracted as merely to form a transverse septum, and in such cases the booming first sound is wanting. When the first sound is duplicated, the first

clear, short, and sharp element of tricuspid origin is very different from the loud booming first sound heard during the quiet action of the same heart. The character of the murmur also affords valuable evidence as to the nature of the segments and the orifice. When the orifice is rough and thick, and the auricular contraction vigorous, you may get a rough purring presystolic thrill felt at the apex.

The Pulse.

The pulse is very variable. When the compensation of the right ventricle is well maintained, then the pulse is infrequent, slow, small and firm, and fairly regular. When the mitral orifice is very much contracted it becomes very small, infrequent, weak, and irregular, both in force and rhythm, with numerous interpolated systoles. When the right ventricle is much dilated, failing in power and free regurgitation through the tricuspid orifice, then the pulse becomes frequent, quick, small, weak and very irregular in force and rhythm. Interpolated pulsations in the down-stroke of the sphygmogram are present in all case of marked stenosis. These pulsations represent systoles and never occur before the aortic notch in the primary or subsequent pulsations. The left ventricle contracts on a small quantity of blood which may be barely sufficient to raise the aortic valve, thus producing a very abortive pulsation in the down stroke, or it may be enough to raise the lever of the sphygmograph to its normal height and maintain the ordinary pressure in the arteries. You may have even five or six of these pulsations recorded in the sphygmogram before the lever reaches the base line. At other times the beats may be perfectly uniform and regular for a long period.

Condition of the Lungs.

As a result of the chronic overloading, with heightened pressure in the pulmonary circuit, we get increased cell proliferation and diapedesis of the blood corpuscles, giving rise to the condition termed brown induration. In some severe cases the lung tissue becomes quite tough and leathery.

There is also usually bronchial catarrh, and not infrequently hæmoptysis. These lung changes give rise eventually to complementary emphysema. The lung symptoms frequently become so prominent as to obtrude themselves on the attention, and obscure the underlying and primary mitral affection.

Congestion and Collapse of Pulmonic Lobules.

In the majority of cases of mitral stenosis, if you carefully percuss the back of the chest, especially after the patient has been for some time in the dorsal decubitus, you will find small, circular, and oval areas from about the size of a shilling to that of a crown-piece, of comparative dullness. Over these areas the vesicular murmur is defective, the breath sounds rather harsh and slightly tubular, and frequently inspiration is accompanied by a few crepitant râles, and the heart sounds are often clearly conveyed. These little areas of dullness arise from congestion of lobular tracts of the pulmonic vessels, and partial collapse of the air cells; the blood is retained a long time in the pulmonic vessels, some of the aerating space is not required, and the air cells are encroached on by the overloaded intrapulmonary vascular cavity. The dullness is never absolute, and the areas are apt to vary from day to day, some clearing up, and others becoming established; they clear up when the patient is moving about, taking deep inspirations, and when friction has been applied to the back. This sign I discovered over thirty years ago, and it is one to which I attach considerable importance. The percussion note is only relatively dull, and it is best elicited by delicate percussion on the pleximeter; there should be no interference with the vibration of the chest walls.

The Liver and Spleen.

The liver is passively congested, especially when there is failure of the right ventricle, and the whole venous system is engorged. The hepatic dullness may extend below the level of the umbilicus, but the spleen is not usually much enlarged.

The Veins of the Neck.

There is frequently visible pulsation in the veins of the neck, especially when the patient is recumbent, and this

may be either auricular or ventricular in rhythm, or both. In tricuspid stenosis the tension in the veins of the neck is much higher than in mitral stenosis alone. In tricuspid stenosis the veins of the heart are much dilated, and those in the substance of the ventricles become like large sinuses.

Dropsy.

Dropsy does not occur until there is failure of the right ventricle, and, unlike that in mitral regurgitation, it frequently begins as an ascites. When it starts in the lower extremities it is due to failure in the left ventricle with fall in the arterial blood pressure rather than to any venous engorgement. Patients suffering from tricuspid stenosis are particularly liable to hydrothorax when dropsy sets in, owing to the obstruction to the vena azygos.

The Size of the Orifice.

I am in the habit of weighing all the factors in each case, and then mentally estimating the size of the orifice. Usually at the autopsy my estimates are pretty near the mark. The estimated measurement which I generally employ are the size of a lead pencil, the tip of my little finger, my little, ring, middle or fore finger, my thumb, or two fingers.

Thrombosis and Embolism.

Thrombi are not infrequently formed in the left auricle, and are readily carried to the brain, spleen, or kidneys. The left middle cerebral artery is a common site of a plug, and then we get aphasia and right hemiplegia. The usually soft and unorganized nature of the embolus renders treatment very successful. All lime salts should be removed from the diet, decalcifying agents and strong ammonia freely used.

The Lime Salts.

The calcium ions are usually in excess in the blood and in the muscular tissue, largely owing to milk forming a staple article of diet. It is unfortunate that the ideas of a large number of medical men as to suitable diets for invalids should be restricted to milk and the numerous abominable milk foods found on the market. In fact, some men's ideas are so fixed that you might almost think they were set in plaster-of-Paris. For the brains of such I would like to prescribe a long course of decalcification. The calcium ions, in my opinion, largely contribute to the evolution of mitral stenosis; they raise the blood pressure by increasing the tone and contraction of the smaller arteries, and by augmenting the viscosity of the blood. At one time I thought the heightened arterial blood pressure was due to arteriolar contraction, but I am now quite willing to give a fair share of the increase to the viscosity of the blood, as I find that the arterial blood pressure can be rapidly and permanently lowered by the free use of decalcifying agents. As the left ventricle has more work to do and has more muscular tissue than the right, it gets a larger supply of lime; its muscular tissue and the muscoli papillares get hypertrophied. The violent collision of the mitral cusps leads to cell proliferation, and the large supply of calcium ions contribute in no small measure to the formation of fibrous tissue, and the cementing together of the edges of the valve. When patches of atheroma have taken place anywhere, the abundance of lime salts are readily deposited in the form of calcium soaps. Dr. Blair Bell has shown "that ordinary fibrous, especially scar tissue, is relatively exceedingly rich in calcium salts."

The calcium ions increase the force of the muscular contraction but diminish muscular irritability; hence the left ventricle often becomes much less responsive than the right, and in this way the calcium ions contribute to the production of the peculiar cardiac rhythm which I have before described. The conclusions of Loeb as to the effect of various ions in muscular contraction are given by Wenckebach as follows:

1. There are certain ions—for example, Na, Cl, Li, Br, I, and others—which (in solution under a pressure of 4.91 atmospheres) are capable of producing rhythmical contractions in muscles. These ions do not produce such contractions by increasing excitability, because (1) the contractions continue when the excitability is diminished; and (2) they do not take place in solutions of non-conductors (for example, glycerine, sugar) at the same osmotic pressure, even when the excitability is normal. It is more natural to think that these contractions are due to definite chemical combinations which these ions form in the muscle.

2. There are ions which inhibit the rhythmical contraction of normal muscle fibres—for example, Ca, K, Mg, Bi, Ba, Co, Mn. The inhibitory action of Cl, K, and probably of all the other ions mentioned here, does not depend on a reduction of the excitability. For on adding a little CaCl_2 to some physiological salt solution the contractions are inhibited, while the excitability of the muscle is less impaired and lasts longer than it does in physiological salt solution, when the rhythmical contractions occur. It is more natural to think that the chemical combination which the ions Ca and K form in the muscle renders its rhythmical contraction more difficult or impossible.

3. Hydroxyl or hydrogen ions accelerate the production of rhythmical contractions when they are added in sufficient dilution to solutions of the ions that excite contractions, as enumerated in 1. But when they are put into solutions of non-conductors or inhibitory ions they do not have the same effect. They have, therefore, a catalytic action in the production of rhythmical contractions, but are unable of themselves to produce them.

4. From the very scanty material that is yet available it seems that only ions, and not non-conductors, have the power of setting up rhythmical contractions in voluntary muscle.

5. The laws regulating the periodic action of the ventricle appear to be similar to those that have been given here for striated muscle.

6. In all experiments that have been described here it is the muscle substance itself that sets up this rhythmical action, since periodic contractions cannot be started from either the nerves or spinal cord through the solutions mentioned in 1.

The human heart requires very much less pressure than that stated by Loeb for involuntary muscle to maintain its rhythmic contraction. The ordinary atmospheric pressure or less is sufficient for the right auricle, a little more than an atmosphere for the right ventricle, perhaps a little more still for the left auricle, and often considerably more for the left ventricle. Large hypertrophied and degenerate hearts require high diastolic pressure to maintain their rhythmic contraction; hence in such cases it is not wise to attempt to reduce the arterial blood pressure very low, because if syncope do occur it is very difficult to get sufficient pressure up to start the heart again. The actions of calcium and of potassium, stated by Loeb to be inhibitory agents, are scarcely comparable, as the former increases the force of the muscular contraction and delays dilatation, while the latter has a paralysing effect on contraction, but hastens dilatation. Sydney Ringer long ago showed that the salts of calcium and potassium were antagonistic both in physiological and toxic doses, but in their antagonism their actions were complementary in maintaining the rhythmic contractions of the heart. I reproduce some of Blair Bell's tracings of the effects of calcium chloride on the circulation of the blood. The first tracing (Fig. 1) shows the rapid effects of a lethal dose, the heart remaining firmly contracted in systole.

The following is a very interesting case of dissociation of the action of the two sides of the heart, or what is called hemisystole. This woman had fallen into the hands of the Philistines, I mean the surgeons, and had the following operations—not all at one sitting, but at least on half a dozen occasions—by four different surgeons during the last fifteen years: Cured two or three times, both ovaries and tubes removed, several uterine fibroids, the appendix, hysterectomy, and adhesions from previous operations too numerous to count. It would seem that the only thing of importance which was not removed was the pain from which she suffered, and for which in vain she sought relief. She might have appropriately said in the language of Byron:

Count o'er the joys thine hours have seen,
Count o'er thy days from anguish free,
And know, whatever thou hast been,
'Tis something better not to be.

M. L., aged 41, admitted to the Royal Infirmary under my care August 6th, 1908, complaining of severe pain in the back and abdomen. Her previous history has been briefly recorded above; she still suffers every second week from what she calls a "very bad period pain," which lasts for a week, and in the intervening week the pain is somewhat easier, but does not cease. It is with the condition of the heart that we are here chiefly concerned. The following note was dictated by myself on August 10th.

The cardiac area is enlarged in all directions, and the deep area extends 2 in. to the right and $5\frac{1}{2}$ in. to the left of the mesial line. The apex beat is somewhat diffuse in the fourth and fifth interspaces, and there is also a marked heaving pulsation over the conus arteriosus. The action is very tumultuous and very variable, but the following represents a series of events. In the suprasternal notch there is a strong pulsation which seems to be a compound of venous and carotid pulsations.

This occurs about 48 times in the minute and corresponds to the pulse at the wrist and the impulse at the apex. Between the large pulsations there occur both in the internal and external jugular veins sometimes one and sometimes two pulsations. At the apex, the beats occur in pairs, first a large strong pulsation rapidly followed by a weak beat. Over the conus arteriosus there are usually two weak beats between the strong heaving impulses. At the apex there is a loud, thumping first sound, followed by a double first sound. Over the right ventricle the first sounds are more uniform, but the first of a series is loud and clear; this is generally followed by a double first sound, and then a low-pitched single first sound. Over the conus arteriosus a similar condition to that over the right ventricle. At the pulmonic cartilage there are over 100 second sounds in the minute, while at the aortic cartilage the number of second sounds does not exceed 48.

Dr. Pantland Hick had heard on one or more previous occasions a definite presystolic murmur preceding the first sound of each series, and he drew my attention to the loud, banging character of this first sound, which, I agreed with him, indicated thickening of the mitral cusps and hypertrophy of the muscular papillares, but from other evidence I did not think that there was much, if any, mitral stenosis. Her pulse at the wrist had been down to 32 in the minute. Arterial blood pressure, diastolic 160 mm. and systolic 240 mm. of mercury. Urine acid, specific gravity 1026, a slight trace of albumen, no sugar, no blood. She was also suffering from mucous colitis.

From a general survey of the case, and an examination of her capillary circulation, I came to the conclusion that the peculiar cardiac rhythm was due to excess of calcium ions in the blood, though I knew that her blood had been examined on previous occasions by Dr. Blair Bell, and the calcium index, like that of most neurasthenics, found very low. Her blood was examined by Dr. Blair Bell's method, on August 12th, at 11 a.m., by Dr. Gerrard, who found the calcium index 1.06, and on August 15th at midday by Dr. Pantland Hick, who found the index 1.1. This does not indicate a very excessive amount of calcium in the circulation, but still I thought it much too high for her, and accordingly the lime salts were cut out of her diet, and she was placed on a mixture of phosphoric acid and nitroglycerine.

On August 21st I took several cardiographic and venous tracings. The beats at the apex were then usually occurring in pairs for one pulse at the wrist, and during the same period there were two or three pulsations in the veins of the neck. On the tracing of the internal jugular there are a large number of extra waves due to the rhythmic impulses of the hand which held the receiving tambour.

September 4th. Pain in the abdomen, very severe at times, and worse on the bowels being moved. Colon is contracted and hard. She is getting a wineglassful of olive oil at bedtime, heart very steady at present, beating about twice that of the pulse.

September 14th. Colon not so contracted, but pain still severe. She complained of severe headache to-day, which I ascribed to the loss of lime salts, and I ordered her some strontium lactate as a substitute. At 4 p.m. to-day Dr. Pantland Hick found her calcium index 0.5.

September 21st. Heart reported not so steady this morning, but the cardiogram taken in the afternoon showed a great improvement on the previous record. Bowels still constipated—only kept regular by frequent doses of salines. The whole colon feels firm and contracted.

September 22nd. She had four stumps removed to-day, extracted under gas.

September 30th. Dr. Gerrard noted pain not so severe, and patient feels better. Heart very steady and sounds good. Pulse regular, and corresponds with every heart beat.

October 6th. She was up to be weighed in the morning, and she stated that she was feeling better. The nurse, on going to the bed a quarter of an hour later, found her cyanotic and dead. I had not seen her for about ten days before death, as I had been from home. When I was at the infirmary on October 4th she was not in the ward, and I was informed that she was better and out in the grounds.

The *post-mortem* examination was made by Dr. E. E. Glynn twenty-four hours later. The following is abstracted from his notes:

Lungs: A few old scars and adhesions at the apices, but no active tuberculosis. Heart: $14\frac{1}{2}$ oz., auricles normal. Right ventricle slightly hypertrophied and dilated; valves normal. Left ventricle hypertrophied and cavity smaller than right; muscular papillares thick; mitral orifice admits two fingers, mitral cusps thickened, and a hard, calcareous nodule about the size of a pea in the posterior cusp. Aortic valves normal. Coronary arteries normal. Large intestine dotted over with small white nodules, apparently lymphoid. Kidneys cyanosed, but otherwise normal. The section of large intestine shows intense auto-digestion with here and there patches of blood pigment, indicating previous prolonged congestion. At one end is a large collection of lymphoid cells, the cause of the little white nodules. A section of the heart muscle stained with osmic acid showed no evidence of fatty degeneration.

Dr. Pantland Hick took 5 grams of the muscle of the right and left ventricles respectively, and macerated each in 5 c.cm. of deci-normal hydrochloric acid. He then examined for calcium according to Blair Bell's method, and he found that from the right ventricle gave an index of 0.3 and that from the left 0.7. Even after the autopsy it is difficult to explain why

Fig. 1.—Effect of calcium chloride (1 c.cm. of a solution of 0.5 gr. in 1 c.cm.) upon the heart.

Fig. 2.—Effect of CaCl (0.5 gr. in 1 c.cm.) upon the heart. First injection, of 0.05 c.cm.

Fig. 3.—Same solution, second injection, of 0.18 c.cm.

Fig. 4.—Same solution, third injection, of 0.6 c.cm.

Fig. 6.—Fourth injection (continued).

Fig. 5.—Same solution, fourth injection, of 0.9 c.cm.

Fig. 7.—Fourth injection (completed).

The above tracings were taken with a cannula in the carotid artery of the rabbit, and the injections were made into the femoral vein.

the heart should have suddenly stopped in diastole, but it is interesting to note the greater calcium content in the left ventricle than in the right.

[The treatment of mitral stenosis was also dealt with, but as this address was very long Sir James Barr has reserved that portion of it for publication on a future occasion.]

A Lecture

ON THE

OCCURRENCE OF HEART-BLOCK IN MAN AND ITS CAUSATION.

DELIVERED AT THE LONDON HOSPITAL MEDICAL SCHOOL
ON NOVEMBER 13TH, 1908,

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[In the opening remarks it was assumed that the audience was aware of the evidence for the myogenic theory in the lower and cold-blooded vertebrates, that the heart beats have their origin near the mouths of the great veins and that the contraction passes as a conducted wave from sinus to auricle and auricle to ventricle.]

We may proceed at the present time to a consideration of certain general propositions which have an intimate bearing upon clinical work, and to a discussion of the experimental and clinical evidence upon which the modern view is based, that in mammals the auriculo-ventricular bundle is the path of impulse conduction between auricle and ventricle. It will be obvious that, in demonstrating that the auriculo-ventricular bundle is the means of stimulus transmission, we shall not only prove that this bundle, already shown to be morphologically identical with the corresponding bundle in the cold-blooded heart, has also identical physiological functions with these structures, but shall at the same time strengthen the position of the myogenic theory as a whole.

THE EVIDENCE FOR CONDUCTION BY MUSCULAR CONTINUITY IN MAMMALIA.

The fact that dissociation of the usual co-ordinate sequence of contraction in the chambers of the mammalian heart can occur has been known for many centuries, though the cause of it remained for a long while obscure. Harvey, in his essay on the movements of the heart, stated that he observed the prolongation of the interval between auricular and ventricular systole which occurs in the dying heart, and noted an occasional ventricular response following upon several auricular contractions under similar circumstances.

Two years after the publication in which His described the auriculo-ventricular bundle, the same observer attempted, in conjunction with Graufner, to destroy the connexion between auricle and ventricle in the heart of a rabbit, and apparently with success. In a preliminary communication he records the fact that complete dissociation of the auricular and ventricular rhythm was produced, though neither detail nor tracing is given.

In 1894 Humblet made further observations. He operated on the heart *in situ*, opening the right auricle, injuring the region of the bundle, and then reclosing the wound. The experiments were performed on the dog and yielded no satisfactory results. The method was discarded for that of perfusion. Using Locke's fluid and perfusing the dog's heart, he recorded the fact that cuts or cautery wounds in the neighbourhood of the bundle have no effect, but that when the bundle itself is interfered with an arrhythmia is produced. In the single tracing which is given complete dissociation appears to be demonstrated.*

The first important series of experiments were performed more than ten years later by Hering upon the perfused dog's heart. He showed that sections traversing the

bundle produced complete heart-block, and illustrated his communication by excellent tracings. He further found that no other incisions would produce a similar result. Almost simultaneously Erlanger published his first observations. In the first instance, an attempt was made to pass a ligature through the heart walls so as to include the bundle. In seven experiments performed, heart-block was obtained on one occasion only. An auriculo-ventricular clamp was then tried, a method similar to that employed by Gaskell for the cold-blooded heart. In seven experiments heart-block was obtained in two instances. The third method introduced yielded results of far greater value, and was finally adopted permanently owing to the uncertainty and unsatisfactory nature of the earlier attempts.

Erlanger devised a special clamp, one blade of which was introduced into the left ventricle and driven underneath the bundle as it lay on the septum. The clamp could be introduced and tightened without interfering with the remaining heart musculature to any extent.

The results obtained in this way have been very striking, and are in the main a complete confirmation of the similar clamp experiments of Gaskell. The following is an abstract of Erlanger's conclusions:

By compression of this bundle all stages of heart block may be obtained. These include:

- (a) An increase of the intersystolic pause.
- (b) An occasional ventricular silence.
- (c) Regularly occurring ventricular silences—for example, one silence in ten, nine, eight, seven, six, five, four, three, and two auricular beats.
- (d) A 2:1 rhythm.
- (e) A 3:1 rhythm.
- (f) Complete heart-block.

The compression of the bundle was subsequently confirmed in Erlanger's experiments by careful autopsies and histological examinations carried out by Retzer. The protocols of the seventeen experiments given in the first communication show that a successful result was obtained in sixteen cases, and that these were the experiments in which the bundle had been damaged. The work has been extended and amplified by the same writer in conjunction with Hirschfelder in researches in which operations of a similar nature were performed with similar results. Erlanger,† in conjunction with Blackman and Cullen, has also been able to damage the bundle in seven dogs, the animals surviving the operation for a varying time, and presenting various grades of partial block or permanent and complete block. The experiments are of importance in that they demonstrate the permanence of the result, and suggest the absence of other paths of conduction, which might only respond to a special call (Erlanger). They also show the possibility of producing syncope, attacks and epileptiform seizures experimentally by this means. Heart-block has been similarly produced by damage to the bundle by Tabora. Biggs has recently produced it in the rabbit by incisions.

The strict conclusion which the experiments so far cited justify is that in the particular animals investigated the conduction of impulses depends upon the integrity of a very limited tract of tissue, and upon the integrity of this tract alone. Further, this tract includes a strand of specialized tissue which has been microscopically demonstrated as being in continuity with auricular and ventricular musculature. Accordingly, we are justified in assuming that it was by this specialized bundle of fibres, and by this bundle alone, that impulses were carried from one chamber to the other in these experiments.

But are we justified in concluding that the auriculo-ventricular bundle is the sole path of conduction in all species of mammalia, and in all individuals of such species? It appears that we must regard the bundle as one of several remains of the primitive tissue of which the embryonic heart is composed, and that during the phylogenetic, if not during the ontogenetic, development of the heart, the connexion between auricles and ventricles was at one time around the whole ring. The amphibian and reptilian heart still shows such a junction. Now, it would be a very surprising fact, if such a fact should be eventually demonstrated, that complete segregation of the joining fibres has occurred in mammalia, and that such segre-

* Humblet (*Arch. Internat. d. Physiol.*, 1905-6, iii, p. 330) reports seven successful experiments upon eight dogs. *Post-mortem* confirmation of the lesions was obtained.

† In Erlanger's hands the experimental production of heart-block has become a part of the preliminary technique, a fact of very great significance, for it demonstrates the certainty of his method.