A Lecture ON SOME PROBLEMS IN CARDIAC PHYSIOLOGY.*

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[WITH SPECIAL PLATE.]

BEFORE 1892 it was impossible to explain the action of the mammalian heart on the comparatively simple lines found adequate in the case of the heart of the frog, owing to the fact that any muscular connexion between auricle and ventricle in the mammal was absolutely denied.

In 1892 it was shown that this idea was erroneous, and that muscular connexion between auricle and ventricle did as a fact exist. In the following years the details of the connexion were worked out by various observers, and the band of tissue is now familiar to every one as the auriculo-ventricular bundle.

As is often the case with new knowledge, it was some time before the existence of the auriculo-ventricular bundle was used in explaining symptoms presented by clinical cases. Within the last few years, however, its importance has been fully recognized and its presence has been generally referred to in explaining certain forms of cardiac irregularity.

Certain difficulties have arisen in connexion with these explanations from time to time, and some observers have doubted whether the case really is as simple as it appears. Clinical experience and experimental results have sometimes thrown doubt on the explanation put forward.

The difficulties are of the following kind: Cases have occurred in which—if the published records are to be trusted—an interruption of the normal rhythm of the heart has been observed, although the auriculo-ventricular bundle has proved to be intact, and cases of normal rhythm have occurred in which the bundle was subsequently found to be destroyed. Many of these difficulties may be capable of solution. Some of them, however, appear to be insoluble.

So long ago as 1892 I described¹ the existence of additional muscular connexion between the auricle and ventricle in the right lateral wall of the heart, and although this observation excited little attention at the time, it lived in the memory of some workers in cardiac physiology, and was sometimes glanced at as likely to afford a possible explanation of puzzling experimental results.

My own work on the heart was unavoidably interrupted, and it is only within the last three or four years that I have been able to return to it.

The position of the problem was then found to be as described. The presence of the auriculo-ventricular bundle was acknowledged, and it was regarded as the one and only path of muscular conduction between auricle and ventricle; and yet it was not adequate to explain the facts found clinically and experimentally.

The problems which presented themselves for solution, therefore, were the following:

1. Do there exist anatomical paths of muscular connexion between auricle and ventricle other than the auriculo-ventricular bundle?
2. If such additional paths exist, what are their number, situation, structure, and connexions?
3. Are such paths—provided they exist—capable of forming a physiological connexion between the auricle and the ventricle?

It appeared best to carry out the histological part of an investigation of this kind upon human material, as the labour involved would in any case be very great, and the whole of the work would have had to be repeated had other material been used. Such a selection made the work more difficult, as it is always troublesome to obtain human material sufficiently fresh to make good prepara-

tions. This and other difficulties were ultimately surmounted, however, and a minute examination of the whole of the auriculo-ventricular connexion was commenced.

The method adopted was as follows: The whole of the auriculo-ventricular ring of the heart was divided up into blocks, and each block in turn was cut into sections. The sections were floated on to glass, stained, mounted, and examined. The stains found most generally useful were the connective-tissue stain of Mallory, Heidenhain's iron haematoxylin, haematoxylin and safranin, and various modifications of the silver impregnation method.

Stress should be laid on the fact that in the systematic examination of the ring every section in the series was stained and examined. In some researches it has appeared that not every section, but every alternate section, or even every third or fourth, has been examined. If it is desired to exclude once for all the possibility of the existence of any extra connexion, it is obviously necessary that every section shall be examined.

Many of the original series of sections have been repeated, sometimes again and again, for the purpose of confirming, or of correcting, the earlier results.

Some of the more important conclusions are the following:

1. *Neuro-Muscular Structures.*²

There exist in the heart, in the neighbourhood of the auriculo-ventricular groove on the left side of the organ, neuro-muscular structures whose constituents are partly nervous and partly muscular, and these have connexions with the nervous structures of the groove and with the muscular tissue of auricle and of ventricle.

2. *Nodal Tissue.*³

There exists in the right lateral wall of the heart a mass of hitherto undescribed nodal tissue.

3. *Muscular Connexions.*⁴

In association with No. 2 there exists at least one muscular path between auricle and ventricle along which impulses can pass, and which is able to keep the chambers in physiological association, even when the auriculo-ventricular bundle has been cut.

4. *Paths of Physiological Conduction.*⁵

Experimental results have been obtained which completely bear out the anatomical fact of the existence of an additional muscular path between auricle and ventricle.

1. NEURO-MUSCULAR STRUCTURES.

The neuro-muscular structures can be described best by referring to the appearances which are found successively when a series of sections is examined. The structures lie in the connective tissue at the base of the auricle or ventricle. The first indication of their presence is the appearance of a few nerve fibres of small size amongst the connective tissue bundles. A few sections further on it is seen that the number of fibres has increased, and soon connective tissue is seen to be arranged round the group and to be forming a sheath for it.

As the series of sections is followed, the group of fibres becomes larger, and may attain a diameter of 170 μ . It now appears as a well-developed bundle of fibres, surrounded by a well-formed capsule of connective tissue, inside which a definite and large lymph space can often be distinguished.

If the bundle be followed further it will be seen that its constituents are changing. Instead of the nervous fibres forming the only kind of tissue present, there are now more darkly staining fibres which can be recognized as muscle, very similar to the fibres of the neighbouring auricle or ventricle. Some, however, have different characters, appear at first sight to be tubular, and prove on closer examination to be composed of more or less structureless protoplasm in the centre, with striation and indication of sarcolemma at the periphery. These fibres bear some resemblance to the fibres of Purkinje found elsewhere in the heart.

The amount of muscle in the bundle gradually increases, and may become large, whilst at some part of its course muscle fibres are given off from the bundle and become connected with the neighbouring auricular tissue. In other situations some of the nerve fibres may be seen

* Being contributions to a study of the relations which exist between the various chambers of the mammalian heart.

to leave the bundle, and, apparently, to become connected with nervous structures lying in the connective tissue of the groove. Throughout their course these bundles are provided with a rich supply of blood vessels.

The complete organ then presents itself as a spindle-shaped mass, commencing with a few nerve fibres of small size, increasing to a bundle of, perhaps, 170 μ in diameter and somewhat resembling a nerve trunk, and richly supplied with blood. Soon muscle appears amongst the nerve fibres, assumes considerable proportions, and ultimately becomes connected with neighbouring muscular masses. The nerve fibres also appear to become connected with neighbouring nervous masses. The bundle is contained in a connective sheath in which lymph spaces may be seen.

2. NODAL TISSUE.

This—the second structure to be described—is found in a different part of the heart wall. It is found in the auricular wall at a point almost on the extreme right lateral aspect of the heart, slightly towards the posterior surface. Amongst the bundles of auricular muscle in this situation will be observed a more circumscribed mass, partly surrounded by fibrous connective tissue, and in free communication with the rest of the auricular muscle.

The mass may be nearly circular in outline, or it may be distinctly olive-shaped. In either case it is seen to consist of an outer part which is similar to normal muscle, and a central portion which shows modifications of the kind usually associated with nodal tissue. The tissue stains differently, its fibres are often exceedingly fine and show rich branching, and the cross striation is not very easily seen. The blood supply is rich.

3. MUSCULAR CONNEXION.

Associated with the presence of this nodal tissue is the existence of a muscular path leading from the auricle to the ventricle and forming a channel along which impulses are able to travel. This path is found at the lower part of the mass of nodal tissue, and is formed by the passage of strands of ventricular fibres derived from two or three different layers of the ventricular wall upwards and outwards until they come into association with the tissue of the node. Thus the node is as it were interposed in the course of the muscular path between auricle and ventricle, and any impulse passing from auricle to ventricle would necessarily pass through the tissue of the node.

The need for such an arrangement is apparent when the physiological conditions are considered. For, as suggested in 1892,¹ the interposition of the fine fibres of the node with their altered character results in a slowing of the rate at which the impulse travels, and thus the pause between the auricular and the ventricular contraction is brought about.

4. EXPERIMENTAL RESULTS.

That the existence of such a channel of communication between the auricle and the ventricle will render necessary important alterations in our ideas of the mechanism of the co-ordination of the action of these chambers is obvious. For if, contrary to preconceived ideas, the auriculo-ventricular bundle is not as a matter of fact the sole muscular path along which impulses may pass from auricle to ventricle, its destruction does not necessarily involve the interruption of such passage, and clinical cases and experimental results—hitherto difficult of interpretation—become intelligible.

Direct experimental results are therefore of especial interest, and the following experiments, amongst others, have been carried out:

In the exposed heart of the mammal the bundle has been cut and electro-cardiograms have been taken subsequently. These showed that the rhythm between auricle and ventricle persisted.

The experiments performed by Flack and Leonard Hill showed that there existed in the right lateral region of the heart a mechanism which in certain circumstances was capable of affecting the auriculo-ventricular rhythm.

More recently I have carried out the following experiments, directed especially to the clearing up of the question. The method adopted was simple. In the beating heart of the mammal a thin knife was passed through the right ventricle, near the groove, and brought out in such a way as to sever completely the auricles from the ventricles

with the exception of a strip of tissue at the right side of the heart. Under these conditions it is found that beats arising spontaneously in the right auricle pass through to the ventricle, and evoke ventricular beats, and, after the heart has ceased to beat spontaneously, beats excited artificially in the auricle still pass through to the ventricle and give rise to ventricular beats.

Since under these conditions the only tissue connecting the auricle to the ventricle is the strip at the right side of the heart, and the histological part of the inquiry has already shown that an anatomical connexion exists in this situation, it is impossible to avoid the conclusion that in this right lateral auriculo-ventricular junction there exists a muscular path capable of transmitting impulses and of co-ordinating the action of the chambers of the heart.

Further, since, as has been shown, the muscular path is completed by the interposition of a mass of nodal tissue, through which the impulses must pass, it is clear that the conditions here are similar to those found in the case of the auriculo-ventricular bundle, and that the auriculo-ventricular pause may be explained on similar lines—that is, as being due to the passage of the impulse over tissue modified histologically and physiologically, with a resulting delay in conduction.

It is clear that the above considerations must exercise a considerable influence upon the nature of our explanation of cardiac action.

(The lecture was illustrated by numerous lantern slides, drawings, photographs and preparations.)

REFERENCES.

- ¹ Proceedings of the Physiological Society, 1892, No. vi (*Journal of Physiology*, vol. xiv, No. 1). *Journal of Physiology*, vol. xiv, Nos. 4 and 5.
- ² Proceedings of the Royal Society, B, vol. lxxxvii, p. 198. Proceedings of the Seventeenth International Congress of Medicine, London, 1913.
- ³ Proceedings of the Physiological Society, November 15th, 1913 (*Journal of Physiology*, vol. xlvii, Nos. 4 and 5). *Ibid.*, March 14th, 1914 (*Journal of Physiology*, vol. xlviii). *Ibid.*, June 27th, 1914.
- ⁴ Proceedings of the Physiological Society, 1892, No. vi (*Journal of Physiology*, vol. xiv, No. 1). *Journal of Physiology*, vol. xiv, Nos. 4 and 5. Proceedings of the Physiological Society, March 14th, 1914 (*Journal of Physiology*, vol. xlviii). *Ibid.*, June 27th, 1914. *Quarterly Journal of Experimental Physiology*, vol. vii, No. 2.
- ⁵ Proceedings of the Physiological Society, June 27th, 1914.

THE *Yellow Fever Bulletin*, vol. iii, No. 2, contains a paper on experiments and observations on yellow fever, by Scott Macfie and Johnston, which is of some importance because it claims to confirm, practically for the first time, observations made by Seidelin, who as long ago as 1909 described a parasite for yellow fever. Since that time Agramonte, Schilling, Guiteras and others have criticized this so-called parasite, and the general opinion amongst experts at the present day is that these bodies are not parasitic in their nature. Many of the criticisms levelled against them have laid special stress upon the very dissimilar appearance of the bodies as depicted in coloured plates, and haematologists have regarded them as well known artefacts often seen in blood examinations. Scott Macfie and Johnston, who both belong to the West African Medical Staff, and worked at the Medical Research Institute, Yaba, near Lagos, S. Nigeria, go further, and claim that during the course of an epidemic of yellow fever they found bodies similar to those described by Seidelin in the blood of guinea-pigs, dogs, and rats, and propound the theory that these animals carry the parasite of yellow fever, and that man is infected from them by way of the mosquito. A careful study of their work is not convincing, and a coloured plate does not serve to remove hesitation felt in accepting so momentous a conclusion as they would draw. It seems rash to say, for example, that the bodies in Figs. 1, 7, and 14 of the coloured plate are the same bodies or in any way similar to those represented in Figs. 9 and 10, and equally does this statement apply to the bodies found in the animal's blood. Figs. 20, 25, and 39 may be and possibly are piroplasmata, but it is difficult to see how they can be held to have any connexion with, for example, Fig. 35, or with the bodies depicted as coming from the human cases. As regards the animal's blood, bodies similar to some of those depicted may be seen in guinea-pigs that have never been out of England. Many more control experiments appear to be necessary, and before the results can be accepted they must be confirmed by competent protozoologists or helminthologists in England or the States. As already said, those who have most closely studied the bodies described by Seidelin do not consider that they are parasitic in nature.

Fig. 1.—*Auriculo-ventricular Junction.* (Heart of adult man.) Shows auriculo-ventricular junction at position G of diagram (left side of heart). The neuro-muscular structure appears as a cylindrical body enclosed in a connective tissue sheath. It has been cut transversely. The darker portions at the upper part of the bundle are muscular fibres. 1, Left auricle; 2, cavity of left auricle; 3, neuro-muscular structure; 4, valve; 5, left ventricle. $\times 17$.

Fig. 2.—*Neuro-muscular Structure.* (Heart of adult man.) Neuro-muscular structure from position G in diagram (left side of heart). The cylindrical body is seen here under a higher magnification, and its constituent parts are more distinct. The darker portions towards the periphery are muscular tissue, some of the fibres being cut transversely and some longitudinally. The nervous tissue is situated towards the centre of the bundle. 1, Connective tissue; 2, muscular fibres; 3, connective tissue sheath. $\times 174$.

Fig. 3.—*Muscular Fibres of Neuro-muscular Structure.* (Heart of adult man.) Section taken from position G in the diagram. The muscular fibres of the neuro-muscular structure are shown streaming away to become continuous with the auricular muscle. 1, Muscular fibres of auricle; 2, connective tissue sheath; 3, muscle fibres. $\times 412$.

Fig. 4.—*Arborization of Muscular Fibres.* (Heart of adult man.) The section is taken from the neighbourhood of the letter G in the diagram. It shows spiral muscular fibres terminating as an arborization in a mass of fibrous connective tissue. $\times 336$.

Fig. 5.—*Right Lateral Node.* (Heart of man.) The section is taken from the position C in the diagram (right side of heart). It shows at the upper part the muscle of the right auricle continuous with the muscular tissue of the node ("right lateral node"). The central portion of the node is composed of modified ("nodal") tissue. At the lower part of the node this modified tissue is in close association with the muscular tissue of the right ventricle. 1, Auricle; 2, node; 3, ventricle; 4, valve. $\times 50$.

Fig. 6.—*Right Lateral Auriculo-ventricular Junction.* (Heart of man.) The section is taken from the position C in the diagram (right side of the heart). At the upper part is shown the muscle of the right auricle continuous with the muscle of the right lateral node. The central part of the node is composed of modified ("nodal") tissue. The lower part of the node is continuous with fibres of the right ventricle derived from three sources, thus forming the right lateral auriculo-ventricular junction." 1, Auricle; 2, nodal tissue; 3, ventricular muscle; 4, ventricle; 5, base of valve; 6, auricular muscle. $\times 76$.

Diagram of base of heart of man, looking upwards, after the apical part of the ventricles has been cut away. Neuro-muscular structures are found at G. The right lateral auriculo-ventricular junction and node are found at C.