The auriculo-ventricular bundle of the human heart

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In a letter contributed to THE LANCET¹ one of us described the initial difficulty in finding and displaying the muscular bundle which unites the auricles and ventricles and which is now regarded as the sole pathway for the passage of the auricular wave of contraction to the ventricles. Since that letter was written we have examined over 130 human hearts and although we failed to find the bundle in some of the earlier specimens we are now confident that our failure was due to our ignorance of certain variations which may occur in its position and relationships. We are now convinced that it is an absolutely constant structure and in the properly prepared heart is big enough to be found and dissected out by knife and forceps alone; its finer structure and exact connexions require the preparation of serial microscopic sections. Through the kindness of Mr. Frank Beddard, F.R.S., prosector to the Zoological Society, and of Principal J. Y. Mackay of University College, Dundee, we have had opportunities of examining the hearts of nearly every mammalian order; in all the auriculo-ventricular bundle is present, in all it has the same position, the same connexions and distribution. We have found it in the heart of the young human foetus in the position and form described by W. His, jun., so long ago as 1893. In seven out of nine malformed human hearts we were able to dissect out the bundle by means of knife and forceps. In a case of heart-block, described by Dr. John Hay,² we found that the bundle was partially obliterated at the point at which it perforates the central fibrous body of the heart. In another case of heart-block (Dr. Otto F. F. Grünbaum's) we found the bundle involved within a gumma of the septum.

Much of our pathological material we owe to Dr. J. Mackenzie of Burnley; in two of the hearts sent by him, in which there was an irregularity in the auriculo-ventricular rhythm, we found the connecting muscular bundle largely replaced by fibrous tissue. In short, all the evidence that we have been able to collect from human and comparative anatomy, from embryology, physiology, and pathology, substantiates the theory that the muscular bundle, which perforates the central fibrous body of the heart and connects together its auricular and ventricular parts, is the sole path by which the auricular wave of contraction passes to, and is distributed within, the ventricles. We take this opportunity of clearly stating that although some of our observations are new our work is in the main but a verification of the accurate and complete monograph published recently by Tawara,³ a Japanese working in the laboratory of Professor Aschoff of Marburg.

The development of our knowledge concerning the auriculo-ventricular bundle (which, for short, may be named the *a. v.* bundle) has been one of intermittent progress. Its history may be said to begin in 1883 when Gaskell⁴ proved that the auricular impulse spread to the ventricles by passing over the muscular connexion which exists between these two parts of the heart. Gaskell's work was not regarded as inapplicable to the mammalian heart until 1893; in that year Dr. A. F. Stanley Kent⁵ published several papers showing that Gaskell's work may also be applied to the mammalian heart, for in it he found, contrary to all previous observations, that there is a muscular continuity between the auricular and ventricular segments of the heart. The muscular connexion, he said, was of two kinds: 1. By a direct continuity of the auricular and ventricular musculature at certain points; one of the points he specified was at the junction of the interauricular and interventricular septa of the heart; it is

¹A *Treatise on the Venereal Diseases of the Eye*, p. 306. An earlier writer, Thomas Howson, described a case of mild iritis in a boy, six years of age, who had suffered from infantile syphilis, and who presented "painful enlargements in the centre of both tibiae." (*Observations on the Ophthalmia Accompanying the Secondary Forms of Lues Venerea*, 1824, p. 107.) The symptoms yielded entirely to mercurial treatment.

²*Loc. cit.*, p. 164, and A *Treatise on the Diseases of the Eye*, 1844, p. 426.

³*Practical Treatise on the Diseases of the Eye*, 1854, p. 546.

⁴*Syphilis*, London, 1889, p. 239.

⁵THE LANCET, March 3rd, 1906, p. 623.

this point of muscular continuity which is now spoken of as the auriculo-ventricular bundle of His. 2. He described an intermediate continuity by means of a network of primitive fusiform muscular fibres which are imbedded in the fibrous tissue of the auriculo-ventricular rings of the heart. The second or intermediate muscular union described by Kent we have failed to find in the human heart.

In the same year as Kent applied Gaskell's conclusions to the mammalian heart in England W. His,⁶ jun., was attacking the 'problem in Germany in quite another way.' He studied the action of the embryonic heart and found that the auricular impulse passed to the ventricle before nerves had reached or were developed within the heart, and concluded that Gaskell's observation was true—the auricular impulses pass to the ventricle by a muscular connexion. He concluded therefore that it was an error to suppose that the muscular continuity between auricles and ventricles was completely broken during development in the hearts of birds and mammals, and that somewhere a strand of continuity must remain. He found that the muscular continuity disappeared everywhere except at one point—viz., at the junction of the auricular and ventricular septa, the point at which Kent had observed a connexion. Although the work of His, jun., was published some months later than Kent's, yet it must be owned that the German formed the more definite conception of his discovery. In the first place he concluded that the *a. v.* bundle was the sole path for the conduction of the auricular impulse to the ventricle; (2) he put his discovery to the proof of experiment and showed that section of the bundle produced discordance in the contraction of auricle and ventricle; and (3) he looked for and found and described the *a. v.* bundle in the heart of man. We have dealt with this small matter at some length because owing to the question of priority we in this country might feel inclined to replace the name of His by that of Kent. We believe that neither this bundle nor any other structure in the human body requires a personal name for its proper designation; it is only fair, if we assign the priority to the Englishman, that we should give the credit of the fuller discovery to the German.

Between the work of Gaskell and that of Kent and of His there intervened a resting period of about ten years. Another period of ten years passed before the

matter was again actively pursued. Writing about a case of irregularity in the rhythm of auricles and ventricles in 1899 His⁷ suggested that the lesion in such cases would be found to affect the *a. v.* bundle. Interest in the matter was undoubtedly stimulated by the exact clinical methods of Mackenzie and Wenckebach and by the experiments of Englemann. In 1904 a number of investigations were made. Retzer⁸ and Braeunig⁹ again verified its existence and investigated the nature of its composition. Max Humblet,¹⁰ Hering¹¹ of Prague, and Erlanger¹² of Baltimore (working probably at the suggestion of Osler) set to work experimentally and confirmed the discovery of His—that the *a. v.* bundle was the sole pathway for auricular impulses across the auriculo-ventricular junction; if the bundle was partially cut or slightly compressed the impulse was delayed; if completely cut or tightly compressed the impulse was arrested or blocked, leaving the auricles and ventricles to go on beating independently. But the real advance at this time came by the application of anatomical methods. It is Tawara's merit to have shown that the *a. v.* bundle described by His and seen by Kent is only the commencement of a great system which distributes the auricular impulse throughout the substance of the two ventricles. Tawara discovered that the bundle descended on the interventricular septum and was continued by ramifications to all parts of the ventricular walls; the ramifications of this system be found to be made up of Purkinje fibres, the presence of which within the heart had never been explained. In short, Tawara formulated the theory that the Purkinje system of fibres is for the conduction and distribution of the auricular impulse within the ventricles. The muscoli papillares especially receive an early and liberal supply from the main divisions of the *a. v.* bundle.

The *a. v.* system of fibres has the same type of arrangement and distribution in the hearts of all mammals, but in none is this system so clearly marked as in the heart of the calf. What is seen

⁷S. TAWARA: *Das Reizleitungssystem des Säugetierherzens*, pp. 196, 10 plates. (Gustav Fischer, Jena, 1906)

⁸Gaskell: *Journal of Physiology*, 1883, vol. iv., p. 43.

⁹Stanley Kent: *Ibid.*, 1893, vol. xiv., p. 43

¹⁰W. His, jun.: *Arbeiten aus der Medicinischen Klinik zu Leipzig*, 1893.

¹¹W. His, Jun.: *Wiener Medicinische Blätter*, No. 44, 1894; *Centralblatt für Physiologie*, No. ix., p. 469.

¹²Retzer: *Archiv für Anatomie und Physiologie (Anatomische Abtheilung)*, 1904, p. 1.

⁶THE LANCET, Jan. 20th, 1906, p. 139.

Figure 1. The right auricle and ventricle of a calf's heart exposed to show the course and connexions of the auriculo-ventricular bundle. 1. Central cartilage exposed by dissection. 2. The main bundle. 3. Auricular fibres from which the main bundle arises. 4. Right septal division. 5. Moderator band. 6. Septal cusp of the tricuspid; the upper part of this cusp and the adjacent part of the infundibular cusp have been removed. 7. Posterior group of the muscili papillares. 8. Orifice of the coronary sinus. 9. So-called "tubercle of Lower" above the orifice of the inferior vena cava. (10). 11. Orifice of the superior vena cava. 12. Septal wall of the right auricle. 13. Appendix of the right auricle. 14. Septal wall of the infundibulum. 15. Beginning of the pulmonary artery. 16. Apex of the right ventricle.

obscurely in the human heart can be seen there as in a diagram. In Fig. 1 the right chambers of the calf's heart have been laid open; the drawing is made from a heart prepared by the Kaiserling method, by far the best we know for a naked-eye examination of this system. The cartilage within the central fibrous body of the calf's heart is shown; the endocardium of the septal wall of the right auricle and the underlying muscular fibres have been removed from the area between the cartilage and the orifice of the coronary sinus to expose an outer or superficial layer of muscle fibres belonging to the auricular canal. The fibres as they reach the central cartilage terminate in a plexus of fibres. From this plexus or network of muscular fibres commences the auriculo-ventricular bundle. The muscle fibres of the bundle and of the plexus are pale red in colour—paler, much paler, than the surrounding musculature. The bundle passes along a groove, almost a canal, in the cartilage; the canal is completed by the fibrous tissue to which the base of the septal cusp of the tricuspid valve is attached. On issuing from the central cartilage the bundle

at once pierces the interventricular septum, apparently burying itself in the musculature. In the figure the bundle has been exposed by removing the overlying musculature. After a short course (one centimetre) within the upper part of the interventricular septum the a. v. bundle divides into right and left septal divisions (see Fig. 1). The right septal division passes forwards on the septal wall of the right ventricle, almost superficial in position, until it reaches the point at which the moderator band is attached to the septum. There twigs are given off to the musculature of the septum but the main continuation of the right septal division enters the moderator band. A section across the moderator band shows the Purkinje fibres in three or four bundles; these bundles are isolated from the rest of the musculature of the moderator band by well-developed connective-tissue sheaths. Through the moderator band they reach the anterior group of muscili papillares and lateral wall of the ventricle; from there extensions to the other muscili papillares are very apparent. Beneath the endocardium a fine network of Purkinje fibres can be seen throughout the ventricle.

In Fig. 1 the bifurcation of the main bundle into right and left septal divisions is shown; in Fig. 2 is depicted the distribution of the left septal division within the left ventricle of the calf's heart. The branch appears on the septal wall of the ventricle about two centimetres below the aortic orifice; just below the aortic orifice the bundle is buried beneath a thick layer of muscle (cut through in Fig. 2 to expose the bundle). This covering stratum of musculature (sub-aortic, it may be termed) is of interest, for, as will be subsequently shown, 25 per cent, of human hearts show a remnant of it. Passing down on the septal wall the left bundle branches into two or more parts, the main part descending towards the apex of the heart, but before reaching that point most of its fibres enter two or three moderator bands (see Fig. 2) by which they pass to the muscili papillares and marginal wall of the left ventricle.

It was undoubtedly a study of the calf's and of the sheep's heart that led Tawara to formulate the theory that the system of fibres just described was a conducting, not a contracting, system. Its root lies in the annular and septal fibres of the right auricle; the trunk is buried in the interventricular septum; its branches and twigs are distributed to all parts of the heart; the muscle fibres which make up the ramifications of this system (not the main

Figure 2. The left ventricle of a calf's heart exposed to show the course and distribution of the left septal division of the auriculo-ventricular bundle. 1. Left septal division appearing on the upper part of the septal wall of the left ventricle. 2. 3. The sub-aortic mass of musculature divided to show the passage of the bundle from the right side of the heart. 4. 5. Branches of the left septal division. 6. Free muscular "moderator" bands containing prolongations of the bundle. 7. Septal or mesial group of muscoli papillares; this group receives one of the free bundles. 8. Mitral valve. 9. Left auricle. 10. Aorta, laid open. 11. Non-coronary cusp of aortic valve. 12. Right coronary cusp. 13. Pulmonary artery.

bundle) are of the peculiar Purkinje type; these fibres, until they reach their terminations and join the ordinary musculature, are isolated by special fibrous sheaths. Further, when these other circumstances are taken into consideration—(1) that the systole of the ventricles is not a peristaltic contraction spreading from auricular to aortic orifices but a coördinated simultaneous contraction of the entire ventricular part of the heart; (2) that physiologists have postulated the presence of a muscular connexion between auricles and ventricles for the transmission of the auricular impulse; and (3) that the Purkinje fibres were until now of unknown significance—when all these circumstances are taken into consideration Tawara's theory commends itself to anatomists and physiologists alike

Figure 3. Dissection of a normal human heart to show the course and relationships of the auriculo-ventricular bundle. Both auricles have been removed and the septal wall of the right ventricle is exposed. 1. Central fibrous body of the heart, corresponding to the cartilage of the calf's heart (see Fig. 1). 2. Placed on the pars membranacea septi above the main bundle and below the attachment of the wall of the right auricle to the aorta. 3. Fibres of the right auricle (left in situ) from which the bundle takes its origin. 4. Septal wall of the infundibular part of the right ventricle placed above the right septal division of the bundle. 5. Great trabecula on the septal wall; part of it represents the moderator band seen in the typical mammalian heart. 6. Septal cusp of the tricuspid; its upper part has been removed; above the cut edge is seen the upper margin of the interventricular septum, along which the main bundle runs. 7. Posterior muscoli papillares. 8. Part of the coronary sinus left in situ. 9. Attachment of anterior group of muscoli papillares into which a large part of the bundle passes. 10. Base of left ventricle. 11. Mitral valve. 12. Sinus of Valsalva of non-coronary aortic cusp. 13. Sinus of Valsalva of right coronary aortic cusp. 14. Aorta. 15. Beginning of pulmonary artery.

as a satisfactory explanation of the presence and arrangement of the Purkinje system. The early and liberal supply of these fibres to the muscoli papillares is a point to be noted. So clearly marked is the conducting system in the heart of the ruminant that one marvels how its presence and its continuity with the *a. v.* bundle have escaped notice until now.

In the human heart the Purkinje system is not so clearly differentiated as in the sheep's heart but there can be no doubt, as may be seen from Fig. 3 and 4, that it is present and exactly identical in its position and arrangement. In the heart shown in Fig. 3 both auricles have been removed and the right ventricle has been laid open by the removal of its lateral wall. Part of the coronary sinus (8, Fig. 3) has been left attached to the base of the left

Figure 4. Left ventricle of the normal human heart laid open to show the distribution of the left division of the auriculo-ventricular bundle. 1. Bundle descending on the septal wall of the ventricle. 2. Remnant of sub-aortic musculature (see Fig. 2). 3. Constant bundle of musculature which partly covers fibres of the auriculo-ventricular bundle. 4, 5, 6, 7. Branches of the left division of the bundle. The marginal or anterior group of muscoli papillares are supplied from 4. 8. The posterior or mesial muscoli papillares receive prolongations from 5 and 7. 9. Anterior cusp of the mitral. 10. Apex of the left ventricle. 11. Left auriculo-ventricular orifice. 12. Left auricle. 13. Right coronary cusp of aorta. 14. Non-coronary cusp of aorta. Below 13, 14, and above 2, 3, is seen the pars membranacea septi. 15. Aorta laid open.

ventricle; some of the annular fibres of the right auricle, from which the *a. v.* bundle begins, have also been left; the main bundle is represented, for diagrammatic effect, as a hard narrow white line; it passes forwards within the lower margin of the membranous part of the septum and on the upper margin of the interventricular septum; the inner or mesial part of the septal cusp of the tricuspid valve has been removed to show the bundle in this part of its course; traced backwards the bundle is seen to perforate the central fibrous body of the heart, which in the figure is laid open so as to show the bundle joining with the fibres of the right auricle.

As the bundle is traced forwards in the membranous part of the septum it is found to separate, as in the sheep's heart, into a right and left septal division. The typical condition of the right septal division is shown in Fig. 3. It always passes down the septum at the same position—viz., at the junction of the infundibulum and sinus of the right ventricle. It is commonly buried in the musculature of the septum, often in the depth of a furrow of thickened endocardium, and passes directly to the anterior group of muscoli papillares—the same destination as in the sheep's heart. In the sheep's heart (Fig. 1) it reached these muscoli through the moderator band. The moderator band of the human heart is the wide thick septal trabecula, shown at 5 in Fig. 3, only slightly separated from the rest of the interventricular septum. This great trabecula has exactly the relationships of the moderator band of the sheep's heart; the classical description of a moderator band is applicable to the common type of mammalian heart, such as the sheep's, but certainly does not hold for the human heart.

Turning to the left side of the human heart, the left septal branch of the *a. v.* bundle will be found to be very apparent; it is seen descending as a wide sub-endocardial fillet on the septal wall of the left ventricle (Fig. 4). The membranous part of the septum is shown beneath the non-coronary and right coronary valves of the aorta (14, 13, Fig. 4). As the main *a. v.* bundle passes forwards in the lower margin of the membranous space it gives off a continual stream of fibres which pass downwards in the sub-endothelial tissue of the septum and form the fillet mentioned above. The thread-like part passing from the septum to the mesial or posterior group of muscoli papillares (Figs. 4 and 5) is almost constant. These threads may be two or three in numbers; they contain extensions of the *a. v.* bundle. The main part of the left septal division separates into two, or sometimes three, branches. The anterior of these branches passes¹³ to the anterior or lateral group of muscoli papillares; the posterior to the posterior or mesial group. These extensions to the muscoli papillares often form free or "moderator" bands, as in the heart of the sheep and ox. Besides the branches to the muscoli papillares numerous twigs go to the lateral walls of the left ventricle. In the arrangement and distribution of the

¹³Braeunig: *Ibid.* (*Physiological Supplement*), 1904, p. 1.

a. v. system there is to be seen a close resemblance between the heart of man and that of the ox.

So far we have described in a general manner the course and distribution of the *a. v.* bundle, merely touching on its relationships to other parts of the heart in a cursory manner. When we came to examine microscopically the structure of the region of the heart in which the main bundle is situated, especially when we came to deal with pathological conditions, we found it necessary to obtain a more accurate conception of the arrangement and structure of the central part of the heart than can be obtained at present from published works. We propose now to describe the structure, arrangement, and connexions of the bundle more minutely—especially its relationship to two important parts of the heart—viz., the central fibrous body and the *pars membranacea septi*.

The central fibrous body (see Figs. 3 and 5) with which the bundle is so closely related, and in which, we have found, it is most likely to become broken by disease, is a highly complex structure. First and foremost, it is the chief tendon by which the fibres of the left ventricle are yoked to the mouth of the aorta; when the left ventricle is forcing its load within the aorta it is by this structure that the resistance is mainly borne. Both cusps of the mitral valve are continued into it and the *musculi papillares*, the anterior group at least, act on it and through it on the aorta. The musculature of the interauricular septum is implanted on it. It is attached to the aorta at the fundus of the non-coronary cusp. (See Fig. 3.) It sends off four processes, two to join the right auriculo-ventricular fibrous ring and two to join the same structure on the left side. It is thus a structure continually subjected to strain, especially in cases where the blood pressure is high from disease of the arteries or of the valves; our experience so far has been to find that it is in arterial disease that the central fibrous body is most likely to become affected and with its cicatrization the bundle suffers also. Again, the central fibrous body is continuous on the one hand with the substance of the mitral valve and on the other with the septal and infundibular cusps of the tricuspid; in the heart from which Fig. 5 was drawn there were mitral stenosis and ulceration of the valves at the inner fornix of the valves. By direct spread of the inflammatory process the bundle may become affected in the central fibrous body.

The *a. v.* bundle has a most direct and intimate relationship to the central fibrous body. Many of the

Figure 5. Semi-diagrammatic representation of the central fibrous body of the heart to show its intimate connexion with the mitral valve. The auricles are cut away and the adjacent parts of the bases of the ventricle are viewed from above. 1. Central fibrous body opened out; the muscular network from which the auriculo-ventricular bundle arises is cut away; the point of perforation of a constant septal artery is shown. 2. The bundle dividing in front into right (2') and left (2'') septal divisions. 3. Base of septal cusp of tricuspid valve. 4. Upper part of the interventricular septum. 5. Base of the right ventricle. 6. Base of the left ventricle. 7. Mitral valve—there is stenosis with endocardial ulceration in the part nearest to the central fibrous body; disease is spreading towards the central fibrous body. 8. Conus arteriosus of the left ventricle from which the aorta arises. 9. Continuation of the central fibrous body into the aorta and interauricular septum. 10. Interventricular septum between the infundibulum of the right ventricle and conus arteriosus of the left. Between 9 and 10 runs the *pars membranacea septi*, here shown in section; along it runs the main auriculo-ventricular bundle.

muscular fibres of the interauricular septum end on it but the fibres that most concern us are the annular fibres of the right auricle—circular fibres surrounding the right auricle just above the base of

the septal cusp. These become applied to the central fibrous body which some of them perforate. Before perforation and during perforation they form a fine meshwork; to expose the meshwork in the central body the attachment of the septal valve of the tricuspid to that body has to be cut through. In Fig. 3 the attachment of the septal cusp to the central body has been cut through. The bundle may be then seen as an easily separated strand—from one to two millimetres wide—but very frequently it is so freely mixed with the tissue of the fibrous body that it cannot be isolated; in microscopic sections this is found to be most frequently the case. In the sheep's heart the plexus or network is very pronounced ("Knotten" Tawara names it) but in the human heart its features are not so characteristic. Yet in the human heart the *a. v.* bundle has distinctly a reticulated arrangement of fibres in and near the central fibrous body and it will be convenient to refer to it as the *a. v.* reticulum. In Fig. 5 the central fibrous body has been opened up, the muscular reticulum removed, and the *a. v.* bundle shown in front of the central fibrous body passing forwards in the pars membranacea septi. The central fibrous body is constantly perforated by a considerable artery derived from the right coronary. The point of perforation of this artery is shown in Fig. 5.

The *a. v.* bundle passes along the upper margin of the interventricular septum within the fibrous tissue of the pars membranacea septi. This structure (the pars membranacea) is roughly triangular in shape; it is commonly very extensive in hearts which have worked against a high arterial pressure. The best conception of its shape and position is obtained by examining it from the left side (Fig. 4). The base of the membranous triangle is formed by the upper margin of the interventricular septum; the posterior margin is bounded by the base of the non-coronary cusp and central fibrous body, with which the base of the mitral valve is continuous (Fig. 4). Viewed from the right side the membranous space appears rather complicated (see Fig. 3). Its triangular shape may still be recognised; the base is formed by the upper margin of the interventricular septum, the anterior margin by the right coronary cusp (Fig. 3) and the right wall of the infundibulum, the posterior boundary by the non-coronary cusp (Fig. 3, 12), and the central fibrous body. On the right aspect the pars membranacea shows three distinct parts: one in the septal wall of the right auricle (auricular part), another in the right

ventricle under the base of the septal cusp (ventricular part), and a third above both auricle and ventricle between the right coronary and non-coronary cusps (intra-cuspidate part) (see Fig. 3, between 13 and 12).

In the sheep's heart, and, indeed, in most mammalian hearts, there is no pars membranacea; the membranous septum is replaced by a mass of musculature which covers over and buries the *a. v.* bundle. Remnants of this subaortic musculature often occur in human hearts; an example is shown in Fig. 4, just covering the left septal division of the *a. v.* bundle under the right coronary cusp. In some human hearts the pars membranacea is partially or completely replaced by muscle which fills up the angle between the aortic cusps usually occupied by the pars membranacea septi. The functional significance of the subaortic musculature is unknown to us.

Between the *a. v.* bundle (as shown in Fig. 3) and the cut edge of the septal cusp is shown the upper margin of the interventricular septum; frequently this musculature rises up within the space normally occupied by the pars membranacea. In such cases the *a. v.* bundle is deflected for part of its course to the left side of the septum. We found that the bundle was so deflected in many of the earlier cases which we examined and in which we failed to detect the bundle in the course of dissection. The right septal division of the *a. v.* bundle leaves the 'main bundle' by turning sharply downwards (Fig. 3); its point of origin may be termed the genu or knee. At the genu the fibres of the *a. v.* bundle appear in part, or even entirely, to terminate in a strong tendinous mass of fibrous tissue situated at the base of the right coronary cusp of the aorta. This mass of fibrous tissue has an important relationship to the *a. v.* bundle and deserves special mention, as it appears in all microscopic preparations made to expose the bundle in this region of the heart. It is much less massive than the central fibrous body but is similar in nature and function. By it the anterior fibres of the interventricular septum are united to the aorta; in systole this tendinous structure has to withstand the tension exercised on it by the heart when forcing the blood within the aorta. The tendinous fibres of this structure unite with those of the central fibrous body along the lower margin of the pars membranacea; on these uniting fibres, as on a floor, the *a. v.* bundle passes forward. In Fig. 3 the right septal division of the *a. v.* bundle is represented as a clearly differentiated structure but in

nearly half the number of human hearts examined we were unable to follow the right septal band as a clearly differentiated continuation of the main bundle. Even in some of the hearts which were cut and examined microscopically it was only after a close search that we were able to find a strand of musculature which was clearly separated by its structure from the ordinary musculature of the septal wall.

In studying the finer structure of the *a. v.* bundle and of its ramifications in the sheep's heart two of its characters impress one—viz., (1) the character of the muscle cells of this system; and (2) the manner in which they are isolated from the ordinary musculature of the heart by sheaths of connective tissue. The network of auricular musculature in which the bundle commences is made up of peculiarly narrow muscle cells, almost fusiform in shape, united together so as to form a meshwork; the striation is less clearly marked than in the rest of the auricular fibres. The main bundle is made up of similar fusiform or narrow elongated fibres while its ramifications are made up of the peculiar Purkinje fibres—so different from the ordinary fibres of the ventricles. The Purkinje fibres are very large; the cells which compose them are pale; with the van Gieson stain they become of a straw yellow colour; only their outer stratum is striated; the great part of their cell body is undifferentiated protoplasm in which the nucleus is contained; wherever a part of this system appears in a microscopic preparation it is at once recognised. It is sometimes said that these Purkinje fibres are embryonic in character—undifferentiated cells. If by embryonic is meant that they resemble the cardiac fibres of the heart of the embryo, then nothing could be further from the truth; if by embryonic is meant the fact that only the superficial stratum of the fibres are striated—the interior being undifferentiated cell substance—then in this feature they are embryonic. But in shape and size they are not embryonic. They are cardiac fibres which have specialised in a peculiar direction; their fibrillar structure is especially distinct.

When the finer structure of the *a. v.* bundle system is examined in the human heart the peculiar features seen so clearly in the sheep's heart can be recognised but not with the same precision. The isolation of the system by sheaths of fibrous tissue is still present, especially in the first stages of the bundle within the ventricles. The structure of the auricular network (situated at, and in, the central fibrous body) from which the bundle arises, and the

main bundle itself, have the same structure as in the sheep but its ramifications are not made up of distinctly marked Purkinje fibres; it is very hard to distinguish the fibres of this system from the ordinary ventricular muscle fibres, except by reference to three features: (1) they are smaller than the usual ventricular muscle fibre; (2) they are isolated by thick fibrous sheaths; and (3) they stain less deeply than the ordinary musculature; nuclei are more numerous; large multi-nucleated fibres occur. Tawara, on the other hand, reproduces drawings of the fibres of this system of the human heart in which the characteristic features of the Purkinje system are clearly recognisable. Further and more accurate observations have convinced us that in this Tawara is right; the ramifications are made up of cells which certainly show the Purkinje characters. We found, as Tawara did, that this system does not enlarge with hypertrophy of the heart or diminish in atrophy.

From our investigations of the arrangement of the *a. v.* bundle system in malformed human hearts, in the heart of the human foetus, and in amphibian and reptilian hearts we have obtained certain facts which throw some light on its history and nature. Why should the bundle perforate the central fibrous body? The central fibrous body for the greater part is derived from the endocardial cushions of the foetal heart, especially the posterior one. Now it was on and in the posterior endocardial cushion of the turtle's heart that we found the freest communication between the auricular and ventricular musculatures; in the heart of the turtle we found a considerable bundle of musculature of the right auricular canal ending on the posterior endocardial cushion (posterior valve of the auriculo-ventricular orifice) and freely mixing at its insertion with the origin of the sub-endocardial musculature of the ventricle. If we are right in regarding the central fibrous body of the human heart as a derivative (in part at least) of the posterior endocardial cushion, then it follows¹⁴ that the muscular network found at the commencement of the *a. v.* bundle in the central fibrous body is the representative of the interdigitation of the auricular and ventricular musculatures in the reptilian heart.

We found that the *a. v.* bundle is differentiated and relatively massive in the heart of the human

¹⁴*Humblot: Archives Internationales de Physiologie, vol. I., p. 278.*

embryo of 45 millimetres long (11 weeks). In malformed hearts it was clearly derived from the circular fibres of the canal of the right auricle; it passed into the ventricle behind, and to the right of, the tissue which goes to form the central fibrous body and pars membranacea septi; on reaching the interventricular foramen it spreads out beneath the endocardium on the lower margin of that foramen and descended on both sides of the septum.

Why should the main bundle pass along the upper margin of the interventricular septum? In this position it is resting on that part of the heart which undergoes least change during the systolic changes of the heart. But there is also an embryological reason. The upper margin of the interventricular septum represents the least disturbed part of the interior of the embryonic heart. The evidence is now accumulated which shows that the interventricular septum is not developed by a process of up-growth as His supposed; its development is the result of an opposite process; the ventricles are outgrowths or bulgings of the primitive cardio tube; the septum is that part of the tube which remains between the outgrowths; hence the upper border of the septum represents the least changed part of the lumen of the embryonic heart and it is there that the *a. v.* bundle is found.

Langendorff¹⁵ has summarised recently the literature bearing on the physiology of this system, so that there is no need for us to deal with this matter. But there is one point which he omits and which we believe throws a side-light on the nature of this system—viz., the functional difference between pale and red musculature as we know it in the voluntary muscular system. The *a. v.* bundle is of the pale type, the ordinary cardiac musculature of the red. Dr. John Hay¹⁶ has demonstrated that the pale voluntary muscles conduct and contract more rapidly than the red.

With regard to the clinical importance of the bundle much has been published recently, especially in connexion with cases of Stokes-Adams disease. From the interpretations placed by Wenckebach and Mackenzie upon tracings obtained in such and similar cases it has been apparent that in most of them there exist irregularities between the auricular and ventricular rhythm. The important question is, What is the cause of such irregularity? W. His,

jun,¹⁷ writing in 1899 upon a case of the disease, opined that a lesion of the auriculo-ventricular bundle might be the cause. Recently both Hering¹⁸ and Erlanger have entered much more fully into the subject. Both believe that a lesion of the fibres of the bundle of His can in itself account for the syndrome of events in Stokes-Adams disease. Erlanger¹⁹ has come to the conclusion as the results of his observations upon a case under the treatment of Professor Osler. A comparison of these results with those of his experiments upon the dog's heart quoted above is exceedingly striking. In the case under observation he observed at different times all degrees of heart block. When the block was complete he found that the ventricles did not respond to influences presumably of vagus origin, whereas the auricles did. Both ventricles and auricles, however, were still under the influence of the accelerator nerves. With partial block the ventricular rate varied within certain limits proportionately to the auricular rate, but if these limits were exceeded the block became complete. Erlanger believes the syncopal attacks of Stokes-Adams disease to be due to the effect of the reduction of the ventricular rate upon the cerebral circulation. He found also that the general blood pressure is lower than normal when the heart block is complete. He considers a certain number of reported cases of the disease and comes to the conclusion that none has been described in which heart block might not have existed; indeed, all cases which have been studied by accurate methods show such to have been undoubtedly the case. Erlanger classes heart block, with and without syncopal attacks, as different phases of the same disease process.

Evidence has recently been forthcoming in support of the conclusion of Hering and Erlanger. Stengel²⁰ has published the result of a post-mortem examination on a case of Stokes-Adams disease. In the left side of the heart was found an atheromatous patch extending through the endocardium over the bundle of His as it passes from the auricle to the

¹⁵Hering: *Pflüger's Archiv*, vol. evili., p. 257.

¹⁶Erlanger: *Journal of Experimental Medicine*, vol. vilii., p. 8.

¹⁷*At the present time there is the utmost confusion as to the nomenclature of the cusps of the aortic valve. If the terms right coronary, left coronary (above which the right and left coronary arteries arise), and non-coronary be used this confusion will be avoided.*

¹⁸Langendorff: *Ergebnisse der Physiologie*, 1905, p. 786.

¹⁹John Hay: *Dissertation on Certain Phenomena regarding Red and Pale Muscles*. Liverpool, 1901.

²⁰W. His, jun.: *Deutsches Archiv für Klinische Medizin*, Band lxiv., p. 329.

ventricle. M. E. Schmoll²¹ of San Francisco appears also to have discovered a lesion of the bundle in a necropsy upon a case of this disease. Recent literature also testifies to the general acceptance of this fact in non-fatal cases. Rihl²² has published an account of five cases which he holds to be due either to partial or complete block as defined by Hering. Lichtheim²³ describes a case which he believes to be due to a lesion of the bundle produced by sclerosis of the coronary arteries. Leuchtweis²⁴ gives details of a case in which he diagnosed total heart block due to a lesion of the bundle. He found, as did Erlanger, that atropine did not influence the rhythm of the ventricles but caused a slight increase in auricular frequency. Finkelburg²⁶ describes a

case in which every third beat of the auricles caused the ventricles to contract. He believes this is due to some impairment of the conducting power of the bundle of His. Belski²⁶ publishes three cases of Stokes-Adams disease, two atypical and one typical. He comes to the conclusion that in each case the explanation lies in the fact that "a Stannius experiment has been performed by nature." Belski makes no reference to the bundle of His but from a careful study of his tracings and from what we now know to be the explanation of Stannius's experiment we can say that in each of these cases a lesion of the bundle of His probably existed. Whether, of course, a lesion of these fibres exists in every case of Stokes-Adams disease is still open to question. His, jun., thinks that in some cases the same phenomena can be produced by lesions of the vagi. In any case sufficient has been written here to show the great importance clinically of the auriculo-ventricular bundle.

²¹*Report of Congress for Internal Medicine, Munich, Semaine Médicale, May 9th, 1906, p. 223.*

²²*Brlanger: Loc. cit. Also Journal of Experimental Medicine, vol. vii., p. 676.*