with the best regards of the Author.

HEART.

BY

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From the Cyclopædia of Anatomy and Physiology.

LONDON:

MARCHANT, PRINTER, INGRAM-COURT.

1838.

HEART.

HEART (in anatomy). Gr. κιαρ, καρδια; Lat. *cor;* Fr. *cœur;* Germ. *Herz;* Ital. *cuore.* The movement of nutritious juices through the texture or textures of which an organized body is composed, is a fundamental law in Physiology. In proportion as the vital actions become more complex and energetic, the more a rapid and certain circulation of these fluids, which is intimately connected with this condition, becomes indispensable, and for this purpose we have a pulsatory sac or sacs, called *hearts,* superadded to the circulatory apparatus. Another invariable concomitant of this energetic manifestation of the vital phenomena is the more perfect exposure of the nutritious fluids to the atmospheric air, and this, combined with the dissimilar media in which different animals live and move, necessitates very important modifications in the number, position, and structure of these pulsatory sacs. These hearts were until lately supposed to be exclusively confined to the sanguiferous vessels, but Müller and Panizza have discovered distinct pulsating sacs placed upon the lymphatic vessels in several of the reptile tribe, and these may be considered *lymphatic hearts.*

In the lowest organized plants, as the Fungi, Algæ, &c. and in the lower classes of animals, as the Polypi, Actiniæ, and a great part of the intestinal worms, the nutritious fluids are transmitted through their substance without any distinct canals or tubes; while in the higher classes of plants, and in the Medusæ, &c. among animals, vessels are present, but these are unprovided with any pulsatory cavities. In the articulated animals generally, the vessels are still without any pulsatory cavities; but to make up for the deficiency, the dorsal vessel itself has a distinct movement of contraction and relaxation. Various pulsatory dilatations are placed upon the vascular system of the common worm *(Lumbricus terrestris);* one or two upon the vascular system of the Holothuria; and one in the Talpa cristata, where the dorsal vessel is reflected upon itself at the posterior extremity of the body to become continuous with an analogous ventral vessel; all of which may be considered as rudimentary hearts.

As we rise in the scale of animals, we find that the heart consists of two distinct portions— of a stronger and more muscular cavity called a *ventricle,* and of a weaker and less muscular cavity called an *auricle.* The latter not only serves as a kind of reservoir to the former, but also, by the contraction of its muscular fibres, drives the blood into it. This heart is placed within a sac or pericardium, and possesses valves to prevent the regurgitation of the blood from the ventricle into the auricle, and from the aorta back again into the ventricle. This may be considered as a perfect *single heart.* This single heart in some of the Mollusca and in Fishes which have a double circulation, propels the blood not only through the lungs, but also through the body. In the Batrachian Reptiles, as in the Frog, though the circulation is single, the heart becomes more complicated; for instead of a single auricle we have two, one of which receives the blood returning from the respiratory apparatus, the other receives the venous blood of the body. The pulmonic and systemic circulations are here separated as far as the auricles are concerned; but a single ventricle in which the venous and arterialized blood are intermixed, still continues to propel the sanguineous current both through the lungs and through the body. In the Ophidia or serpent tribe the heart possesses the same number of cavities as in the Batrachian Reptiles; but we have a still nearer approach to the double circulation in the presence of a rudimentary septum ventriculorum. In some of the Sauria, as the Crocodile, the ventricle is divided by partitions into distinct chambers, which nevertheless communicate freely with each other. It would appear, however, from Meckel's description, that the ventricle is divided by a complete septum into two separate and distinct chambers in the *Crocodilus lucius*. In the Mammalia and Birds, where no intermixture of the venous and arterialized blood takes place, but where all the blood sent along the aorta has been previously subjected freely to the influence of the atmospheric air, we find two distinct hearts, which in the adult have no communication with each other; one the respiratory heart for the transmission of the blood through the lungs, the other the systemic heart for the transmission of the arterialized blood through all the textures of the body. These are not placed separate from each other, as in some of the Mollusca, which with a double circulation have an aquatic respiration, but are in juxta-position, and in fact many of the muscular fibres are common to both.

Human Heart *(normal anatomy)*.

Position.—The heart in the human species is lodged within the cavity of the thorax, occupies the middle mediastinum, and is enclosed in a fibro-serous capsule called pericardium. It is placed obliquely from above downwards and from behind forwards, in front of the spine and behind the sternum. The apex is directed downwards, forwards, and to the left side, projects into the notch on the anterior margin of the left lung, and in the quiescent state of the organ corresponds to the posterior surface of the cartilage of the sixth rib. The base looks upwards, backwards, and to the right side; is separated from the anterior part of the spine by the pericardium, œsophagus, aorta, and other parts which lie in the posterior mediastinum; and extends from about the fourth to the eighth dorsal vertebra. Its right margin rests upon the upper surface of the cordiform tendon of the diaphragm, by which it is separated from the stomach and liver; its left margin, which is more vertical, looks upwards and to the left side, and occupies an excavation on the inner surface of the left lung. Its posterior or flat surface rests partly upon the cordiform tendon of the diaphragm, having the pericardium interposed between them, and partly upon the inner concave surface of the left lung.* Its position corresponds to the union of the superior third of the body with the two inferior thirds. The lungs overlap the lateral, and part (rarely the whole) of the anterior portion of the heart, leaving only in general about an inch and a half or two square inches of the anterior surface of the right ventricle uncovered by the lung. It is of importance to remember this fact in percussing this region. The two sacs of the pleuræ, as they pass between the spine and sternum to form the mediastina, are interposed between the lungs and the heart. The heart is subject to slight change of position from the influence of the contiguous organs. It is carried a little downwards during violent contraction of the diaphragm, and is pressed upwards when the abdominal viscera are strongly compressed by the powerful contraction of the abdominal muscles. During expiration it has been seen to recede deeper into the thorax, and during inspiration again to come forward. When the body is bent to the right side, the apex recedes from the inner side of the left wall of the thorax; when bent to the left side, it is still more closely approximated to it.

Form and external surface.—Its form is that of a flattened cone, and it is neither symmetrical as regards the mesial line of the body, nor (as we shall afterwards find) is the organ itself symmetrical. It presents an anterior and a posterior surface; a right inferior or acute margin; a left superior or obtuse margin; a base, and an apex. Its anterior surface, which is also turned towards the left side, is convex and considerably longer than the posterior and right, which is flattened. On the anterior surface of the heart we find a distinct groove, running nearly in the axis of the organ, passing from above downwards and from right to left, and containing the left coronary artery. A larger portion of the heart appears to lie to the right than to the left of this groove. There is a similar groove on the posterior surface, which is nearly vertical, shorter than the anterior, and contains a branch of the right coronary artery. These two grooves are connected with each other at or near the apex generally by a small notch, which is sometimes of sufficient depth to give the heart a bifid appearance.* These grooves mark the division of the heart into right and left sides. These terms are, however, more applicable when describing the organ in the lower animals; for in the human species the right side is also anterior and inferior, and the left side posterior and superior. Near the base of the heart and at the commencement of the longitudinal grooves, we find a circular groove deeper anteriorly than posteriorly, which contains in its posterior part the coronary vein and branches of the coronary arteries. This circular groove points out the division between the auricular and ventricular portions of the heart. Two large arteries are placed in front of the anterior part of this groove, the one posterior to the other. That nearest to the groove is the aorta, which springs from the base of the left ventricle; the one placed anterior is the pulmonary artery, which arises from the upper part of the right ventricle, and at its origin covers, along with that part of the ventricle to which it is attached, the commencement of the aorta. The ventricles form the principal part of the heart, and occupy the middle and apex, while the auricles are placed at the base. The base of the ventricles is connected to the base of the auricles. Two large veins, the superior and inferior venæ cavæ,

* In the lower animals its position is vertical, occupying the mesial line of the body.

* This notch in the human heart looks like the rudiments of the fissure which in the Dugong and Rytina separates the two ventricles from each other nearly up to the base. This bifid form of the heart, which is merely a temporary condition in the human species, is permanent in the Dugong and Rytina. See *fig.* 264, vol. i. p. 576.

enter the right, and the four pulmonary veins pass into the left auricle. The apex of the heart is in general formed by the left ventricle alone. The base of the ventricles is cut obliquely from before backwards and from above downwards, and this explains how the anterior surface of the ventricles should be longer than the posterior. I have found the difference of length between the two surfaces in a considerable number of uninjected hearts to vary from half an inch, or rather less, to an inch. There is little difference between the length of the two ventricles in the uninjected heart. In the injected heart the anterior wall not only becomes elongated but much more convex, while the posterior wall is simply elongated, so that the difference in length between the anterior and posterior surfaces becomes increased. This change is more marked in the right ventricle than in the left. Cruveilhier states that he found the anterior surface of the left ventricle to exceed the posterior by nine or ten lines, and the anterior surface of the right to exceed the posterior by fifteen lines. These measurements have evidently been taken from injected hearts. On the surface of the heart, but more particularly upon the anterior surface of the right ventricle, a white spot, varying in size, is frequently observed. According to Baillie it is placed on the free or inner surface of the external serous membrane.* These spots are so common an appearance that it is somewhat difficult to believe that they are morbid. It is, however, very probable that they are the result of some inflammatory action.

Except in very emaciated subjects there is a greater or less quantity of fat occupying the auricular and ventricular grooves. This fat is generally in greater abundance in old subjects than in young, in accordance with the general law, that the adipose tissue in young persons is principally collected on the surface, and in old persons around the internal organs. When in greater quantity, it is deposited along the ramifications of the coronary vessels, and may, in cases of great obesity, almost completely envelope the surface of the heart. It is generally placed in greater quantities on the right side than on the left.

The human heart may be considered as consisting of two distinct hearts separated from each other by a fleshy septum, and which in the adult have in general no communication. The position of the fleshy septum separating the ventricles is marked by the ventricular grooves. Each heart consists of an auricle and ventricle which communicate by a large orifice. The right heart is occasionally termed the *pulmonic heart*, from its circulating the blood through the lungs; and as it circulates the dark blood it was termed the *cœur à sang noir* by Bichat. The left is occasionally called *systemic heart*, as it circulates the blood through the body generally, and is the *cœur à sang rouge* of Bichat. The auricles, from their immediate connexion with the large veins of the heart, sometimes receive the name of venous portion of the heart *(pars cordis venosa)*; and in the same manner the term arterial portion of the heart *(pars cordis arteriosa)* has been applied to the ventricles from their connexion with the large arteries. In describing the different cavities of the heart we shall take them in the order in which the blood passes through them.

Right auricle (auricula dextra vel inferior, atrium venarum cavarum). External surface.—To see the external form of the auricles properly it is necessary that they be first filled with injection. The right auricle is of an irregular figure, having some resemblance to a cube, and occupies the anterior, right, and inferior part of the base of the heart. It receives all the systemic venous blood of the body. Its inferior portion rests upon the diaphragm. Its largest diameter runs in a direction from behind forward, and from right to left. It is broadest posteriorly, becoming narrow and prolonged anteriorly, where it terminates in a small and free appendix, which, from its resemblance to the external ear of the dog, has been termed auricle. This appendix is generally serrated on the edges, more particularly on the external, and projects between the aorta and the upper and anterior margin of the right ventricle. To this smaller portion the term *proper auricle* has been given, while the larger portion has been called *sinus venosus*. This division of the auricle into proper auricle and sinus venosus is more distinct in the left than in the right auricle. The posterior surface of the right auricle is connected with the entrance of the two cavæ; its inferior with the base of the right ventricle; its internal with the left auricle; its outer surface is free; and anteriorly it is prolonged into the proper auricle. The junction of its internal surface with the corresponding surface of the opposite auricle is marked by an indistinct groove, which corresponds to the attachment of the septum separating the two auricles. Its external surface is placed on a plane internal to the outer edge of the right ventricle.

Internal surface.—The inner surface of the right auricle can be satisfactorily examined only when it is opened *in situ*. Its interior can be best exposed by making a longitudinal incision from the appendix to the orifice of the inferior cava, then opening the superior cava along its anterior surface and connecting the two incisions. The inner aspect of the right auricle presents four surfaces:—1. a posterior, where the two venæ cavæ enter; 2. an outer, upon which numerous muscular bands are seen standing in relief; 3. an internal, which is nearly smooth, forms the septum between the two auricles, and presents an oval depression, about the size of the point of the finger, called the *fossa ovalis*; 4. an anterior, formed by the appendix, and which also presents numerous muscular bundles. The superior or descending vena cava enters at the upper and posterior angle, the inferior or ascending cava at the

* In three hearts in which I carefully examined these white patches, I could distinctly trace the serous membrane over them. See the observations of M. Bizot (Mémoires de la Société Médicale d'Observation de Paris, tom. i. p. 347, 1836,) on these spots.

posterior and inferior. The entrance of the superior cava looks downwards and forwards in the direction of the body of the auricle; the entrance of the cava inferior is directed upwards, backwards, and inwards. These two orifices are circular, and that of the cava inferior is larger than that of the cava superior. The right margins of these veins are continuous with each other; the left or anterior margins are continuous with the auricle, which in fact appears at first sight to be formed by an expansion of the veins; hence the term sinus venosus. Around the left margin of the entrance of the cava superior there is a prominent band of muscular fibres; and around its right and posterior margin there is another but less prominent band placed at its angle of junction with the right margin of the inferior cava. This last band occupies the position of the supposed tubercle of Lower *(tuberculum Loweri)*. The cava inferior occasionally forms a dilatation immediately before it enters into the auricle. The venæ cavæ have properly no valves at their entrance into the auricles.* The fossa ovalis *(valvula foraminis ovalis, vestigium foraminis ovalis)*, which marks the position of the foramen ovale by which the two auricles communicated freely with each other in the fœtus, is seen at the lower and right portion of the auricle, partly placed in a notch in the posterior and lower part of the fleshy portion of the septum, and partly in the upper part of the vena cava ascendens as it passes in to form the sinus venosus. The upper and anterior margins of this depression are thick and projecting *(annulus seu isthmus Vieusseni, columnæ foraminis ovalis)*. This was supposed by Vieussens to prevent the blood of the cava superior from falling into the cava inferior, an effect which Lower also imagined might be produced by the tubercle which he supposed was placed at the junction of the two veins. We have already pointed out that the orifices of the two veins are placed in different directions, which is sufficient to prevent the descending column of blood falling directly upon the ascending. The posterior and lower margins of the fossa ovalis are ill-defined. The surface of the depression is sometimes smooth, at other times uneven and reticulated. Between the upper margin of the depression and the annulus or thickened edge of the fossa ovalis we frequently find a small slit passing from below upwards, and forming a valvular opening between the two auricles. The remains of the Eustachian valve *(foraminis ovalis anterior valvula)* may be seen running from the anterior and left side of the entrance of the cava inferior to the left side of the fossa ovalis, where it attaches itself to the annulus. This valve exhibits very various appearances in the adult: sometimes it is very indistinctly marked, at other times it is sufficiently apparent, and much more rarely it approaches the size which it presents in fœtal life. It is frequently reticulated. Its convex margin is attached to the surface of the vein and auricle; its concave margin is free; its superior and convex surface looks towards the auricle, and its lower and concave surface towards the entrance of the vein. Placed to the left of the Eustachian valve, and between it and the upper and outer part of the base of the ventricle, is the orifice of the coronary vein. A valve *(valvula Thebesii)*, the free and concave margin of which is directed upwards, covers the entrance of this vein. It is sometimes imperfect, occasionally reticulated. Instead of one coronary valve we may have two or more, one placed behind another. These two valves, viz. the Eustachian and Thebesian, are formed by a reduplicature of the lining serous membrane of the heart.

The Eustachian valve frequently, however, contains some muscular fibres at its fixed margin. A number of small openings *(foramina Thebesii)* may be seen on the inner surface of the auricle, some of which lead into depressions; others are the orifices of small veins. The muscular fibres projecting from the anterior and outer surface, already alluded to, pass vertically from the auricle to the edges of the auriculo-ventricular opening. These, from their supposed resemblance to the teeth of a comb, are termed *musculi pectinati.* Smaller bundles cross among the larger, giving the inner surface at this part a reticulated appearance. At the places where the transverse fibres are deficient, the outer and inner serous membranes of the heart lie in close contact. In the floor or base of the auricle there is a large oval opening leading into the ventricle *(right auriculo-ventricular opening)*, having its upper margin surrounded by a white ring. The upper part of this ring has a yellowish colour from the auricular tendinous ring being here translucent, so that the fat lying in the auricular groove is seen through it.

Right ventricle (ventriculus anterior, v. dexter, v. pulmonalis.) External surface.—The right ventricle occupies the anterior and inferior portion of the right side of the heart. Its form is pyramidal, the base looking towards the auricle, its apex towards the apex of the heart. Its walls are much thicker than those of the auricle. This thickness arises from the increased number of its muscular fibres.

Internal surface.—The right ventricle may be best opened by making an incision along its right edge from the base to the apex, and another from the root of the pulmonary artery along its anterior surface near the septum to join the other at the apex. On examining the interior, its internal and posterior walls are seen to be common to it and the opposite ventricle, the anterior and external walls to belong exclusively to itself. Its posterior and internal walls are convex, its anterior and internal concave. Its posterior and external walls are decidedly shorter than its internal and anterior. Its parietes are rather thinner at their attachment to the anterior margin of the septum than along its posterior margin. They are also considerably thinner at the apex than towards the base. A number of fleshy columns

* The Eustachian valve cannot be considered as essentially connected with the cava inferior in the adult.

(*columnæ carneæ, teretes lacerti*) project from the inner surface. We will find that they present three different appearances in both ventricles. 1. The more numerous are attached to the walls of the ventricles by their two extremities, so that we can introduce a probe under the middle part. These divide and subdivide in a variety of ways. 2. Others are attached to the walls of the ventricles by the whole of their external surface, while their internal surface stands in relief from these walls. 3. Others are fixed to the walls of the ventricle by their lower extremities, are perfectly free in the rest of their course, and terminate either in a blunt extremity or in several short processes. These last are few in number, nearly vertical, and have received the name of *musculi papillares*. These columnæ carneæ form an intricate network on the inner surface of the ventricle, and some of them occasionally cross its cavity near the apex. They are more numerous on the anterior and external than on the posterior and internal walls. Two large openings are placed at the base of the ventricle. The larger, oval in the empty, somewhat circular in the distended heart, is the right auriculo-ventricular opening, the upper margin of which was already seen in the right auricle. The smaller is circular, is placed anterior and to the left, is about three-quarters of an inch higher than the larger, and is the orifice of the pulmonary artery. That portion of the ventricle from which the pulmonary artery springs is prolonged upwards above the level of the rest of the ventricle. To this prolongation Cruveilhier has given the name of the infundibulum.*

The inner surface, particularly the posterior part of this infundibulum, is smooth and deprived of columnæ carneæ. Around the auriculo-ventricular opening a valve is placed, the fixed margin of which is attached to the circumference of the opening; the free margin projects into the ventricle. This valve, which forms a complete ring at its attachment, terminates in several apices, three of which are much more prominent than the rest, and on this account it receives the name of the tricuspid or triglochin valve (*valvula triglochis v. tricuspis*). The anterior of these three portions, which is placed on the side nearest to the orifice of the pulmonary artery, is more prominent and broader than the posterior and internal portions, and is separated from them by deeper notches than these two are from each other. From this circumstance some are inclined to consider this valve as consisting of two portions only. It contains several small tubercles at its free margin. This valve, like the other valves at the arterial and left auricular orifices, to be afterwards described, is composed of a reduplicature of the lining membrane containing some tendinous fibres between them. It is translucent and of great toughness. A number of tendinous cords (*chordæ tendineæ*) pass between the apices of these valves and the inner surface of the ventricle. Though the arrangement of these chordæ tendineæ is not uniform in all cases, yet it is of importance to remark, as prominently bearing upon the discussions connected with the manner in which these valves at the auriculo-ventricular opening perform their office, that their general distribution is the same, and evidently intended for a specific purpose.* The greater part of these chordæ tendineæ spring from the free and blunt extremities of the third kind of columnæ carneæ (*musculi papillares*) which we have described; some from the other two kinds, and others again from the smooth portion of the septum, and more particularly from the lower part of the smooth surface which leads into the infundibulum. These tendinous cords diverge to reach their insertion, some of them dividing and subdividing two or three times, occasionally crossing each other, and are inserted principally into the apices and margins of the notches which separate the valve into its three portions. A few of these cords pass between the columnæ and inner surface of the ventricle without being attached to the valve. The internal lip of the valve has its lower margin tied more closely down to the surface of the ventricle by these cords than the other two lips; besides several short cords frequently pass between the internal surface of the ventricle and the ventricular surface of that portion of the valve. At the exit of the pulmonary artery from the upper, anterior, and left part of the ventricle, three valves are placed (*fig.* 3). These from their form have received the name of semilunar or sigmoid valves. Their fixed margins are convex, and adhere to the tendinous ring to which the origin of the artery is attached; their free edges, from the presence of a small triangular tubercle in the middle of each (*corpus Arantii, corpusculum Morgagni, corpus sesamoideum,*) form two slight semilunar curves (*fig.* 3). The extremities of the curved attached edges look in the course of the artery. When the blood rushes from the ventricle into the pulmonary artery, the valves are laid against the sides of the vessel, and the free edge becomes vertical; when, on the other hand, a portion of the blood falls back towards the ventricle, the valves are thrown inwards and completely occupy the calibre of the artery. At this time the concave surfaces of the valves are directed in the course of the artery, the convex surfaces towards the ventricle. These valves may be distinguished by the terms anterior, posterior or left, and superior or right. The suggestion of

* This part is very minutely described by Wolff under the term *conus arteriosus*. Under the term *infundibulum* Wolff included a larger portion of the ventricle, apparently that portion placed above a line drawn from the upper and right margin of the ventricle obliquely downwards to the anterior fissure. As the upper part of the right ventricle becomes gradually narrower, he supposed that it increases the velocity and impetus of the blood as it is driven from the ventricle.—Acta Acad. Imper. Petropol. pro anno 1780, tom. vi. p. 209. 1784.

* Mr. T. W. King states (Guy's Hospital Reports, no. iv. p. 123.) that there is a disposition in the chordæ tendineæ from each fleshy column to attach themselves to the adjoining edges of two lips of the valve, as in the left ventricle.

Fantonus, that as three circular valves meeting in the axis of a canal would leave a small space in the axis itself, so the use of these corpora Arantii may be to fill up the interval which would thus otherwise be left, has generally been adopted.* These valves are thin and transparent, yet of considerable strength. Their attached are thicker than their free margins. That portion of the pulmonary artery which is placed immediately above the attachment of the semilunar valves bulges out and forms three projections, named from their discoverer *sinuses of Valsalva*. These sinuses are more apparent in old than in young persons.

Left auricle (auricula sinistra; a. posterior; atrium seu sinus venarum pulmonalium, a. aorticum). External surface.—It occupies the upper, posterior, and left part of the base of the heart, and receives the blood brought back from the lungs by the pulmonary veins. The only part of the left auricle that can be fairly seen after the pericardium has been opened, and none of the parts disturbed, is the appendix. To see it properly the pulmonary artery and aorta must be cut through and thrown forwards. It is of a very irregular shape, some anatomists comparing it to an oblong quadrilateral, others to an irregular cuboidal figure. Posteriorly it rests upon the spinal column, from which it is separated by the parts mentioned in describing the position of the heart itself, and appears as if confined between the spine and base of the heart,—a fact which has been considerably insisted upon in some of the explanations of the tilting motion of the heart. Superiorly and to the right it is connected to the auricle of the opposite side. More anteriorly and still to the right it is free, and is separated from the right auricle by the aorta and pulmonary artery. Its base is connected to the base of the corresponding ventricle. The auricle is prolonged forwards at first to the left, but bends towards the right before terminating. This prolongation is the appendix or proper auricle. This appendix is longer, narrower, more curved, more denticulated on the edges, and more capacious than the corresponding part of the right auricle, and projects along the left side of the pulmonary artery, a little beyond and below the anterior margin of the left ventricle. The two left pulmonary veins enter the posterior and left side, and the two right pulmonary veins enter the posterior and right side of the auricle.

The left auricle, like the right, has been divided into sinus venosus and proper auricle. *Inner surface.*—The inner surface may be divided into, 1st, a posterior, which is smooth, and which belongs exclusively to itself; 2d, an anterior, which communicates by a round opening with the cavity of the appendix; 3d, a right, the anterior and greater part of which is formed by the septum of the auricles. Upon this is observed the fossa ovalis, but without the distinct depression which it presented in the right auricle. The upper margin of the valve, between which and the upper thick edge of the fossa ovalis the oblique aperture exists, which we formerly stated to be frequently observed here, is often distinctly seen in the left auricle. The valvular nature of this small slit must prevent any intermixture of the blood of the two sides. This margin, when present, looks forwards and to the left. The two right pulmonary veins open upon this surface immediately posterior to the septum, and between the septum and posterior surface. 4th, A left, into which the two pulmonary veins of the left side open.

The pulmonary veins of the two lungs are thus separated from each other by the whole breadth of the auricle. The veins of the same side open into the auricle, the one immediately below the other, so that they occupy the whole height of the auricle. The superior is generally the larger. The two veins of the same side occasionally enter by a common opening, or this may occur on one side only. At other times we may have five openings. These veins, like the cavæ, have no valves at their termination in the auricle. At the lower and anterior part of the auricle a large oval opening presents itself. This is the left auriculo-ventricular opening, and like that on the right side it has its upper margin surrounded by a white tendinous ring. This ring, unlike that of the right side, is everywhere sufficiently opaque to prevent the fat placed in the auricular groove to be seen through it.

The inner surface of the left auricle differs materially from that of the right in its greater smoothness, and the consequently smaller number of its musculi pectinati. In fact, the only place in which these are observed, and that too to a comparatively smaller extent than in the corresponding portion of the right, is the appendix. This arises from the greater strength of the left auricle, the muscular fibres being so closely laid together as not to leave any interval between them.

Left ventricle (ventriculus sinister, v. posterior, v. aorticus.) External surface.—It is of a conical shape, and occupies the posterior and left part of the heart. It is rounded and does not present the flattened appearance of the right ventricle. It projects downwards beyond the right, and forms the apex of the heart. Though the left proceeds lower down than the right ventricle, that portion of the right called infundibulum or conus arteriosus mounts higher than any part of the left. The left is on the whole a little longer than the right. The circumference of the base of the right ventricle is greater than that of the left, exceeding it in some cases in the injected heart by about two inches.

Internal surface.—This ventricle is best opened by making an incision close upon the

* I find that the late Dr. A. Duncan, jun. has justly remarked that there is no necessity for calling in the aid of the corpora Arantii to produce the complete obstruction of the calibre of the artery, as the free edges of these valves, when they are thrown inwards, do not exactly lie in close apposition but overlap each other. Besides these bodies are occasionally very indistinct, and frequently do not project beyond the free margin of the valves, especially in the pulmonary semilunar valves.

anterior fissure from the apex near to the commencement of the aorta, then another incision midway between the posterior fissure and left edge of the ventricle, commencing near the base and carrying it downwards to join the other at the apex. The anterior and right parietes of the internal surface are formed by the septum; the posterior and left belong exclusively to itself. The walls of the left ventricle are considerably thicker than those of the right, and remain apart, while those of the right fall together. As connected with this we may observe that the septum is concave towards the left ventricle and convex towards the right. As the obstacles to be overcome in transmitting the blood through the body are greater than those to be overcome in transmitting it through the lungs, so is the left ventricle thicker than the right. It is important to remark, as connected with the pathology of spontaneous rupture of the heart, that the walls of the left, like those of the right ventricle, are considerably thinner at the apex than towards the base.* The anterior and right parietes are longer than the posterior and left. The columnæ may be arranged into three kinds, such as we have described in the right ventricle. They are not so numerous in the left ventricle as in the right. The greater number are also smaller, and are principally placed upon the posterior and left wall, near the apex of which they form deep areolæ.† The upper part of the septum which leads to the aortic opening, which we shall presently describe, is quite smooth. In the base of the ventricle we find two openings placed closely together; one of these, the smaller, is placed to the right and a little anterior, is the commencement of the aorta, and occupies the upper and right corner of the ventricle; the other is larger and placed to the left and a little posterior, and is the auriculo-ventricular opening of this side. The aortic opening is only separated from the auriculo-ventricular opening by the tendinous ring, and from the orifice of the pulmonary artery by the upper part of the septum. A valve resembling the tricuspid is attached to the tendinous ring around the auriculo-ventricular opening, which, from being more decidedly divided into two lips, is termed *bicuspid*, and from its fanciful resemblance to a bishop's mitre has generally received the name of *mitral valve*. Like the tricuspid it forms a complete ring around the margin of the auriculo-ventricular opening. The anterior lip of the valve in the quiescent state of the heart hangs suspended between the auriculo-ventricular opening and the origin of the aorta, and is considerably larger and more moveable than the posterior, which is smaller and more limited in its movements. The mitral valve is formed in the same manner as the tricuspid, and is somewhat thicker and stronger, and like it contains a number of tubercles in its free margin. The large anterior lip of the mitral valve projecting downwards into the ventricle was described by Lieutaud and by others since his time as dividing the ventricle into two portions, an aortic and a ventricular. These are separated from each other at the upper part by the valve only; at every other part they communicate with each other. The same authors have described the larger lip of the tricuspid valve as effecting a similar division of the pulmonic ventricle. Two of the columnæ carneæ in the left ventricle belong to the third kind (musculi papillares) already described, and are much stronger than any to be found in the right ventricle. They are attached to the lower part of its cavity, pass upwards, and about the middle of the ventricle terminate in a blunt extremity, from which a number of chordæ tendineæ pass to be attached to the margins of the mitral valve. Bouillaud describes these two columnæ as uniformly occupying the same position, one being placed at the junction of its left and posterior walls to form the left margin of the heart; the other on the posterior wall near its junction with the posterior margin of the septum.* Each of these fleshy columns consists of two fasciculi, of an anterior and superior, and of a posterior and inferior. The posterior and inferior fasciculus is shorter and less strong than the anterior. The chordæ tendineæ of the two anterior or internal fasciculi proceed to attach themselves to the margins of the anterior or larger lip of the valves, those from one fasciculus passing to one edge of the lip, and those of the other fasciculus to the other edge. As these chordæ tendineæ proceed from the fasciculi to the valve, they diverge from those of the same fasciculus, but converge towards those of the other fasciculus. (*Fig.* 4 shews the attachment of the chordæ tendineæ of the two anterior or internal fasciculi.) The chordæ tendineæ from the posterior fasciculi pass in a similar manner to be attached to the posterior lip. The posterior lip is fixed closer in its situation than the anterior, by the chordæ tendineæ, and this is frequently increased by some of these cords passing from the walls of the ventricle to be attached to the ventricular surface of the valve, sometimes nearly as high as the fixed margin of the valve. These chordæ tendineæ are stronger, fewer in number, and less subdivided than those in the right ventricle. Several of them pass between the fleshy columns without being attached to the valves, as in the right ventricle. Though the description here given is not perfectly uniform in every case, but is liable to frequent varieties,—by the non-divi

* The circular arrangement of the muscular fibres around the apex (*fig.* 9) must have the effect of rapidly approximating the inner surfaces of the ventricles at the apex during their systole, more particularly when the apex is elongated, as in the heart of the horse, and thus prevent the pressure from falling upon the extremity of the apex, where it is very weakly protected.

† Laennec has erroneously stated in general terms that the columnæ of the right ventricle are larger than those of the left.

* I have satisfied myself by numerous examinations, of the accuracy of Bouillaud's account of the position of these musculi papillares and the arrangement of the chordæ tendineæ in the human heart. I have found them occupying a similar position in the heart of the horse, ox, ass, sheep, pig, dog, rabbit, hedge-hog, and some birds, and suspect that this will be found a general law in all the warm-blooded animals.

sion of the musculi papillares into two fasciculi; by their subdivision, on the other hand, into several smaller bundles, but so grouped that the position of the smaller corresponds to the larger; and by the smaller columns furnishing a certain number of the cords usually given off by the larger; yet there appears to be a remarkable similarity between the course and arrangement of the chordæ tendineæ in all cases. The object of this we will afterwards see when inquiring into the precise manner in which these valves prevent regurgitation into the auricle during the systole of the ventricle. The origin of the aorta is furnished with three semilunar valves (*fig.* 4), which very exactly resemble in their position, shape, and appearance those placed at the commencement of the pulmonary artery. They are somewhat stronger, and have the corpora sesamoidea generally larger than those in the pulmonary artery. Behind these valves are three dilatations (*sinuses of Valsalva*) upon the commencement of the aorta, similar to, but more prominent, than those at the commencement of the pulmonary artery (*fig.* 4).

It was maintained by several of the older eminent anatomists that the semilunar valves must necessarily cover the entrance of the coronary arteries,* and that they were filled, not during the passage of the blood along the aorta, but by the falling back of part of it during the diastole of the heart, or as Boerhaave expressed it, "Hæ arteriæ sunt in diastole, dum reliquæ corporis arteriæ in systole constituuntur."† Haller mentions two circumstances which must satisfy every one, if any thing more than the bare inspection of the parts was necessary, that the coronary arteries are at least *generally* filled in the same manner as the other arteries which arise from the aorta, and these are—1st, the result of experiments on living animals, where the blood is seen to spring per saltum from the cut coronary arteries during the systole of the heart; 2d, when a fœtus is injected by the umbilical vein, the coronary arteries are also filled. More lately, however, Vaust‡ has maintained that the origin of the coronary arteries is generally covered by the semilunar valves. He states that he has injected a great number of hearts from the pulmonary veins; in some of these the injection passed into the coronary arteries, but in by much the greater number these vessels did not contain a single drop of injection. On examination of these cases he found that the semilunar valves entirely covered the origin of the coronary arteries. In attempting to ascertain this point on the uninjected heart, we must bear in mind the different conditions of the aorta in the living body and after death. In the dead body the sinuses of Valsalva are collapsed, so that the semilunar valves can be laid over the origin of the coronary arteries in some cases, where they would become free when the sinuses are distended as they are with blood in the living body. Making every allowance for this source of fallacy, I am satisfied that I have seen one or two cases in which these valves appeared fairly to cover the origin of the coronary arteries. Supposing that the origin of the coronary arteries were covered in some instances by the valves, it would in all probability be a matter of little moment, as far as the efficiency of the circulation through these arteries was concerned, as long as the aorta retained its elasticity, for the force with which it drives the distending fluid backwards during the diastole of the heart (a force which can be ascertained in the dead body) would be sufficient to carry on the circulation. The circumstances would, however, become very much altered in those cases which are sufficiently common in advanced age, where the aorta has from disease of its coats entirely lost its elasticity, and the coronary arteries have also become studded with calcareous matter, unless we suppose what could scarcely happen, that the blood contained in the sinuses is forced along the arteries when the valves are thrown outwards.*

Septum of the ventricles.—The septum between the ventricles is triangular, and the apex extends to the point of the heart. It is of considerable thickness at the base, but becomes thinner at the apex. Its position is oblique like that of the heart. It is concave towards the right ventricle, and convex towards the left. From the slight rotation of the heart on its axis, the anterior surface of the septum is directed towards the right side, and the posterior towards the left. It is composed, like the other walls of the ventricle, principally of muscular fibres, lined on the one side by the internal serous membrane of the right ventricle, and on the other side by the corresponding membrane of the left.

We have preferred considering the relative thickness of the parietes, the different capacities of the several cavities of the heart, the relative dimensions of the auriculo-ventricular, aortic, and pulmonary orifices, and the size and weight of the heart under distinct heads, not only as this enables us to obtain a more connected view than we could otherwise have done of points upon which there are many conflicting opinions, and upon which it is so frequently necessary to possess, as far as we possibly can, accurate notions in deciding upon the normal or abnormal state of the organ, but we were also afraid that if mixed up with the other parts of the descriptive anatomy they would have

* Morgagni was doubtful in this matter, and thought that he had observed them sometimes covered by the valves, at other times free. *Advers. ., Animadver.* xxv.

† Institut. Med. 183.

‡ Recherches sur la Structure et les Mouvements du Cœur, p. 22, (1821.)

* Among the numerous and striking examples which the history of medical science furnishes us of the powerful tendency which preconceived notions have, if not powerfully guarded against, of influencing our observations of the plainest facts, we may instance the statements of Petriolus on this question. He, apparently deeply imbued with the old hypothesis that the heart is the seat of courage, maintained that in bold and carnivorous animals the coronary arteries were above the valves; in timid and herbivorous animals, on the contrary, they arose behind the valves, while in man they were of uncertain origin, as he was bold or timid.

endered it more complicated. We will find hat considerable differences in these respects nay exist between different hearts and between lifferent parts of the same heart, which, to udge from the perfect regularity with which all ts functions proceeded before death, must be considered as perfectly healthy; and it is from his want of uniformity in the different parts of apparently healthy hearts that we can in some measure account for the discrepant statements on this subject which exist in the works of the most celebrated and accurate anatomists.

Thickness of the walls of the several cavities of the heart.—The left auricle is somewhat thicker than the right, and the left ventricle very considerably thicker than the right. Bouillaud* found the average thickness of the walls of the left auricle in four healthy hearts to be $1\frac{1}{2}$ lines, and that of the right auricle to be 1 line. Lobstein has rather strangely stated that the right auricle is twice the thickness of the left. He makes the thickness of the right auricle to be 1 line, and that of the left to be only $\frac{1}{2}$ line. Laennec reckons the relative proportion of the thickness of the left ventricle to the right as rather more than 2 to 1. Bouillaud found the average thickness of the right ventricle at its base in a great number of cases to be $2\frac{1}{2}$ lines, and that of the left ventricle at the same part to be 7 lines. Cruveilhier† states the proportionate thickness of the right to the left ventricle as 1 to 4, or even as 1 to 5. According to Soemmerring,‡ the relative thickness of the two ventricles is as 1 to 3. Andral§ states that in the adult the thickness of the left to the right ventricle is as 2 to 1, but in infancy and in old age it is as 3 or 4 to 1.

M. Bizot has lately published the results of the careful measurements of the healthy heart in one hundred and fifty-seven individuals of all ages.|| The greater part of these observations were collected at La Pitié, under the auspices of Louis. According to M. Bizot, the heart goes on increasing in all its dimensions—length, breadth, and thickness—up to the latest periods of life. The growth is, however, more rapid before twenty-nine years than after that age. While, then, the muscles of animal life are diminishing in size in advanced life, the heart is still increasing in bulk. The heart of the male is, on an average, larger than that of the female at all the different stages of life. M. Bizot remarks that the longitudinal section of the left ventricle is fusiform, the thickest part being situated at the junction of the superior third with the middle third.¶ The thickness of this ventricle goes on increasing from youth up to advanced age. The following are a few of the measurements of the thickness of the walls of the ventricles given by M. Bizot.

Left ventricle, male.

Age.	Base.	Middle part.	Apex.
1 to 4 years	3 lines.	$2\frac{9}{10}$ lines.	$1\frac{9}{10}$ line.
50 to 79 years ..	$4\frac{37}{38}$,,	$5\frac{20}{38}$,,	$4\frac{1}{29}$,,
Average from 16 to 79 years ..	$4\frac{65}{122}$,,	$5\frac{19}{122}$,,	$3\frac{95}{122}$,,

Left ventricle, female.

Age.	Base.	Middle part.	Apex.
1 to 4 years	$2\frac{9}{16}$ lines.	$2\frac{7}{8}$ lines.	$2\frac{1}{16}$ lines.
50 to 89 years ..	$4\frac{1}{2}$,,	5 ,,	$3\frac{3}{4}$,,
Average from 16 to 89 years ..	$4\frac{3}{8}$,,	$4\frac{4}{5}$,,	$3\frac{13}{30}$,,

Thickness of right ventricle.—The thickest portion of the right ventricle is not placed, as M. Bizot remarks, at the same point as in the left. In the right ventricle it is at the base of the heart, 4 lines below the tendinous ring. The thickness of the walls of the right ventricle, unlike the left, remains more nearly stationary at the different periods of life. They are, however, a little thicker in advanced age than at an earlier period of life.

Right ventricle, male.

Age.	Base.	Middle part.	Apex.
1 to 4 years	$\frac{9}{10}$ line.	$\frac{6}{10}$ line.	$\frac{5}{10}$ line.
30 to 49 years ..	$1\frac{39}{46}$,,	$1\frac{7}{23}$,,	$\frac{45}{46}$,,
50 to 79 years ..	$2\frac{1}{19}$,,	$1\frac{53}{168}$,,	$\frac{81}{84}$,,
Average from 16 to 79 years ..	$1\frac{113}{122}$,,	$1\frac{99}{244}$,,	$1\frac{2}{61}$,,

Right ventricle, female.

Age.	Base.	Middle part.	Apex.
1 to 4 years	$1\frac{3}{16}$ line.	$\frac{7}{8}$ line.	$\frac{13}{21}$ line.
30 to 49 years ..	$1\frac{19}{22}$,,	$1\frac{13}{34}$,,	$\frac{25}{27}$,,
50 to 79 years .	$1\frac{1}{4}$,,	$1\frac{1}{4}$,,	1 ,,
Average from 15 to 59 years ..	$1\frac{2}{3}$,,	$1\frac{7}{24}$,,	$\frac{673}{720}$,,

Care was taken to make all these measurements at points where there were no columnæ carneæ.

The thickness of the septum ventriculorum, according to Meckel, is 11 lines at its base. Bouillaud obtained the same results in the only case in which he appears to have measured the thickness of the septum. M. Bizot has given measurements of the ventricular septum at six different periods of life, from which I have selected the following.

Age.	*Male.* Middle part.	*Female.* Middle part.
1 to 4 years......	$3\frac{1}{10}$ lines.	$2\frac{5}{8}$ lines.
16 to 29 years....	$4\frac{17}{18}$,,	$4\frac{11}{14}$,,
50 to 79 years....	$5\frac{1}{3}$,,	$5\frac{3}{19}$,,

The thickness of the septum ventriculorum goes on increasing ~~in thickness~~ from infancy to an advanced period of life.

Relative capacities of the several cavities.—The most conflicting statements exist upon this point, and we find it perfectly impossible to come to any satisfactory decision. Each cavity of the heart is supposed, when moderately distended, to contain rather more than two ounces of fluid. The auricles may be safely said to be of less capacity than the ventricles; and this disparity is strikingly marked in the larger animals, as the horse and ox. The right auricle is generally allowed to be larger than the left, and the difference,

* Traité Clinique des Maladies du Cœur, t. i. p. 53. 1835.

† Anatomie Descriptive, t. iii. p. 17.

‡ De Corporis Humani Fabrica, t. v.

§ Anatomie Pathologique, t. ii. p. 283.

|| Mémoires de la Société Médic. d'Observation de Paris, t. i. p. 262. 1836.

¶ Op. cit. p. 269 and 284.

as stated by Cloquet and Cruveilhier, is as 5 to 4. The right ventricle is generally found larger than the left after death. This difference has been very variously estimated by different anatomists. Some, as Winslow, Senac, Haller, Lieutaud,* and Boyer, have maintained that there is a marked disparity between the capacities of the two cavities, while Meckel, Laennec, Bouillaud, Portal, and others believed that this difference is to a smaller extent. Lower was the first to maintain that both ventricles are of equal size. Sabatier, Andral, and others have supported this opinion; while Cruveilhier† states that he has satisfied himself, from comparative injections of the two cavities, that the left ventricle is a little larger than the right. Gordon has occasionally found both ventricles of equal size, and Portal has seen them of the same size in young persons. Santorini and Michelattus believed that, though the capacity of the left ventricle appears a little smaller than that of the right, yet that the superior force of the left auricle over the right dilates the left ventricle sufficiently to render it equal to the right.

The majority of anatomists, however, have always maintained that the capacity of the right ventricle is greater than that of the left, and have adduced the following arguments in support of this opinion: 1, that the right auricle, right auriculo-ventricular orifice, and origin of the pulmonary artery are larger than the auricle and corresponding orifices of the opposite side: 2, that when both ventricles have been filled with water, mercury, or wax, more of these substances is found contained within the right than the left: 3, the experiment of Legallois‡ shew that when an animal is bled to death, this disparity between the size of the ventricles is still found. Those who maintain that the capacity of these two cavities is equal do so on the following grounds:—1, that as the walls of the right ventricle are weaker than those of the left, when the same force is used in injecting both, the right must, as a matter of course, be more dilated than the left. 2. Sabatier ingeniously suggested that, as during the last moments of life the passage of the blood from the right side of the heart is generally impeded, producing engorgement of that side, while the left side was generally empty, this might account for the greater size of the right ventricle. 3. Sabatier and Weiss§ maintained that in those cases where the kind of death was such that the right side of the heart could not be engorged as in fatal hæmorrhage, no difference between the capacity of the two sides could be observed. 4. The experiments of Sabatier, in which, after tying the aorta and producing engorgement of the left side of the heart, while the right side was emptied by a wound made into the vena cava or pulmonary artery, the left ventricle was found to be of greater capacity than the right.

M. Bizot maintains that the capacity of the ventricles goes on increasing from youth up to old age; and that this, contrary to the opinion of Beclard, is not so rapid in old age as in the earlier periods of life. The following are a few of M. Bizot's measurements:—

Age.	Length.	Breadth.
Left ventricle, male.		
1 to 4 years	20 lines.	31 lines.
50 to 79 years	36 "	$56\frac{2}{3}$ "
Average from 15 to 79 years	$34\frac{24}{61}$ "	$54\frac{2}{61}$ "
Left ventricle, female.		
1 to 4 years	$18\frac{1}{2}$ lines.	$29\frac{5}{8}$ lines.
50 to 79 years	31 "	$49\frac{1}{2}$ "
Average from 15 to 89 years	$31\frac{1}{33}$ "	$48\frac{23}{30}$ "
Right ventricle, male.		
1 to 4 years	$20\frac{1}{5}$ lines.	$47\frac{4}{5}$ lines.
50 to 79 years	$37\frac{1}{3}$ "	87 "
Average from 15 to 79 years	$37\frac{14}{61}$ "	$82\frac{11}{60}$ "
Right ventricle, female.		
1 to 4 years	$18\frac{7}{8}$ lines.	$44\frac{1}{8}$ lines.
50 to 79 years	$35\frac{11}{19}$ "	76 "
Average from 15 to 89 years	34 "	$76\frac{2}{3}$ "

Every one must confess that the right ventricle is generally found larger after a natural death in the human subject than the left; and it appears exceedingly probable that these two cavities, in the healthy state of the organ, contain different quantities of blood during life. As the capacity of the auricles is rather smaller than that of the ventricles, it may be asked how can the auricles furnish blood sufficient to distend the ventricles? We shall afterwards more particularly explain that the blood passes from the auricles into the ventricles at two different times during the interval between each contraction, viz. at the moment of its relaxation, and again during the contraction of the auricles. Various attempts have been made by those who maintain that the right side of the heart is larger than the left, to explain how the equilibrium of the circulation can be maintained. Helvetius* supposed that this could be accounted for by the diminution which the blood suffered in passing through the lungs; and in proof of this he erroneously maintained that the pulmonary arteries were larger than the pulmonary veins. Legallois believed that this could be explained (as appears very probable) by the greater size of the right auriculo-ventricular opening, allowing a greater reflux of blood back again into the auricle, during the systole of the ventricles.

* Mémoires de l'Academie Roy. des Sciences, t. viii. p. 561, 1754. Lieutaud's authority is sometimes quoted in support of the opinion that these cavities are of equal capacity.

† Anatomie Descriptive, t. iii.

‡ Dictionnaire des Sciences Méd. t. v. p. 436. These experiments were performed upon dogs, cats, guinea-pigs, and rabbits.

§ De dextro cordis ventriculo post mortem ampliore.

* Mémoire de l'Acad. Roy. 1718, p. 285.

Relative dimensions of the auriculo-ventricular orifices.—The right auriculo-ventricular orifice is larger than the left, as was correctly stated by Portal.* According to Cruveilhier, the largest diameter of the right auriculo-ventricular opening which is antero-posterior is from 16 to 18 lines, and its smallest diameter is 12 lines; while the largest diameter of the left auriculo-ventricular opening, which is directed almost transversely, is from 13 to 14, and its smallest is from 9 to 10 lines. Bouillaud gives the results which he obtained from the accurate measurement of the circumference of these two openings in three perfectly healthy hearts. The average circumference of the left auriculo-ventricular opening was 3 inches $6\frac{1}{3}$ lines: the maximum was 3 inches 10 lines, and the minimum was 3 inches 3 lines. The average circumference of the right auriculo-ventricular opening was 3 inches 10 lines: the maximum was 4 inches, and the minimum was 3 inches 9 lines.

Circumference of the aortic and pulmonary orifices.—The circumference of the aortic and ventriculo-pulmonary orifices is sometimes nearly equal; more generally, however, the ventriculo-pulmonary is the larger. Bouillaud gives the following measurements of these openings taken from four healthy hearts:—Average circumference of the aortic opening, 2 inches $5\frac{1}{2}$ lines: the maximum 2 inches 8 lines, and the minimum 2 inches 4 lines. Average circumference of the ventriculo-pulmonary opening, 2 inches $7\frac{3}{4}$ lines: the maximum 2 inches 10 lines, and the minimum 2 inches 6 lines. I have found this difference between the circumference of these two openings marked distinctly at seven years of age. M. Bizot has given measurements of the arterial orifices, of which the following is the average.

Aortic orifice, male.

Average from 16 to 79 years.. $45\frac{17}{33}$ lines.

Aortic orifice, female.

Average from 16 to 89 years .. $41\frac{1}{3}$ lines.

Pulmonary orifice, male.

Average from 16 to 79 years.. $54\frac{12}{61}$ lines.

Pulmonary orifice, female.

Average from 16 to 89 years .. $48\frac{1}{4}$ lines.

Size and weight.—Laennec has stated that the *size* of the heart in general nearly corresponds to the closed fist of the individual. This can only be considered as a loose approximation, as the size of the hand may vary in different individuals otherways resembling each other, either from original conformation or from dissimilar modes of life; and, besides, the size and form of the healthy heart itself may vary sufficiently to effect an apparent difference in these respects.

The average length of the heart, according to Meckel, is $5\frac{1}{2}$ inches, of which about 4 inches are to be allowed for the ventricles, and $1\frac{1}{2}$ inch for the auricles. Bouillaud found that a line drawn from the origin of the aorta to the point of the heart ranged, in nine healthy hearts, from 4 inches to 3 inches $2\frac{1}{2}$ lines. The average length was 3 inches $7\frac{1}{3}$ lines.

The *weight* of the heart, according to Meckel, is about 10 ounces, and its proportionate weight to the whole body is as 1 to 200. Tiedemann is of opinion that the proportionate weight of the heart to the body is as 1 to 160.* The weight of the healthy and empty heart, according to Cruveilhier, is from 7 to 8 ounces. Bouillaud found the average weight in thirteen healthy hearts to be 8 ounces 3 drachms. According to Lobstein it weighs between 9 and 10 ounces. The size and weight of the heart must generally be to a great extent in conformity with the size and weight of the body. In an athletic male we would expect it to weigh about 10 ounces, in an ordinary-sized individual about 8 ounces, and in weakly persons, or in cases of protracted debility, it would be still more diminished in weight. For the same reason it is generally larger and heavier in males than in females.

Structure of the heart.—The heart consists of muscular and tendinous textures, of cellular tissue, of bloodvessels, of nerves, and of lymphatics, enclosed between two serous membranes.

Tendinous texture.—The tendinous texture of the heart is placed, 1, around the auriculo-ventricular and arterial orifices; 2, within the reduplicature of the lining membrane forming the auriculo-ventricular and arterial valves; 3, it forms the chordæ tendineæ.

Auriculo-ventricular tendinous rings.—Around each auriculo-ventricular opening we find a tendinous circle or ring, from the upper part of which the muscular fibres of the auricles arise, and from the lower part those of the ventricles, thus affording perhaps the only example in the human body of a strictly involuntary muscle having tendinous attachments. The tendinous ring surrounding the left auriculo-ventricular opening is stronger than that surrounding the right. These tendinous zones are thicker along the lower edge where the muscular fibres of the ventricle are attached, and become thinner along the upper edge where the muscular fibres of the auricles are attached, so that the fat occupying the auricular groove is seen through the upper portion of the ring on the right side. The right margin of the left auriculo-ventricular ring is connected with that surrounding the aortic opening. The existence of the auriculo-ventricular and arterial tendinous rings was well known to Lower.†

Arterial tendinous rings.—The form of the tendinous rings surrounding the arterial openings, and the manner in which the large arteries are attached to their upper edges, have not, I think, been described with sufficient accuracy. These textures are very plainly observed

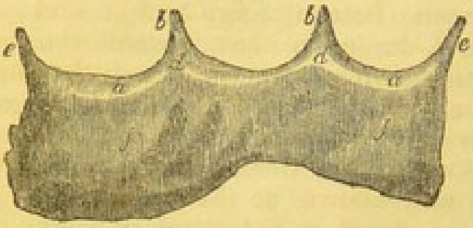
* Anatomie Médicale, t. iii. p. 69.

* If we consider the ordinary weight of an adult heart to be 8 ounces, and the average weight of the whole body to be 150 lbs. the proportionate weight of the heart to the body would be as 1 to 225.

† Tractatus De Corde, p. 29. 1669.

in the heart of the ox and horse after a little dissection. The following description is drawn up from numerous dissections of these parts made on the human heart. The tendinous ring surrounding the aortic opening is stronger and thicker than that surrounding the orifice of the pulmonary artery. Both of them are stronger than the auriculo-ventricular rings. Each of the arterial rings appears as if composed of three semilunar portions placed on the same plane, the convexities of which are turned towards the ventricles and the concavities towards the vessels (*fig.* 1, *a a*).* Each of

Fig. 1.



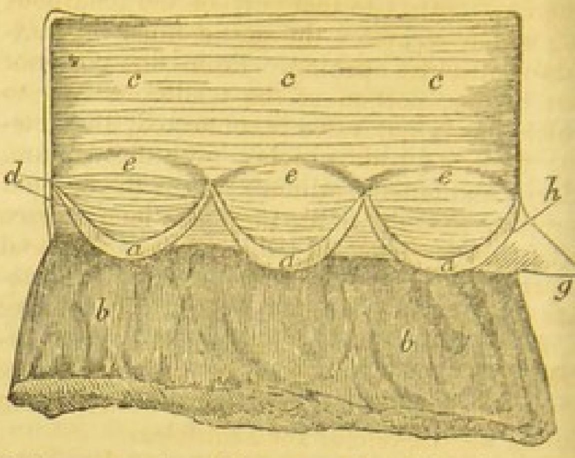
Appearance of tendinous ring at the origin of the pulmonary artery. In slitting open the artery, one of the three projecting extremities of the tendinous ring has been divided.

these semilunar portions has its projecting extremities intimately blended at their terminations with the corresponding projecting extremities of those next to it, (*fig.* 1, *b b*,) so that the three form a complete circle, with three triangular portions projecting from its upper edge. The semilunar portions approach fibro-cartilage in their structure, and have the intervals left between their convex edges filled with a texture more decidedly fibrous, (*fig.* 1, *d*,) and which is considerably weaker than the semilunar portions, more particularly on the left side of the heart.† The thinness of the tendinous structure filling up these intervals has led some anatomists erroneously to describe these portions of the heart as protected only by the two serous membranes. The right tendinous zone is broader than the left and very thin, particularly at its inner margin, at which part in both sides of the heart it assumes more of the tendinous than of the fibro-cartilaginous structure. These tendinous rings are placed obliquely from without inwards and from above downwards, so that the outer edge is on a plane superior to the inner. The sigmoid valves are attached to the inner edge of the upper surface, (*fig.* 2, *a*,) and the tendinous fibres placed in the fixed margins of these valves contribute to the thickening of the ring at this part; the middle coat of the arteries is connected to the outer edge of the same surface, and to the anterior part of the projecting extremities, (*fig.* 2, *b*;) while the muscular fibres of the ventricles (*fig.* 1, *f*; *fig.* 2, *f*,) are attached to the lower surface of the projecting portion of the convexity, and to the lower margin of the fibrous tissue filling up the space between the convexities of the projecting ends, (*fig.* 2, *d.*) There is, however, this difference between the right and left arterial openings with respect to the attachment of the muscular fibres;—on the right side the muscular fibres arise from the projecting portion of the convexity of the whole three tendinous festoons, (*fig.* 3, *c, c*,) while in the left side the muscular fibres are attached only to one and part of a second, (*fig.* 4, *b b*,) as the larger lip of the mitral valve (*fig.* 4, *a*) is suspended

* These tendinous festoons are represented stronger in the woodcut than they are naturally.

† These intervals are occupied by muscular fibres in the heart of the ox and horse.

Fig. 2.



Pulmonary artery slit open at its origin, its internal membrane stripped off, and two of the sigmoid valves completely removed.

a a a, tendinous festoons.
b b, muscular fibres of the right ventricle.
c c c, middle fibrous coat of the artery after the internal serous membrane has been stripped off.
g, small portion of one of the semilunar valves left to show its attachment to the inner edge of the upper surface of the tendinous festoon.

Fig. 3.

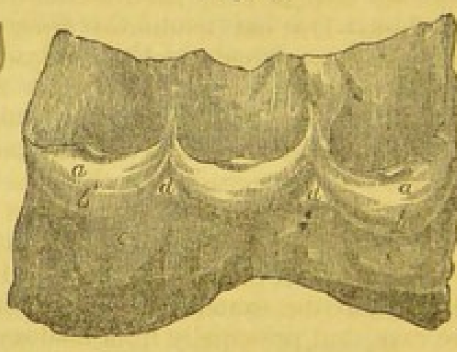
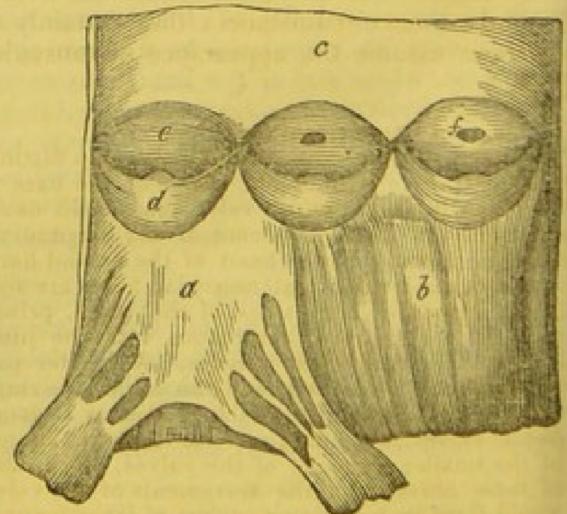


Fig. 4.



from the posterior or left, and a great part of the anterior,—in fact to that part of the tendinous ring which separates the aortic from the auriculo-ventricular opening. From the posterior part of that portion of the tendinous ring to which the mitral valve is connected, the anterior fibres of both auricles, near the septum, arise. As the left tendinous ring is thicker and narrower than the right, there is a larger space left between the fixed edge of the valves and the attachment of the middle coat of the arteries than there is on the left side. This space is of some importance, as upon it a considerable part of the pressure of the column of blood in the large arteries must be thrown during the diastole of the ventricles.

There is a good representation of these tendinous rings given in Tab. II. Opera Valsalvæ, tom. i. At page 129 they are thus described: "In horum sinuum ambitu quà valvulæ sinubus annectuntur quidem quasi Agger videtur occurrere substantiæ durioris ad similitudinem cartilaginis tarsi palpebrarum." I find also that Gerdy* appears to have had an accurate notion of the form and appearance of these tendinous rings. He was aware of the existence of the projecting angles of the tendinous ring which pass up between the festoons of the middle coat of the arteries, and which have been overlooked in succeeding descriptions. I find also that the late Dr. A. Duncan, jun. has, in his unpublished manuscript, given a very accurate account of these structures in the heart of the ox.

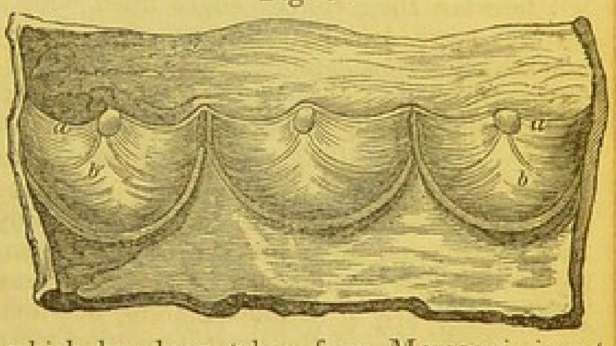
Tendinous structure in the auriculo-ventricular valves.—Distinct tendinous fibres exist in the auriculo-ventricular valves enclosed between the reduplication of the lining serous membrane. These are continuous with the auriculo-ventricular tendinous zones, and are most distinct and of great strength at the base. I could never observe any distinct traces of muscular fibres in these valves in the human heart either when fresh or after long boiling. Bouillaud has, from the examination of one inconclusive case, but principally from analogy with the corresponding valves of the heart of the ox, supposed that they may exist in some cases in hypertrophy of the valves. In making examinations of this kind we must be exceedingly careful not to mistake the tendinous fibres when tinged with blood for muscular fibres, for under these circumstances they certainly at all times assume the appearance of muscular fibres.†

* Journal Complementaire, tom. x.

† In the heart of the dog I have seen a distinct band of transverse muscular fibres in the base of the larger lip of the mitral valve, but could never satisfy myself of the existence of any longitudinal muscular fibres. In the heart of the ox and horse very distinct longitudinal muscular fibres are seen in the valves of both sides of the heart, principally, if not entirely, continuous with the inner layer of the fibres of the auricles. A greater part pass over the inner surface of the tendinous rings, and are firmly attached to the tendinous structure of the valves, reaching nearly to the lower margin of the smaller segments of the valves. The effect of these fibres upon the movements of the valves would form an interesting subject of investigation.

Tendinous structure in the arterial valves.—Distinct tendinous fibres also exist in the arterial valves, which must add considerably to their strength and prevent their more frequent rupture. Three of these tendinous bands in each valve are stronger than the others, and their position deserves attention, as they are often the seat of disease. One of these bands occupies the free margin of the valve, and passes between the projecting extremities of the tendinous festoons (*fig.* 5, *a*). Upon the middle of this band the corpus Arantii, which is formed of a similar texture, is placed. The other band comes from a point a little above the middle of the projecting end of the tendinous festoon (*fig.* 5, *b*), and passes up in a curved manner towards the corpus Arantii, leaving between it and the superior band a triangular space on each side, in which, if any tendinous fibres exist, they are exceedingly obscure. These two tendinous bands were well known to Morgagni. The third band is placed in the attached margin of the valve, and renders this part the thickest and strongest. Between the middle band and the attached margin of the valve a number of weaker bands are placed, which also pass upwards, generally assuming a curved form. Morgagni termed these lower and weaker fibres *fibræ carneæ*, but they evidently belong to the same structure as the stronger bands. The arrangement of these tendinous fibres is best seen in the aortic valves, and the appearance exhibited in the accompanying representation, (*fig.* 5,)

Fig. 5.



which has been taken from Morgagni, is not always distinctly observed, where the valves are perfectly healthy, but become sufficiently obvious in certain cases of disease.

Attachment of the middle coat of the arteries to the arterial tendinous rings.—The inner and outer serous membranes are continued from the heart upon the arteries; the one becoming the inner coat of the arteries, and the other is continued for a short distance upon their external surface. A thin layer of cellular tissue also passes from the heart along the arteries between their middle coat and their external serous membrane. These are, however, so far unimportant compared with the attachment of the middle coat of the arteries to the tendinous festoons which we have just described. The middle coat is so very firmly and strongly attached both to the external edges and to the anterior portion of the upper part of these projecting extremities, (*fig.* 2, *d*,) that it can be detached with great difficulty. Those fibres of the middle coat attached to the projecting extremities, which are apparently of the same number and thickness as in that portion of the artery immediately above, form a distinct curved edge (*fig.* 2, *e*), as they pass from the extremity of one festoon to the other. As we trace the middle coat of the artery downwards into the concavities formed by each festoon, we find that below this curved edge they become strikingly thinner and continue to diminish in thickness and in length, (since they can only stretch between the projecting extremities,) until we arrive at the bottom of the concavity. These three thin portions of the middle coat must then be placed behind the semilunar valves, and correspond to the sinuses of Valsalva.* The thinness of the middle coat at the sinuses of Valsalva will render this portion of the artery more dilatable, and predispose it to rupture when its coats are diseased.† The tendinous zones are distensible, but to a considerably less extent than the middle coat of the arteries. I am not aware that this account of the manner in which the middle coat of the arteries is attached to the tendinous rings has been previously given. I suspect, however, that Dr. Duncan must have been perfectly aware of it from some parts of his manuscript. The differences between these tendinous festoons and the yellow elastic coat of the arteries, and the manner of their attachment, can easily be made out in the human heart; they are, however, more apparent in the larger animals, as the horse and ox. The different characters of the two tissues are obvious at the first glance after boiling, even in the human heart.

Muscular tissue.‡—The greater part of the heart is composed of muscular fibres arranged in a very intricate manner. These fibres are connected together by cellular tissue,* which, however, exists in much smaller quantity in the heart than in the other muscles of the body. These fibres are attached generally by both extremities to the tendinous rings situated around the orifices of the heart; the fibres of the auricles pass upwards to form the auricles, and those of the ventricles downwards to form the ventricles, so that these tendinous rings must form the fixed points towards which all the contractions of the heart take place. None of the muscular fibres of the auricles are continuous at any part with those of the ventricles, and we will find that while some of them are confined to a single auricle, others belong to both. In the same manner a great part of the fibres of the ventricles are common to both, and are interwoven together, while others again belong exclusively to a single ventricle, or, as Winslow† expressed it, the heart is composed of two muscles enveloped in a third. The intimate arrangement of these muscular fibres, particularly those of the ventricles, is exceedingly complex, as the contraction of the organ is not in one particular direction only, but in all directions, and has long been considered as a kind of Gordian knot in anatomy. Vesalius, Albinus, and Haller‡ confessed their inability to trace them, and more lately De Blainville§ assures us, from his own experience, that we can only arrive at very general conclusions (*des choses très-générales*) on this subject. By adopting the method of long-continued boiling of the organ before commencing to attempt to trace the course and arrangement of its fibres, we will find that after a few trials several of the most important points connected with the distribution of these can be ascertained, and by perseverance they can be unravelled to a great extent. By long boiling the muscular fibres are rendered hard and firm, while the tendinous and cellular tissues are softened or dissolved, and the fat melted. Dr. Duncan, who employed this method to a great extent, states that the essential circumstance is to continue the boiling long enough, and that he has never been able to carry it too far. I have found from eighteen to twenty hours generally sufficient for this purpose. Some have recommended that the heart should be previously put for a short time into a strong solution of salt, and Vaust advises that it should be boiled in a solution of nitre, for the purpose of rendering the fibres firmer. The boiling is infinitely superior to the maceration in vinegar. By stopping the boiling before the tendinous rings are rendered too soft, we can easily see their form and their connexions to the muscular fibres.

The general connexion and distribution of

* So striking is the difference between the middle coat as it fills up the concavity of these festoons, and where it stretches between the projecting extremities in the hedgehog, that at first sight it appears to be deficient at that part.

† According to Valsalva aneurisms are frequently found in this situation: "Atque hic aortæ sinus maximus ille est, in quo sæpe aneurysmata circa præcordia contingunt, ut propria observatione edoctus sum." Valsalvæ Opera. Epist. Anat. ed. Morgagni, tom. i. p. 131 1740. This greater tendency to aneurismatic dilatation must depend upon two circumstances. The increased calibre of the artery at this part will increase the pressure upon its walls from the well-known hydrostatic law, that "in a quantity of fluid submitted to compression, the whole mass is equally affected, and similarly in all directions," and the diminished thickness of the middle coat will materially favour this distending force.

‡ While I was engaged in examining the arrangement of the muscular fibres of the heart, Dr. Alison had the kindness to procure for me the manuscript of the late Dr A. Duncan, jun. on this subject. It was well known not only in this country but on the continent that Dr. Duncan had for a very long period attended very particularly to this question, and was in the habit of demonstrating the parts he had ascertained to his pupils. Unfortunately his intentions of publishing on the subject were never carried into execution, and his papers referring to it were left in so confused a state that it is exceedingly difficult and in most parts impossible to make out the description. I have availed myself of those parts that are legible in the following pages, and these I have scrupulously acknowledged. Dr. Duncan's dissections of the heart were taken entirely from the ox and sheep.

* [This however is denied by other observers, and from very recent and careful examinations. See the succeeding article by Mr. Searle.—Ed.]

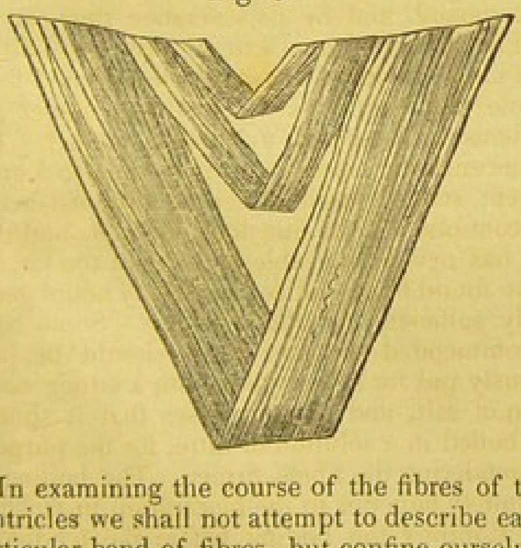
† Mémoires de l'Academie Royale des Sciences, 1711, p. 197.

‡ El. Phys. tom. i. p. 351.

§ Cours de Physiologie, &c. tom. ii. p. 359.

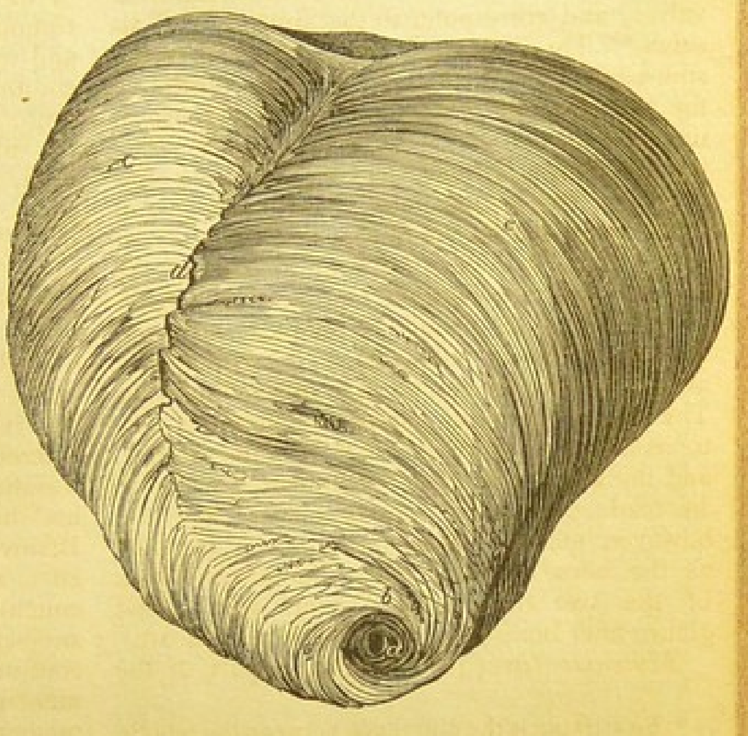
the muscular fibres of the ventricles may be stated to be as follows. 1st, Most of these fibres are connected by both extremities to the tendinous structure of the heart, a fact well known to Lower,* though overlooked by many subsequent anatomists. 2d, The direction of these fibres is more or less oblique, a comparatively small part of them only being vertical, and that too for a limited part of their course. The degree of obliquity of these spiral turns is different in different portions of the heart: they are more oblique on the surface and less oblique as we proceed to the deeper fibres, more particularly at the base. The deeper fibres approach more to the circular form. 3d, As has been already stated, part of these fibres are common to both ventricles; while part only belong exclusively to a single ventricle, and that principally at the base. 4th, The external fibres are longer than the next in order, and after turning round the apex pass upwards into the interior, below the lower margin of the shorter fibres, and form the inner surface of the ventricles, while the deeper again turn up below the lower margin of the fibres next in succession, so that the longer enclose by their two extremities all the shorter fibres. By this arrangement we can explain how the base and middle part of the ventricles should be much thicker than the apex. This arrangement has been particularly insisted upon by Dr. Duncan and Gerdy, and to illustrate it Gerdy has given an ideal illustration, of which *fig.* 6 is a copy.

Fig. 6.



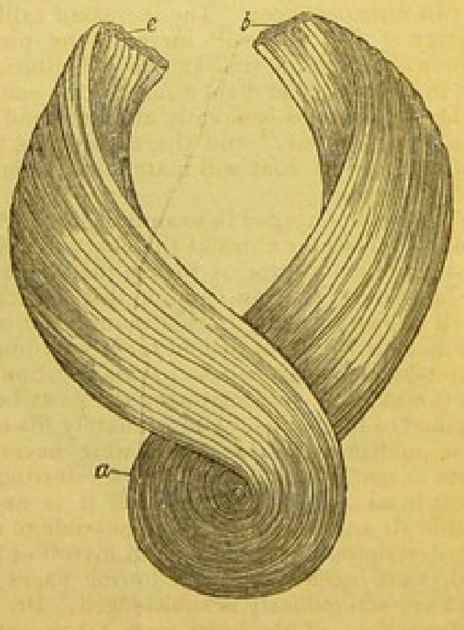
In examining the course of the fibres of the ventricles we shall not attempt to describe each particular band of fibres, but confine ourselves to their general arrangement.† In examining the surface of the ventricles the superficial fibres of the anterior surface are observed to run in a spiral manner from above downwards and from right to left, while those on the posterior surface, which are in general more vertical, run from left to right. Most of these bands are thin and broad at the upper part, and become narrower and thicker as they approach the apex, where they form a remarkable twisting, which has been termed the vortex, (of which *fig.* 7, taken from the human heart after boiling, is an accurate representation,) and then pass in to assist in forming the inner surface

Fig. 7.



of the left ventricle and the columnæ carneæ. The manner in which the external fibres turn in at the apex to form the inner surface of the ventricles and enclose the deeper fibres was well known to Lower, and he has illustrated it by an engraving, of which *fig.* 8 is a copy.

Fig. 8.

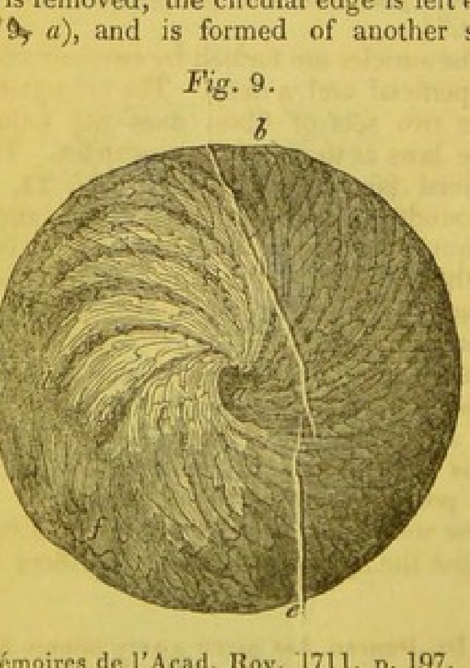


* Tractatus de Corde, p. 34 to 37. Lugd. Batav. 1669.

† Wolff has named and minutely described eight distinct bands of muscular fibres on the surface of the right ventricle: Acta Petropolit. pro anno 1781, tom. viii. p. 251, 1785.

This arrangement of the external fibres was also well known to Winslow* and Lancisi.† Winslow, however, denied that they described the figure of eight, as stated by Lower. More lately Gerdy has given a description of this arrangement, to which he has added an engraving, which approaches more to the appearance of the perfect figure of eight than that given by Lower. I, however, prefer that given by Lower, as it more nearly resembles the arrangement which I have myself seen in tracing these fibres. A small part of the right and posterior side of this vortex is formed by fibres from the posterior surface of the left ventricle, and from that part of the posterior surface of the right ventricle near the septum, and are attached above to the auricular tendinous rings, while the whole of the anterior and left side of the vortex is formed by fibres from the anterior surface and right margin of the ventricles. On tearing these last fibres, which form the principal part of the apex, from the anterior surface of the left ventricle, we find, as we proceed upwards, that a comparatively small part of them cross the anterior fissure upon the right ventricle to reach the right auricular tendinous ring. The greater number dip in at the anterior longitudinal fissure, and we shall afterwards find that they can be traced to the base of the septum of the ventricles. By tearing off these fibres downwards, we open into the apex of the left ventricle. A general notion of the manner in which these fibres, passing from the base of the septum, turn in at the apex, and proceed upwards on the inner surface of the left ventricle, may be obtained from *fig.* 8. To have been quite accurate the inner fibres should have been more scattered, and some of them represented as terminating in the columnæ carneæ. By unravelling the fibres which form the apex, we may open into the interior of the left ventricle without breaking a single muscular fibre. Having thus opened the apex of the heart, although the point is removed, the circular edge is left entire (*fig.* 7 9, *a*), and is formed of another series

Fig. 9.



of fibres, which, like those taken away, advance spirally from the base to the apex, and turning over the edge (*fig.* 7 9, *b*) ascend in the opposite direction, continuing their course after being reflected. "Proceeding in the same manner the whole apex of the left ventricle may be removed, and the same principle of arrangement is found throughout the whole heart even to the base. When we get down as far as the apex of the right ventricle, although the principle remains the same, its effects are more complicated, as it applies to two cavities instead of one." I have frequently satisfied myself of the correctness of the description contained in this passage, which I have quoted from the manuscript of Dr. Duncan. This is the same kind of arrangement which, we have already stated, has been insisted upon by Gerdy, but which we believe can be more satisfactorily seen by tracing the fibres in this manner. Gerdy lays it down as a general law that all the fibres of the heart form loops, the apices of which look towards the apex of the heart (*fig.* 6). I find that Dr. Duncan states that while the apices of those loops which form the lower part of the heart point to the apex, as Gerdy has described, "yet he commits a great error when he asserts that the apices of all the fibres of the heart point in that direction, since the number of tops which point in the opposte direction is not less."* When the superficial fibres of the heart have been removed as represented in *fig.* 7 9, we will find that if we trace the great mass of fibres occupying the lower and middle part of the left ventricle, they will be seen to run spirally in strong bundles from above downwards and from right to left, to wind round and form the posterior as well as the anterior part of the point of the heart; that the greater mass pass in at the apex of the left ventricle to assist in forming the columnæ carneæ and internal surface, while others pass in at the apex of the right ventricle, and others again, after turning a little upwards, dip into the interior below some of the higher fibres. On tracing them upwards, on the other hand, they dip in at the anterior longitudinal fissure (*fig.* 7 9, *d*) where they are as it were dovetailed with other fibres from the anterior surface of the right ventricle passing in at the same fissure, and then mount almost vertically upwards to the base of the septum, forming part of the septum of the right ventricle, only separated from its lining membrane by a thin layer of fibres, and are inserted in a strong band in the ox into the bone of the heart, which is placed between the auriculo-ventricular openings and aorta, while in the human heart they are spread

* Mémoires de l'Acad. Roy. 1711. p. 197.

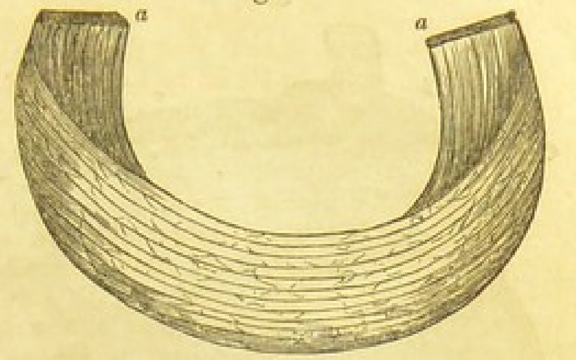
† De Motu Cordis: Opera omnia, tom. iv. p. 96. 1745.

* I could not discover in Dr. Duncan's manuscript any other description or allusion to the fibres here mentioned whose arrangement is opposed to the general law which Gerdy is anxious to establish. There is no doubt, however, that many of these loops at the base are principally directed to the periphery of the organ, and very little downwards, and that a few in the infundibulum are slightly directed upwards.

over a wider surface at this their upper insertion. I have been more particular in describing this part of the heart, as this arrangement of the fibres appears to me to be intimately connected with the production of the tilting motion of the heart. The fibres which occupy the upper part of the anterior surface of the left ventricle, as well as those occupying the upper part of the posterior surface (nearer the base than those bands already described as passing from the anterior surface), partly dip into the interior of the left ventricle as they wind round it, partly pass in at the posterior longitudinal groove to assist in forming the septum, while other strong bands, more particularly near the base, cross this groove and dip into the interior of the right ventricle. In the human heart I have stripped off pretty strong superficial bundles from the upper part of the posterior surface of the left ventricle over the posterior longitudinal groove, and over the surface of the right ventricle as far as the anterior longitudinal fissure, into which they dipped. In stripping off the fibres from the posterior and anterior surface of the right ventricle at this stage of the dissection, part of them disappear in their course around the ventricle, where they dip in to assist in forming the interior; others proceed as far as the anterior groove before they dip inwards; while part of the fibres which arise from the conus arteriosus cross the upper part of the anterior fissure upon the anterior surface of the left ventricle, where they pass into the interior of the left ventricle. These fibres, crossing the anterior surface of the right ventricle, and which dip in at the anterior fissure, form the inner surface of the septum of the right ventricle. On tracing those fibres which dip inwards at so many different points, they are observed to rise upwards to the tendinous rings either directly or indirectly through the medium of the chordæ tendineæ. In following the fibres in this manner we perceive the intimate connexion that exists between the two ventricles, and that their contraction must be simultaneous. We also see that comparatively few fibres cross the anterior longitudinal groove except near the base, while large bundles of fibres cross the posterior groove. When these fibres crossing the two grooves have been torn away, the two ventricles become detached from each other. By this time the apices of both ventricles have been opened.

On examining the deeper fibres (which occupy that part of the heart near the base), they are seen to form a series of curved bands, of one of which *fig.* 10 is a representation. These bands are imbricated, the lower disappearing by its internal extremity below the higher, so as to be inserted by that extremity into the tendinous rings at a point more internal than the corresponding extremity of the higher bands. Some of these bands are common to both ventricles, others belong exclusively to one. The fibres of the right ventricle become very complicated where they form the conus arteriosus and fleshy pons between the

Fig. 10.



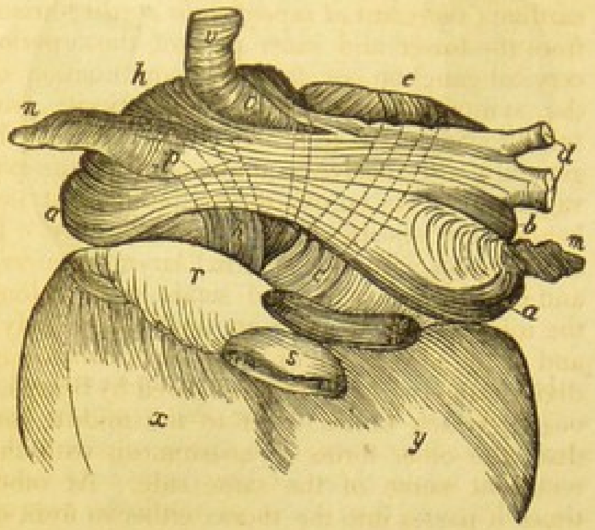
pulmonary artery and right auriculo-ventricular orifice. The fibres of the left ventricle are stronger and coarser than those of the right ventricle, while those of the conus arteriosus are still firmer than those on the lower part of the right ventricle.* "There do not occur in any part of the heart cellular sheaths or tendinous aponeuroses dividing bundles of fibres as separate muscular fasciculi. Although a complex it is not a compound muscle, and does not consist of a number of distinct bellies or heads. The only thing approaching to this structure are the columnæ and a strong muscular stay between the peripheral and septal wall of the pulmonic ventricle, and the reticulated texture on the inside of the ventricles, much more conspicuous in man than in oxen." "Many fibres are attached to each other by agglutination or in a manner not easily understood." "Many fibres bifurcate, and the divided fibres follow different directions: or two fibres from different parts approximate, and at last are united and proceed as one fibre. I am doubtful if this can be considered as a tendinous point of union of all three. These points of union are often arranged in one line so as to give some appearance of a pennated muscle, but the tendinous points, if they exist, do not adhere to form membranes or strings. This bifurcation is very evident in the connection of the septal with the peripheral walls of the heart."†

The auricles are formed by two sets of fibres, a superficial and a deep. The arrangement of these two sets of fibres does not follow the same laws as those of the ventricles. The superficial layer (*fig.* 11, *a a*, *fig.* 12, *a a*), surrounds the base of the auricles, and is of unequal height and thickness. It is broader on the anterior and narrow on the posterior surface, more particularly on the posterior and outer part of the right. It extends upwards towards their superior edge on the anterior surface, and on the posterior surface of the left as far as the inferior pulmonary veins. It is very thin, particularly on the outer and posterior part of the right auricle. In its course round the auricles the fibres diverge to enclose the appendices, and the orifices of the

* Dr. Duncan has given a very minute description of the fibres of this and other parts of the heart, which are much too long for insertion here. He has also given a very accurate and minute description of the bone in the heart of the ox.

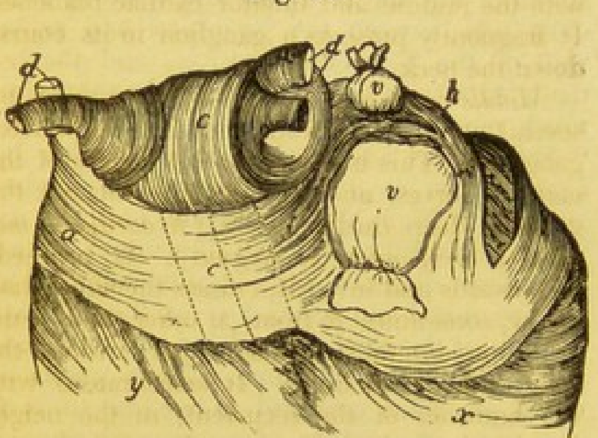
† Dr. Duncan.

Fig. 11.



large veins. These fibres cross transversely between the anterior surface of the two auricles and connect them together. These superficial fibres are also prolonged into the interauricular septum (*fig.* 12, *f*) to assist in forming the

Fig. 12.



circular band of fibres which surrounds the fossa ovalis. Gerdy figures a superficial band of fibres (*fig.* 11, *b*) as belonging exclusively to the left auricle.

The deep fibres belong exclusively to a single auricle. They are superficial at various parts, where the external or circular fibres are deficient. By their inner surface they are connected to the inner membrane of the auricles, and a thin layer of cellular tissue unites their outer surface to the inner surface of the superficial fibres. In the left auricle Gerdy describes, 1st, a left auricular loop (*fig.* 11, *c c*, *fig.* 12, *c c*), which embraces the auricle from its superior edge to its base, which runs a little obliquely to the left, before, above, and then behind the auricle, and is attached by its extremities to the auricular tendinous ring near the septum. It is contracted at that part where it passes between the pulmonary veins. 2d. The pulmonary veins are surrounded by circular fibres (*fig.* 11, *d d*, *fig.* 12, *d d*), which are continued along their course to a variable extent,—sometimes they merely surround the termination of one or more of these veins, at other times I have seen them prolonged outwards as far as the roots of the lungs. These fibres generally form a continuous layer, and of sufficient thickness to render them capable of constricting these vessels considerably. 3d. Some fibres proper to the appendix (*fig.* 11, *m m*), which, by passing between and uniting themselves to the other fibres of the appendix, form that reticulated appearance which it presents in its inner surface. Some of these fibres are circular, others form incomplete circles.

In the right auricle, Gerdy has described, 1st, a right auricular loop (*fig.* 11, *h h*, *fig.* 12, *h*), which is attached anteriorly to the tendinous structure at the base of the auricle; it extends upwards in the anterior edge of the septum auriculorum; it then curves round the fossa ovalis, of which it forms the projecting edge, and at the orifice of the vena cava superior it divides into a right and left band. The first proceeds downwards, becomes engaged with some of the superficial fibres around the cava superior, and forms the angle between them (*tuberculum Loweri*), from which it passes downward to the auricular tendinous ring along the right side of the cava inferior. The left division passes along the left side of the cava inferior, in the posterior edge of the auricular septum, where it intermixes with the fibres which embrace the entrance of the coronary vein. 2d, Some muscular fibres (*fig.* 11, *p*), which pass between the anterior part of the tendinous ring and the appendix. 3d, Some circular fibres, which surround the entrance of the cava superior (*fig.* 11, *o*): these do not extend upwards beyond the orifice of the vein. 4th, The bundles of fibres which arise from the right side of the auricular ring proceed upwards to the posterior part of the appendix, and form the musculi pectinati seen in the interior of the auricle. 5th, A few fibres proper to the auricle (*fig.* 11, *n*), which assume the circular form. The action of all these fibres superficial as well as deep must be to diminish the capacity of their cavities, and draw them towards the auriculo-ventricular openings, and thus favour the passage of their contents through these openings.

Inner membrane of the heart.—Each side of the heart has its own lining membrane, and both of these are closely allied to the serous membranes in structure and appearance. They are continuous with the inner coat of the vessels which open into their different cavities. These have been termed the endocarde by Bouillaud to distinguish them from the serous coat of the pericardium on the outer surface of the heart. If we commence to trace the inner membrane of the right side from the entrance of the two cavæ, we find that it is folded upon itself to form the Eustachian valve at the entrance of the inferior cava; it then passes upon the inner surface of the auricle, and at the opening of the coronary vein it is again folded upon itself to form the valve of the coronary vein. It passes through the auriculo-ventricular opening, adheres to the inner surface of the tendinous ring, and is there folded upon itself to assist in forming the tricuspid valve. It now proceeds upon the inner surface of the ventricle, and at the origin of the pulmonary artery it assists in forming the semilunar valves, and becomes continuous with its inner coat. If we trace the inner membrane of the left side of the heart from the entrance of the pulmonary veins, we find that, after lining the auricle, it is continued through the auriculo-ventricular opening, and is there folded upon itself to assist in forming the mitral valve. In the left ventricle it surrounds the chordæ tendineæ and unattached columnæ carneæ in the same manner as in the right ventricle; and at the origin of the aorta it assists in forming the semilunar valve, and becomes continuous with the inner coat of the artery. These membranes adhere intimately to the inner surface of the heart by close cellular tissue, and have their inner surface perfectly polished and smooth. That of the left auricle is thicker than that of the right. They are thicker in the auricles than in the ventricles. In the ventricles, except near the origin of the large arteries, they are exceedingly thin.

Nerves of the heart.—The heart is supplied with nerves from the sympathetic and par vagum. The sympathetic branches come from the superior, middle, and inferior cervical ganglia, and frequently also from the first dorsal ganglion. The branches from the par vagum come directly from the trunk of the nerve, and indirectly from the recurrent or inferior laryngeal. The course of these on the right side differs from those of the left in some respects, and requires a separate description. These nerves, like most of the other branches of the sympathetic, are very irregular in their size, number, and origin, so that it would be difficult to find two subjects in which they are exactly alike; they are also very irregular in their course before they reach the cardiac plexus, but become more regular when they gain the arteries of the heart, whose branches they accompany. These nerves, after forming different anastomoses and plexuses with each other of the same side, converge at the upper and back part of the arch of the aorta, where they form a free anastomosis with those of the opposite side, and then pass on to the heart. The left cardiac nerves are sometimes much smaller than those on the right side, so as to appear, as in the dissection described by Lobstein,* merely accessory to those on the right. On the other hand the size of those on the left side may preponderate considerably over those on the right. The proportional size of the different nerves of the same side is also very various. When the nerves of one side are small, the deficiency is made up by the greater size of those of the opposite side; and when any particular branch is either unusually small or entirely wanting, its place is supplied by the greater size of the other nerves of the same side, or of those of the opposite side. The branches from the par vagum, particularly those coming from the recurrent, vary also considerably in size. All the sympathetic branches of the cardiac plexuses are of a gray colour, and are generally not so soft as Scarpa has described them.

The right cardiac branches of the sympathetic are generally three in number: 1st, superior cardiac (*supremus et superficialis cordis*) arises from the lower and inner part of the superior cervical ganglion, or from the continuation of the sympathetic between the superior and middle ganglia, or from both these origins. It generally also receives a filament from the par vagum. In its course down the neck it lies behind the sheath of the carotid artery. It anastomoses with the external laryngeal nerve and descendens noni, and sends a twig along the inferior thyroid artery to the thyroid body; and at the lower part of the neck it sometimes divides into two branches as figured by Scarpa,* one of which unites itself to the middle cardiac, the other forms an anastomosis with the recurrent nerve of the same side. At other times it passes into the thorax either in front or behind the subclavian artery, takes the course of the arteria innominata, and reaches the posterior part of the arch of the aorta, where it anastomoses with branches of the middle and inferior cardiac nerves, or with branches of the recurrent. It more rarely appears to pass to the cardiac plexus without any anastomosis with the middle and inferior cardiac branches. It frequently presents a ganglion in its course down the neck.

Middle cardiac nerve.—This nerve arises by several short twigs from the middle cervical ganglion. This is generally the largest of the cardiac nerves, and is named by Scarpa the great or deep cardiac nerve (*n. cardiacus medius, s. profundus, s. magnus*). It proceeds downwards and inwards, crosses the subclavian artery, sometimes in front, at other times it divides into several branches, which surround the artery and again unite. It anastomoses with the branches of the recurrent, in the neighbourhood of which it runs, also with the par vagum, superior and inferior cardiac nerves; and following the course of the arteria innominata it passes behind the arch of the aorta to terminate in the cardiac plexus.

Inferior cardiac nerve (n. cardiacus minor of Scarpa).—This nerve generally arises by filaments from the inferior cervical ganglion, sometimes from the first dorsal ganglion, at other times from both. It proceeds behind the subclavian artery near to the recurrent nerve. It follows the course of the innominata close to the middle cardiac, with which it anastomoses, and proceeds to join the cardiac plexus.

Left cardiac nerves.—Perhaps the differences in the course of the right and left cardiac nerves are principally to be attributed to the known differences between the large arteries of the two sides. The left superficialis cordis is figured by Scarpa† as dividing a little above the arch of the aorta into four branches; two of these pass in front of the aorta to form an anastomosis with a branch of the par vagum and deep cardiac; a third also passes in front of the aorta to unite itself with the middle cardiac; and the remainder of the nerve proceeds behind the arch to unite itself with the cardiac plexus.

* De Nervi Sympathetici humani fabrica, &c. pp. 16 & 18.

* Tab. iii. Tabulæ Neurologicæ, &c.
† Tab. iv. op. cit.

The left middle cardiac nerve is generally smaller than the right, and is frequently partly formed by a branch from the inferior cervical ganglion. It passes behind the arch of the aorta, sometimes in the form of a single trunk, sometimes double, at other times triple, and generally throws itself into the upper and left part of the cardiac plexus.

Cardiac plexus (great cardiac plexus of Haller) is placed behind the arch of the aorta and in front of the lower part of the trachea, extending from the arteria innominata to the right branch of the pulmonary artery, and is formed by the convergence of nearly the whole of the cardiac nerves of both sides, but more particularly of the middle cardiac nerves. There is occasionally a distinct ganglion at the junction of these nerves; more generally there is only a plexiform arrangement. From this plexus a very few branches pass upon the anterior surface of the aorta *(cardiaci superficiales aortæ)*, and anastomose with the right coronary plexus: some twigs also pass backwards to anastomose with the bronchial plexuses. By far the greater part of the cardiac plexus proceeds to the heart in the form of two large divisions to form the right and left coronary plexuses which accompany the coronary arteries. Where the right branch leaves the lower part of the plexus there is a gangliform swelling (ganglion of Wrisberg), which is occasionally, however, very indistinct. This ganglion furnishes the greater part of the superficial plexus of the aorta which we have just described. This great right cardiac branch divides into two parts; the smaller passes between the aorta and pulmonary artery to reach the right side of the origin of the pulmonary artery, where it attaches itself to the right coronary artery to form the principal part of the right coronary plexus; the other and larger portion creeps under the pulmonary artery to the posterior part of the heart, to assist in forming the left coronary plexus. The great left cardiac branch, which principally comes from the upper part of the cardiac plexus, and at first passes from right to left posterior to the ductus arteriosus, after which it is joined by other smaller branches which pass in front of the ductus arteriosus. It also divides into two branches; the smaller passes between the aorta and pulmonary artery, and reaches the origin of the right coronary artery, and throws itself into the right coronary plexus; the larger bends round the posterior surface of the pulmonary artery to reach the left coronary artery, where it forms, with the larger branch of the right, the left coronary plexus. There is thus a free interchange of filaments between the nerves of both sides. The left coronary plexus is considerably larger than the right, in proportion as the left side of the heart is thicker than the right. These coronary plexuses consist of a number of minute filaments which accompany the ramifications of the coronary arteries everywhere, and are distributed upon the surface of the auricles as well as upon the ventricles. They anastomose with each other upon the anterior and posterior surface of the heart. All the nerves of the heart enter into its substance upon the surface of the arteries, and cannot be traced beyond the second or third division of the arteries. The nerves of the heart are generally considered to be small compared to the size of the organ.* Though the nerves of the heart are not equal in size to those of the tongue and eye, yet Scarpa is doubtful if they are not equal to the nerves of the other voluntary muscles, as, for example, the muscles of the arm. It must be remembered that the minute subdivision and diffusion of these nerves over a large extent of surface, by which many of them can only be seen after a minute examination, causes them to appear of less size than what they collectively really are. Soemmerring maintained that very few of the nerves of the heart were distributed to the muscular tissue of the heart, and that they more properly belonged to the arteries: "nervi cardiaci proprie ad arterias, ad aortam et arterias coronarias pertinent, eaque filia subtilia nervorum parum sibi (cordi) constant."† Behrends, the pupil of Soemmerring, affirmed that not a single twig went to the muscular tissue of the heart, but that they were entirely distributed on the coats of the arteries.‡ The announcement of these opinions, bearing so directly as they do upon the Hallerian doctrine of the nature of irritability, so keenly agitated immediately before throughout Europe, could not fail to create considerable sensation at the time, and it is probable that to this we owe the splendid work of Scarpa upon the nerves of the heart, which has entirely set the question concerning the distribution of these nerves at rest. Scarpa has shown that when followed to their minute distribution, the nerves of the other muscles accompany the arteries in the same manner as the nerves of the heart, and that the nerves of the heart only differ from those of voluntary motion in this, that the nerves accompanying the arteries of the voluntary muscles are firmer and thicker than those of the heart.

Bloodvessels of the heart.—The heart is supplied with blood by the two coronary arteries, for a description of which see Aorta. The blood is returned by the coronary veins. The branches of the coronary veins generally accompany those of the arteries. They are divided into the larger coronary vein and smaller coronary veins.

Great coronary vein (vena coronaria maxima cordis).—This vein is formed by several branches, three of which surpass the others considerably in size. One of these lies in the anterior longitudinal groove; another runs along the obtuse or left margin of the heart; and the third, which may be replaced by two or three

* Bichat in his Anatomie Générale says, "that the nervous mass intended for the muscles of organic life is much inferior to that of the voluntary muscles. The heart and deltoid muscle, on being compared together, display in this respect a very considerable difference."

† Corporis humani fabrica, tom. v.

‡ Dissertatio qua demonstratur cor nervis carere. After making this general statement, he admits, in one part of his treatise, that he has traced two twigs of the cardiac nerves into the substance of the heart.

smaller veins, runs along the posterior surface of the left ventricle, between the obtuse margin and posterior longitudinal groove. The first of these is frequently described as the trunk of the vein, and it commences at the apex of the heart, where it anastomoses with the smaller posterior and anterior veins. It runs upwards in the anterior longitudinal groove along with the left coronary artery, gradually increasing in size as it ascends, from the junction of the other veins. When it reaches the base of the ventricles it changes its direction, enters the groove between the left auricle and ventricle, leaves the coronary artery, passes from left to right in the posterior part of the same groove, when it becomes considerably dilated *(sinus of the coronary vein)*. It then opens into the right auricle at its lower and back part close upon the posterior edge of the septum auriculorum.

Smaller posterior coronary vein (vena coronaria cordis minor).—It commences at the apex of the heart, runs up in the posterior longitudinal groove, or a little to its right side, and receives its blood principally from the right ventricle. It generally joins the sinus of the coronary vein; at other times it enters the auricle separately immediately by the side of the great coronary vein, so that its aperture is also covered by the coronary valve.

Smaller anterior coronary veins (venæ innominatæ of Vieussens).—These are very small and variable in number, and are placed on the anterior surface of the right ventricle. One of these, larger than the others, (generally the superior,) sometimes receives the name of anterior vein of Galen. They frequently unite to form a single trunk; more generally perhaps they continue separate, pass in front of the right coronary artery as it lies in the auriculo-ventricular groove, and enter the right auricle at its anterior and inferior part. One of the musculi pectinati overlaps their entrance, forming a kind of valve.

Venæ minimæ, or *veins of Thebesius*, are minute veins, which enter the auricle at various points. It was maintained by Vieussens, Thebesius, and Ruysch, that some of the coronary veins opened into the left side of the heart, thus producing a slight intermixture of the dark blood with the arterial. This has been more lately asserted by Abernethy,* and has been supposed to occur more frequently in phthisical cases; the difficulty of transmitting the blood through the lungs causes their enlargement. Such injections are liable to great fallacy, from the great facility with which fine injections, or even coarse injections when forcibly pushed into the vessels, escape into the cavities of organs. Especial care is, therefore, required in conducting them. Notwithstanding that we have the authority of some of the most accurate anatomists in favour of this opinion, it is very doubtful if any of these veins open into the left side of the heart.†

Sinus of the coronary vein.—This is always described as a dilatation of the large coronary vein, but I have found it decidedly muscular in man and in several of the Mammalia, as the dog, horse, ox, and sheep; and it presents the appearance of a muscular reservoir placed at the termination of this vein, similar to the auricles at the termination of the two cavæ. This sinus is placed in the posterior part of the groove between the left auricle and ventricle, adheres intimately to the outer surface of the auricle, and communicates by one extremity with the auricle, and by the other with the large coronary vein. The commencement of the dilatation is generally abrupt, and the first appearance of the muscular fibres well defined. I have seen it vary from two inches to only half an inch in length. These muscular fibres are generally circular; part of them, however, are oblique. Some of them belong exclusively to the vein; a great part appear to be connected with the muscular fibres of the auricle. This muscular sinus must serve to prevent regurgitation along the coronary veins. I have also generally found a distinct valve at the termination of the coronary vein in the sinus. This valve resembles the valves found in the veins of the extremities. It is generally single, sometimes it is double. I have also occasionally found one or more single valves in the course of the vein.* A distinct valve may also occasionally be seen at the termination of the posterior coronary vein in the sinus. Portal† mentions that he has seen the coronary valve situated in the interior of the vein a little from its mouth. Thebesius and Morgagni have observed valves placed in some of the smaller veins where they terminate in the larger. The valves of the coronary veins do not in general prevent the passage of injections contrary to the course of the blood along them.

Lymphatics of the heart.—The lymphatics of the heart are divided into two sets—superficial and deep; the superficial commencing below the external serous membrane, and the deep upon the internal membrane. They follow the course of the coronary vessels. Some of them pass directly into the thoracic duct, and, according to Meckel, sometimes directly into the subclavian or jugular veins. Others pass into the lymphatic glands situated in front of the arch of the aorta, while others pass into the glands situated around the bifurcation of the trachea, and a few also join the lymphatic vessels of the lungs.

Pericardium.—The pericardium is a fibrous

* Philos. Trans. 1798.

† Professor Jeffray (Observations on the Heart, &c. of the Fœtus, p. 2) mentions a case in which the large coronary vein opened into the left auricle. Lecat (Mém. de l'Acad. des Scien. 1738, p. 62) found the coronary veins in a young child unite themselves into a single trunk and enter the left subclavian. It is probable that Soemmerring had this case in view when he states, "Rarissime vena hæc in vena subclavia *dextra* finitur," (de corp. hum. fab. tom. v. p. 340. 1800) particularly as Haller, (Element. Phys. tom. i. p. 375, 1757), in quoting the case, has inadvertently substituted the word *dextra* for *sinistra*.

* I have seen two or three pair of double valves in the course of the coronary vein in the horse and ass. These animals have no Thebesian valve.

† Anatomie Médicale, tom. iii.

bag surrounding the heart and origin of the large bloodvessels, but without any direct attachment to the heart itself, having its inner surface lined by a serous membrane. It is from this latter circumstance that it is generally termed a fibro-serous membrane. It is placed behind the cartilages of the second, third, fourth, and fifth ribs of the left side and middle part of the sternum. Posteriorly it rests upon the parts contained in the posterior mediastinum; anteriorly it corresponds to the anterior mediastinum, and may be reached by perforating the left side of the sternum, as has been proposed in some cases of hydrops pericardii. The pleuræ adhere to its lateral and part of its anterior surface by pretty close cellular tissue, when the interposed fat is small in quantity. The phrenic nerves with their small accompanying arteries pass down the thorax between the pleuræ and lateral surfaces of the pericardium. Below, the fibrous part of the pericardium adheres intimately to the upper surface of the cordiform tendon of the diaphragm, and is also connected by pretty dense cellular tissue to the upper surface of the muscular fibres running into the anterior part of the left lobe of the tendon. It adheres more firmly to the cordiform tendon at the edges, particularly anteriorly, than at the centre. It is broader below where it adheres to the upper surface of the diaphragm, narrower above where it is attached to the large vessels that pass in and out from the heart. Upon these large vessels the fibrous part of the pericardium is prolonged, forming a kind of sheath, which gradually becomes thinner until it is confounded with the cellular coat of the vessels. From the manner, however, in which the vena cava inferior enters the heart, it can have no fibrous sheath of this kind. At the different points where the fibrous coat becomes applied upon these vessels, and where the cava inferior passes through the cordiform tendon, the serous coat is reflected upon the outer surface of the vessels, and accompanies them back to the heart to cover the outer surface of that organ. In this manner the serous part of the pericardium is a shut sac, the outer surface of which adheres to the inner surface of the fibrous portion, and to the outer surface of the heart. The inner surface, like that of all the other serous membranes, is unadherent, smooth, and shining, and is everywhere in contact with itself, and only contains the small quantity of fluid which serves to lubricate its interior. The serous portion of the pericardium adheres intimately to the inner surface of the fibrous. At that part, however, where the serous leaves the fibrous to pass back upon the surface of the large vessels, there is a small triangular space left between them. The serous membrane is reflected upon and covers the outer surface of the aorta rather more than two inches above its origin; upon the pulmonary artery about the same distance and immediately before its bifurcation; upon the cava superior about an inch above its entrance into the right auricle; upon the cava inferior shortly before it reaches the heart; upon the two right pulmonary veins soon after they have emerged from the right lung; and upon the left pulmonary veins shortly before they enter the auricle. This serous membrane, in passing upon the aorta and pulmonary arteries, covers the anterior surfaces of both before it passes round upon their posterior; it then envelopes both arteries in the same sheath, so that their opposed surfaces are only separated from each other by a little cellular tissue. It leaves part of the posterior surface of the cavæ and pulmonary veins uncovered, occasionally, however, enveloping the whole or nearly the whole, of the left pulmonary veins. It adheres but loosely to the large bloodvessels, and firmly to the outer surface of the auricles and ventricles. The attachment of the fibrous part to the cordiform tendon is very firm at the edges and blended with the tendon, but becomes looser towards the centre. Cloquet* describes the serous membrane as lying in contact with the upper surface of the cordiform tendon; or, in other words, he appears to consider the fibrous part not to be prolonged over the upper surface of the tendon, but to stop at its attached margin. In most cases I have been able to trace the fibrous part of the pericardium over the upper surface of the cordiform tendon, but almost always more or less diminished in thickness. In some cases I was unable to detect anything like a fibrous layer at this part. The fibrous part of the pericardium is comparatively thin, and is composed of tendinous fibres interwoven together. It is not much larger than sufficient to contain the heart when its cavities are distended. This fact taken along with the physical properties of the membrane, not admitting of sudden dilatation, explains how the sudden escape of a small quantity of blood (8 oz. or sometimes less) into the interior of the pericardium is sufficient to arrest the heart's action.

The arteries of the pericardium are small and come from various sources, from the bronchial, œsophageal, phrenic, from the arteries of the thymus gland, internal mammary, coronary arteries, and the aorta itself. Its veins partly terminate in the azygos, and partly accompany the corresponding arteries to terminate in the veins of the same name. Its lymphatics pass to the glands placed around the cava superior. The nerves can be traced into its texture.

Uses of the pericardium.—The pericardium restrains within certain limits the irregular movements of the heart. The inner serous surface of the pericardium must also facilitate its ordinary and healthy movements.

Relative position of the vessels within the pericardium.—The pulmonary artery at its origin overlaps the anterior surface of the aorta as it springs from the left ventricle. (See *fig.* 11, *s*, for the relative position of these vessels at their

* Traité d'Anatomie Descriptive, p. 633, translated by Knox. Cloquet does not state distinctly that the fibrous part of the pericardium is not continued over the cordiform tendon, but this may be inferred from the statement that the serous membrane "is applied below, directly and in a very close manner upon the aponeuroses of the diaphragm."

origin.) It then proceeds into the concavity of the arch of the aorta, and as it is about to pass through the fibrous coat of the pericardium, it divides into its two branches, the right and left. The left branch passes in front of the descending portion of the arch of the aorta to reach the left lung; the right branch passes behind the ascending portion of the arch to reach the right lung. In the fœtus the pulmonary artery divides into three branches, the two we have just mentioned, and a third, the ductus arteriosus, which unites the pulmonary artery to the descending portion of the arch,—in other words, after the aorta has given off the large branches to the head and superior extremities. The descending cava, immediately before it perforates the fibrous coat of the pericardium, crosses the right branches close upon the bifurcation of the trachea; within the pericardium it lies on the right side of the ascending portion of the arch of the aorta. The inferior cava is seen perforating the cordiform tendon of the diaphragm, and almost immediately afterwards it enters the posterior and inferior angle of the right auricle. The pulmonary veins are placed inferior to the two branches of the pulmonary artery. The two right pulmonary veins pass behind the right auricle to reach the left, which they enter near the septum auriculorum.

Peculiarities of the fœtal heart.—(For an account of the developement of the heart and large bloodvessels see OVUM.) The heart of the fœtus before the fourth month is placed vertically, but towards that period the apex begins to turn towards the left side. The auricular part of the heart is considerably larger in proportion than the ventricular. The relative size of the heart to the body at birth differs considerably from that of the fœtus at an earlier period of its developement. According to Meckel the relative size of the heart to the body about the second or third month of uterine life is 1 to 50; at birth and for a few years afterwards as 1 to 120. The greater size of the heart of the fœtus seems to depend principally upon the greater thickness of the walls of its cavities. The great disparity between the thickness of the two sides so very apparent shortly after birth does not exist in the earlier periods of uterine life, though also generally sufficiently well-marked in the fœtus at the full time. This is explained by the circumstance that the two sides of the heart at this period have nearly equal obstacles to overcome in propelling the blood.* In the earlier stages of its developement the infundibuliform portion of the right ventricle is less prominent than at a later period. The left ventricle is at first a little larger than the right; at birth and for a short while after they are equal. The two auricles communicate with each other through the foramen ovale.* This foramen is at its maximum size about the sixth month.

Valve of the foramen ovale.—This valve, which, however, can scarcely be called a valve, as it is a provision for effecting the obliteration of the foramen ovale at the time the child assumes its independent existence, first makes its appearance at the lower part of the foramen about the third month, or, according to Senac and Portal, about the second month. It is formed by the inner membranes of the two sides of the heart, containing some muscular fibres between them, particularly at its lower part. It is of a semilunar form; its convex edge adheres to a greater or less portion of the margins of the valve as its growth is more or less advanced; its concave margin, which is free and loose, looks upwards and forwards. This valve may be said to belong almost exclusively to the left auricle, as it is attached to that margin of the foramen.† Though this valve is of sufficient size at birth to shut the foramen, yet its concave or upper margin is easily depressed so as to leave a considerable interval between it and the upper margin of the foramen. We will find, from the manner in which the valve is attached to the left margin of the foramen, that it is much more easily depressed by a current passing from the right auricle into the left than in the opposite direction. In fact any force of this kind applied in the opposite direction would rather tend to keep the valve applied to the upper edge of the opening; a circumstance which occurs after birth when the blood flows along the pulmonary veins into the left auricle, and which must materially assist in producing complete obliteration of the foramen. The manner in which the blood passes between the auricles through the foramen ovale in the fœtus was the subject of a violent controversy in France at the termination of the seventeenth and the commencement of the eighteenth centuries. It was first commenced between Meri on the one side, who had proposed a new theory of the fœtal circulation by which the blood was made to pass from the left auricle into the right, and by Duverry and Fauvery on the opposite side, who maintained the opinion of Harvey, and which is now universally adopted, that it passes from right to left. Many celebrated anatomists and mathematicians attached themselves to the opposite parties, and at last the controversy extended itself to the neighbouring kingdoms.‡

Eustachian valve.—This valve, the appearance and position of which have been already

* In two fœtuses, however, which I lately examined, and where I had positive evidence that they had not yet reached the sixth month of utero-gestation, the difference between the thickness of the two ventricles of the heart was distinctly marked.

* This opening is frequently termed *trou de Botal* by the French writers though described by Galen.

† This explains how the depression (fossa ovalis), marking in the adult the position of the valve, should be better seen from the right than the left auricle.

‡ Those who may be anxious to acquaint themselves more fully with the nature of this controversy and to examine the arguments adduced on both sides may consult the Mémoires de l'Academie for that period, and Senac's Traité de la Structure du Cœur, tom. i. p. 369, and the Supplement in tom. ii.

pointed out in describing the interior of the right auricle, is also intimately connected with the peculiarities of fœtal life. It was discovered by Eustachius about the middle of the sixteenth century, who contented himself by pointing out its position. Little attention was paid to it until the commencement of the eighteenth century, when it was more particularly brought into notice by Boerhaave and Lancisi, who published a new edition of the works and plates of Eustachius, which had then become very scarce. Lancisi supposed that this valve prevented the blood of the superior cava from falling with too much force upon the column ascending by the cava inferior. Winslow,* finding it only perfect in the fœtal state, and having cause to believe that its diminution kept pace with the increase of the valve of the foramen ovale, was led to adopt the opinion that its presence had a special reference to that state, and believed that it not only served to break the current of the superior cava as stated by Lancisi, but also opposed the regurgitation of the blood of the auricle into the inferior cava. In the absence of this valve he supposed there would arise two inconveniences in the fœtus—the imperfect intermixture of the contained blood, and the regurgitation of the blood of the umbilical vein into the placenta. Senac† believed that the Eustachian valve can have no effect in preventing the blood of the cava superior from falling upon the current ascending by the cava inferior, and that it must direct a part of the blood of the cava inferior through the foramen ovale. Sabatier‡ more particularly pointed out that from the position of this valve passing from the anterior and left part of the vena cava inferior to the left side of the foramen ovale, and from the situation of the foramen ovale at the inferior part of the auricle, the blood of the cava inferior must be directed through the foramen ovale; and further, from the difference in the direction of the two cavæ themselves—the superior looking downwards, forwards, and to the left side, while the inferior, though it is also slightly directed to the left, passes at the same time upwards and backwards, when combined with the upper thick margin of the foramen ovale—it would necessarily happen that the blood of the superior cava must fill the right auricle.

In three injections of the fœtal circulation which I performed, where arrangements were made to imitate, as far as possibly could be done, the manner in which the two currents flow into the heart during the life of the fœtus, results were obtained confirmatory of the opinion of Sabatier.§ This arrangement cannot of course exist in the early months of uterine life from the imperfect developement of the heart itself, and in all probability part only of the blood of the inferior cava is transmitted through the foramen ovale into the left side of the heart for a short time before birth. The pulmonary veins appear to bring very little blood to the left side of the heart until the time approaches that the fœtus must necessarily assume an independent existence. The circulatory apparatus becomes gradually prepared for this change;—the Eustachian valve begins to shrink, the foramen ovale to diminish in size, and a greater quantity of blood is transmitted through the lungs. Billard* has ascertained from the examination of the bodies of a great number of infants who died within a few days after birth, that the foramen ovale and the other circulatory passages peculiar to the fœtus are generally shut about the eighth day after birth. In nineteen infants who had lived only one day the foramen ovale was completely open in fourteen; in two it had commenced to become obliterated, in the remaining two it was completely shut. On the subsequent days the number of those with the foramen shut continued to increase; and in twenty examined, who had died on the eighth day, five only had the foramen open.

Physiology of the heart.

Mode of action of the valves of the heart.—While the blood is rushing through the auriculo-ventricular openings during the contraction of the auricles, the lips of the mitral and tricuspid valves are separated from each other and thrown outwards from the axis of the opening, and the larger lip of both is at this time carried towards the arterial orifices. It has generally been supposed that the mitral and tricuspid valves are, during the systole of the ventricles, passively floated up towards, and obstruct the auriculo-ventricular orifices so as to prevent the free regurgitation of the blood into the auricles; and that the use of the cordæ tendineæ is merely to limit the movements of the valves,—to permit them to be raised sufficiently to close the orifices, but at the same time to provide against the otherwise unavoidably fatal consequences that would result from these unresisting valves being carried through into the auricles by the current of blood. Mayo, Bouillaud, and others have, however, maintained that the lips of these valves are not approximated in the mechanical manner just stated, but by the contraction of the musculi papillares of which the cordæ tendineæ are the proper tendons. As the musculi papillares contract along with the other fibres of the ventricles, the lips of the valves are drawn towards the axis of the opening, and are closely applied to each other, forming a kind of cone, the apex of which projects downwards into the ventricles. It is from the adoption of these views that Bouillaud proposes to call these musculi papillares, the tensor, elevator, or adductor muscles of the valves. That the lips of the

* Mémoires de l'Acad. Roy., année 1717.

† Op. cit. tom. i. p. 228.

‡ Traité complet d'Anatomie, tom. ii. p. 224.

§ Edinburgh Medical and Surgical Journal, 1835. These injections are also confirmatory of one made by Kilian, where the fluid thrown along the aorta passed to the head and superior extremities, and that along the pulmonary artery to the lower part of the body.

* Traité des Maladies des Enfans nouveau-nés, &c., p. 557, 1828.

valves are approximated in this manner appears to me to be the much more probable opinion; for when we examine the uniform position and course of the musculi papillares and chordæ tendineæ, more particularly those of the left ventricle; that the chordæ tendineæ pass from each musculus papillaris to both lips of the mitral valve, occasionally crossing each other; and that the posterior or smaller lip, though it may be drawn inwards so as to meet the larger and more moveable, is so bound down as to be scarcely capable in most cases of being floated up on a level with the orifice; and further, when we also remember that the musculi papillares contract at the same time with the other fibres of the heart, we can scarcely resist coming to this conclusion. Besides, if the lips of the valves were floated up to the orifice, a greater quantity of blood would regurgitate into the auricles during the systole of the ventricle than in all likelihood takes place; for as the lips of the valve must be widely separated from each other when the systole commences, it is evident that a less quantity of blood must have passed through the orifice before the lips are sufficiently approximated to obstruct its further passage when these are assisted by an active force, than when they are merely passively brought together by the current of blood passing in that direction. It has, however, been supposed that the musculi papillares do not contract with the other fibres of the ventricles. Haller states* that on laying open the heart he has seen the muscles of the valves contract during the systole of the heart. It may be objected to this experiment that the unusual stimulus applied to the heart in cutting its fibres across may have deranged the usual order of its contractions. I have repeatedly opened the heart in rabbits and waited until its contractions had ceased, and on renewing its movements by irritating the inner surface at a distance from the cut edges, I have observed that the columnæ carneæ acted simultaneously with the other muscular fibres of the heart.† I was also satisfied that the musculi papillares were proportionally more shortened during their contraction than the heart itself taken as a whole, which is nothing more than what we would expect when we remember that the fibres of the musculi papillares are so far free and run longitudinally, while by far the greater part of the other fibres run in a spiral manner.

Haller, in relating his observations on the contraction of the musculi papillares, makes another statement, which, however, is decidedly adverse to this opinion. The chordæ tendineæ appeared to him to be relaxed during the contraction of the musculi papillares.

It is difficult to make satisfactory observations upon the effects of the contractions of the musculi papillares upon the tension of the chordæ tendineæ. In several animals upon which we attempted to ascertain this, it was only when the heart was acting languidly that we could observe what was likely to be the effect of the contraction of the musculi papillares on the chordæ tendineæ when they were placed as far as possible in their natural relation to each other. We could never observe that they contracted sufficiently to move the valves, but they certainly rendered some of the chordæ tendineæ more tense. When, however, we take into account, that in an experiment of this kind, the valves are not thrown out widely from the orifices of the auriculo-ventricular orifices, the ventricle is not distended with blood, the chordæ tendineæ consequently not put so far on the stretch as occurs at the commencement of the systole, and that the contractions of the musculi papillares are languid, we can easily perceive how, in the natural systole of the heart, these contractions of the musculi papillares should be sufficient to move the valves inwards, though not to such an extent as to apply them closely to each other. The contraction of these musculi papillares apparently sets the valves in motion, and they are subsequently applied to each other by the currents of blood. It may be supposed that if the contraction of these musculi papillares can render the chordæ tendineæ sufficiently tense to move the valves, this would prevent the subsequent elevation of them to obstruct the auriculo-ventricular opening. We believe, however, that it is only at the commencement of the systole that they are sufficiently tense to move the valves, for as the contraction proceeds the capacity of the heart is so much diminished, both in its transverse and longitudinal dimensions, that they become relaxed. Besides, if we could suppose that these musculi papillares are capable of contracting through a sufficient space to draw the valves together, this would be all that is necessary to prevent the regurgitation of the blood through the auriculo-ventricular opening.*

So convinced, indeed, were the older anatomists and physiologists that the chordæ tendineæ are relaxed during the systole of the heart, and of the necessity of an accompanying diminution of the length of the ventricles themselves to effect this, that this argument adduced by Bassuel appears to have been principally instrumental in deciding the once keenly controverted question whether or not the heart was elongated during its contraction.†

* Elementa Physiolog. tom. i. p. 390. Sur le Mouvement du sang, p. 129. Mémoires sur la Nature sensible, tom. i. p. 379.

† [The observations of the London Committee appointed by the British Association to examine into the motions and sounds of the heart confirmed this view of the simultaneity of contraction of the columnæ carneæ and ventricular fibres.—Ed.]

* All these experiments upon the action of the columnæ carneæ were finished and the article forwarded to London about the middle of June, 1836.

† Mr. T. W. King in an elaborate essay (Guy's Hospital Reports, No. iv. April 1837,) has pointed out what he conceives to be a "safety-valve function in the right ventricle of the human heart." This view is founded upon the fact which he believes that he has ascertained, "that the tricuspid valve, naturally weak and imperfect, closes less and less accurately, according to the increasing degrees of the ventricular distention." From this he is "convinced that, in all cases in which the

It may be supposed that the relative size of the auriculo-ventricular orifices to the length of the lips of the valves would not admit of their apices being brought together in the form of a cone as described, but it must be remembered that from the course of the muscular fibres in the immediate neighbourhood of those openings, their areas must be diminished during the systole of the heart. There is at least one thing certain connected with the action of these valves, viz. that the contraction of the musculi papillares can never cause the valves to strike the inner surface of the ventricle and produce a sound as has been supposed.

The manner in which the semilunar valves at the origin of the aorta and pulmonary artery perform their office is entirely mechanical and easily understood. During the systole of the heart they are thrown outwards from the axes of these vessels; but during its diastole, when part of the blood driven into the artery would fall back into the ventricles, these valves are thrown inwards and obstruct completely the whole calibre of the arteries. In all probability the sinuses of Valsalva placed behind these valves contain a certain quantity of blood even during the systole of the heart, and this reacting upon the valves through the agency of the elasticity of the arteries brought into operation at the termination of the systole, materially assists in producing the more rapid and certain action of the valves.

Movements of the heart.—The heart is a muscle of involuntary motion, being, for the wisest of purposes, placed beyond the direct control of volition. The case of Colonel Townshend* is of too obscure a nature to entitle us to found upon it an opposite doctrine, more particularly as it is at direct variance with every other fact or observation.

The movements of the heart, when the body is at rest or in a state of health, proceed without our consciousness. In certain cases of disease they are attended by uneasy feelings, but they are never at any time or under any circumstances dependent upon sensation for their continuance.

It is not so easy a matter as may at first be imagined to ascertain the order of succession in which the different cavities of the heart contract and dilate, and the different circumstances which attend these movements, even by experiments on living animals, more particularly the warm-blooded animals; for if the heart when exposed is acting vigorously and rapidly, every one who has examined for himself must have felt the exceeding difficulty of following and analysing these movements by the eye. If, on the other hand, the animal has become debilitated and the movements of the heart languid, these are apt to deviate from their natural order, and to be performed in an irregular and unnatural manner.* It is in this way that we can account not only for the discrepant statements of the older observers, but also for the very frequent announcement of new views on this subject which appear in the medical periodicals of our own day. As we will find that many of these theories connected with the physiological actions of the heart even in the present day, have been founded upon false notions of the normal anatomy and natural movements of the organ, and only require a reference to these for their full and satisfactory refutation, it will be necessary that we attend particularly to the manner in which these different contractions and relaxations succeed each other, and the visible phenomena by which they are accompanied, as observed by the most accurate experimenters.

When the heart of a living animal is exposed and the organ is acting in a natural manner, the auricles are observed to become distended with blood, then to contract rapidly and simultaneously, and propel part of it into the ventricles; this is accompanied with a corresponding enlargement of the ventricles, which is immediately followed by their simultaneous contraction and the propulsion of their blood along the large arteries: then follows a pause, during which the auricles become gradually distended by the blood flowing along the veins. When the auricles are filled, they again contract, and the same train of phenomena just described occur in uniform succession.

Systole and diastole of the auricles.—The contraction or systole of the auricles is preceded by their relaxation or diastole. During the diastole the auricles become distended with the blood flowing along the veins. The commencement of the diastole occurs during the contraction of the ventricles; the latter part corresponds to the pause in the heart's action, and to the interval between the recurrence of the sounds of the heart, and is more or less long in proportion as the blood flows more or less rapidly along the veins.

The systole of the auricles is performed with great rapidity when the action of the heart is still vigorous, and appears to be effected by the simultaneous contraction of all its fibres. The terminations of the cavæ and pulmonary veins are seen to contract simultaneously with the fibres of the auricles, but sometimes they are seen to contract previous to the auricles, into which they expel their blood. In the cold-blooded animals this contraction of the terminations of the large veins extends over a greater surface, and is visible in the venæ he-

right ventricle is, in any material degree, temporarily distended or permanently dilated, the heart and lungs are relieved by a considerable reflux of the ventricle's contents into the auricle and systemic veins." In experiments upon the lower animals I have repeatedly seen the right ventricle, when gorged with blood and acting feebly, empty itself through an opening in the jugular vein. Edinb. Med. and Surg. Journ. 1836.

* Cheyne's English Malady, p. 307. 1734, London.

* The illustrious Harvey thus describes the difficulties which he experienced in his first attempts to analyse the movements of the heart: "ita ut modo hinc systolem, illinc diastolem, modo e contra, modo varios, modo confusos fieri motus me existimarem cernere."

paticæ.* Judging from the number of muscular fibres which surround the termination of the pulmonary veins in the human species, we would expect these contractions to occur to a greater extent in these veins than in the cavæ. These contractions in the veins must assist the *vis à tergo*, or the force with which the column of blood flows along the veins towards the heart, in limiting the regurgitation along these during the contraction of the auricles. This regurgitation along the veins appears to be to a small extent only when the circulation is proceeding in a natural manner, but becomes considerable where there is any impediment to the free passage of the blood into the ventricles, and when the blood becomes stagnated in the veins. When the actions of the heart are enfeebled, the contractions of the auricles are slower, and may become more or less vermicular, as I have myself occasionally observed. Two or more contractions of the auricle may also now be necessary before the languid ventricle can be excited to contraction. When the action of the heart is still more enfeebled, particular portions only of the auricles continue to contract. According to the observations of Harvey, Lower, Senac, Haller, and others, the contractions of the auricles are performed with considerable force.

Harvey states that he has observed that if the finger is applied to the ventricles in those cases where the action of the auricles continues after the contractions of the ventricles have ceased, a distinct beat is felt in the ventricle at each stroke of the auricle; and Senac, in quoting this, adds (evidently from his own observation) that it is similar to the pulse in the arteries. Senac also states that if an opening be made into the apex of the heart under those circumstances, a jet of blood rushes through it at each stroke of the auricle. He, however, admits that the contraction of the auricles in these cases is not sufficient to dilate sensibly the walls of the ventricles, but, of course, very considerable allowance ought to be made for the enfeebled state of the auricles at this stage of the experiment.† In the experiments of Dr. Hope, Mr. Carlisle, M. Bouillaud, and the Dublin Committee for investigating the cause of the sounds of the heart, the contraction of the auricles appeared to be comparatively trifling, and was most apparent in the appendices. From my own observations upon rabbits and dogs I am convinced that the auricles contract considerably more when the movements of the heart are proceeding in a natural manner, than some of these last experiments would lead us to believe, and that this contraction is not confined to the appendix, but extends over the whole auricle. When the circulation through the lungs becomes impeded, the right ventricle is then unable to empty itself, and the auricle of the same side (and this is the one that is most generally observed in such experiments) is consequently impeded in its movements. The auricles do not certainly exert the force or contract to the extent which some have stated, do not expel the whole of their contents, and their diastole is comparatively feeble; but that none of the muscular fibres of the auricles are passive, but exert a force proportionate to their strength, we have evidence both from experiment and the effects of disease. In some of those cases where an impediment to the passage of the blood from the auricle to the ventricle exists, all the muscular fibres of the auricles become much increased in thickness and in strength. As the left auricle has naturally greater difficulties to overcome in propelling its blood than the right, so we find that the left auricle is considerably more muscular than the right.* The appendix from its being loose, and supplied by a band of longitudinal fibres drawing it backwards, must enjoy a freer motion than the other parts of the auricle.

Systole and diastole of the ventricles.—When the heart is acting vigorously, the contraction of the ventricles succeeds immediately upon that of the auricles, so that they sometimes appear continuous; or, in other words, the sudden distention of the ventricles by the blood propelled into them during the systole of the auricles is rapidly followed by the contraction of the ventricles. The systole of the ventricles must occur during the diastole of the auricles. As we are only sensible of the systole of the ventricles from external examination during life, the expression *systole of the heart* is always employed as synonymous with the systole of the ventricles. When the action of the heart is a little less active, an apparent interval is observable between the completion of the contraction of the auricles and the commencement of the contraction of the ventricles, —the irritability of the ventricles being at this time somewhat impaired, their contraction does not so quickly follow their sudden distention. The ventricles during their systole are diminished in all their dimensions; the apex is drawn upwards to the base and tilted forwards so as to strike the parietes of the thorax between the cartilages of the fifth and sixth ribs.†

* The contractions of the different parts of the heart in cold-blooded animals have been observed to occur in the following order: first, the termination of the large veins, then the auricles, then the ventricles, and, lastly, the bulb of the aorta.

† I have convinced myself of the accuracy of these statements of Harvey and Senac in experiments upon dogs opened soon after they had been deprived of sensation.

* In the case mentioned by Allan Burns, where an ossific deposit covered the whole surface of the ventricles, so as to entirely, or nearly entirely, prevent their action, the auricles must have performed part of their functions for some time before death. In one of the experiments of Dr. Williams, of London, upon asses, he observed the circulation along the arteries continue although the ventricles were quiescent, and the auricles alone contracted.

† "Dr. C. J. B. Williams has, in a lecture lately published in the Medical Gazette (July 28, 1838, p. 692,) pointed out that, during a deep inspiration, the ribs are elevated without raising the heart in the same degree, and the impulse may be felt

The parietes of the ventricles at this time are firm and resisting, and present some rugæ on their outer surface. Haller* states that though the principal movement of the ventricles during their systole is from the apex upwards, yet he has sometimes observed a slight but distinct movement from the base downwards. The contraction of the ventricles is performed with great force, and, when vigorous, appears to be accomplished by the simultaneous action of all its fibres; but at other times, when it has become enfeebled, it has been observed to commence at the apex and extend itself upwards.

The diastole of the ventricles consists of two distinct stages. The first, which immediately follows its systole, is sudden, the apex being pushed downwards and apparently passing deeper into the chest, and is occasioned by the return of the heart to its state of rest. The second is also sudden, and attended by a rapid but not very extensive enlargement of the heart in all its dimensions. The parietes of the heart are soft and flaccid, and their external surface smooth during their diastole. The diastole of the heart is performed with considerable force, so that Pechlin, Perrault, Hamberger, and others long ago maintained that this equally with the systole is the result of a vital action. This opinion was again revived by Bichat, Dumas, and their followers, and is still introduced by some into the discussions upon the movements of the heart. Before we can admit an opinion of this kind, it would be necessary that very strong evidence be adduced in its favour, as it is at perfect variance with all that we know of the arrangement of the fibres of the heart, and of the laws of muscular contractility.†

Oesterreicher‡ has performed the following experiment, which appears nearly decisive on this point. When a body is placed on the heart of a frog heavy enough to press it flat, but sufficiently small to allow the heart to be observed, it will be seen that the body will be lifted during the contraction of the heart, but that during its extension it will remain flat. From this it appears that the extension of the heart after the contraction is not a muscular act. The diastole of the heart depends then upon two circumstances. 1st, Upon the natural elasticity of the organ, which it possesses in common with every other muscle, and by which it instantly resumes its state of rest as soon as its contraction has ceased. This, which is usually termed the relaxation of a muscle in whatever part of the body it occurs, must be expected to be more energetic in the heart than in the muscles of voluntary motion, as from the arrangement of its fibres a great part must be more strongly compressed. This occurs during the first of the two stages into which we divided the diastole. 2d, Upon its sudden distention during the contraction of the auricles, when we have every reason to believe that the ventricles are completely passive. This constitutes the second stage of the diastole. The blood must then pass from the auricles into the ventricles during each diastole at two distinct periods of time, corresponding to these two stages. During the first stage, or the relaxation of the ventricles, it flows from the auricles to fill up the vacuum produced in their interior; while, during the second stage, it is forcibly propelled by the auricles. It would be difficult to estimate the relative proportion of these two quantities of blood. Those who suppose that the contraction of the auricles is feeble must consequently believe that most of the blood passes from the auricles into the ventricles during the first stage.

It has been long disputed whether or not the ventricles empty themselves completely during each systole. It is very difficult to perceive anything like correct data upon this point in the warm-blooded animals with opaque hearts; but reasoning from analogy, from what we see in the cold-blooded animals whose hearts become quite pale during each systole, (not, as Harvey supposed, from the blood being pressed out of its parietes, but from the blood in its cavity, seen through its transparent sides, being almost entirely expelled during its systole,) we would be inclined to believe that little blood remained after each systole in the active state of the organ, while we can easily suppose that a greater or less quantity is left after each contraction when the organ is less vigorous.

It was the subject of a violent dispute at the commencement of the last century between the Montpellier and Parisian anatomists and physiologists, whether or not the heart became shortened or elongated during its contraction. In all the warm-blooded animals at least it undoubtedly becomes shortened.* We may at the same time state that the obliteration of the cavity of the ventricle depends much more upon the approximation of its sides than the drawing up of the apex.

Impulse of the heart.—It has been at various times, and still is by some late and modern experimenters,† maintained that the apex of the heart strikes the parietes of the thorax during

below the sixth rib. On the other hand, when the ribs are depressed, as during a deep expiration, the apex of the heart may be felt beating between the fourth and fifth ribs."

* El. Phys. tom. i. p. 400.

† Scharschmid supposed that certain pretended longitudinal fibres by shortening the heart enlarged its cavities, while the transverse fibres by contracting separately diminish its capacity.

‡ Müller's Handbuch der Physiologie des menschen, Erster Band, p. 163.

* The authority of Harvey has been quoted in favour of the opinion that the heart becomes elongated during its contraction, and certainly in one part of his work it is distinctly stated, that it is so to a certain extent: "Undique contrahi magis vero secundum latera; ita uti minores magnitudinis et *longiusculum*, et collectum appareat."

† Pigeaux, Stokes, Burdach, and Beau. Dr. Corrigan has, much to his credit, publicly renounced his previously published opinions on this question, after more accurate observations had convinced him of his error.

its diastole, and not during its systole. This is in reality what we would *à priori* expect, for it certainly does at first appear somewhat paradoxical that the heart should strike the parietes of the chest when the apex is approximated to the base. The concurrent testimony of the most accurate observers has, however, fully established the correctness of the fact. Harvey observed it in the human body when the heart had been exposed from the effects of disease.* One of the principal arguments adduced in support of this opinion by these authors was drawn from the fact that the pulse at the wrist is not synchronous with the impulse against the chest, an opinion which had been pretty generally maintained since the time of Aristotle. It is difficult to be convinced of this when the pulse is quick; but when it is slow, and in certain cases of disease of the heart, it can generally be satisfactorily ascertained. So far then they are right, but in the next and most important step of the argument they fall into a decided error; for they proceed upon the supposition that the pulse is synchronous in all the arteries of the body at the same time, and consequently the impulse of the heart at the chest cannot be synchronous with the flow of blood along the arteries, or, in other words, with the systole of the heart. In opposition to this opinion, Dr. Young† had previously shown upon the principles of hydraulics that the pulse along the arteries must be progressive, yet in general so rapid as to appear to arrive at the extremities of the body without the intervention of any perceptible interval of time. And when the attention of medical men was turned to this subject, various observers soon ascertained by repeated experiments that the pulse could be felt in favourable cases to pass along the arteries in a progressive manner, — that the pulse in the large arteries at the root of the neck and impulse at the chest are synchronous or nearly so, that both precede that at the wrist, and more distinctly still that of the dorsal artery of the foot.‡

Various attempts have been made to explain in what manner the apex of the heart is made to impinge against the parietes of the chest by those who maintain that it occurs during the systole of the ventricles. Senac supposed that this was principally effected by the curvature of the two large arteries, but principally of the aorta, which arise from the ventricles; for at each stroke of the ventricles when an additional quantity of blood is driven into the large arteries, as they are curved they make an attempt to straighten themselves; and as this takes place to a slight extent, the heart, which is attached to their extremities, ought to be displaced, and its apex, which describes the arc of a circle greater than the other parts of the heart, is thus made to impinge against the walls of the chest. He also believed that the distention of the left auricle with blood during its diastole has also, from its position between the spine and base of the heart, the effect of pushing the heart forwards; and this occurring at the same time with the attempt which the curved arteries make to straighten themselves, it thus acts as a second or subsidiary cause in tilting the heart forwards.* Though this supposed effect of the curvature of the large arteries has been a favourite explanation with many of the impulse of the heart against the chest, yet it really appears to have little, if any, influence in producing this. Shebeare,† and, more lately, Dr. Corrigan,‡ have shown that the direction of the curvature of the large arteries is such, that if any effect of this kind is produced, the heart would not be carried to the left side, but in the direction of the curve, which is exactly in the opposite direction. Besides the tilting forwards of the heart has been observed though no blood was passing along the large vessels at the time, and the same thing takes place after the large vessels have been cut through and the heart removed from the body.§ Haller and others have supposed that the secondary cause assigned by Senac,—viz. the sudden distention with blood of the left sinus venosus which lies impacted between the spine and left ventricle,—is the principal if not the sole cause by which the heart is pushed forwards against the ribs. In confirmation of this opinion Haller states ‖ that if we inflate the left auricle after having opened the chest, we see the point of the heart approach with vivacity the region of the mamma. As we cannot, however, under these circumstances distend the auricle without also distending the corresponding ventricle, this movement of the heart depends more upon the sudden inflation of the ventricle than upon any

* "Simul cordis ipsius motum observavimus, nempe illud in diastole introrsum subduci et retrahi; in systole vero emergere denuo et protrudi fierique in corde systolem quo tempore diastole in carpo percipiebatur: atque proprium cordis motum et functionem esse systolem: denique cor tunc pectus ferique et prominulum esse cum erigitur sursum." As quoted by Shebeare, Pract. of Physic, vol. i. p. 195.

† Phil. Trans. 1809.

‡ It is interesting and curious, as shewing the revolution of opinions, to compare the strict similarity of the arguments adduced by the modern supporters of this doctrine with those maintained by Shebeare in 1755. (Practice of Physic, vol. i. p. 193.) "This, however plausible it may appear, cannot be the true cause of it (impulse of the heart), because then this stroke must be during the systole of the ventricles, which would be synchronous with the diastole of the arteries; whereas the beating of the heart precedes the dilatation of the arteries, and thence this stroke must be made during the diastole of the ventricles: thus the diastole or distention of the heart is the cause of the beating against the ribs."

* Op. cit. tom. i. p. 356. The cause of the tilting motion of the heart was also, at a later period, attributed to the curvature of the aorta and to this exclusively by Dr. W. Hunter. Note in John Hunter's Treatise on Inflammation, p. 146, 1794.

† Op. cit. p. 195.

‡ Dublin Med. Trans. vol. i. p. 154.

§ Dr. Carson (Inquiry into the Causes of the Motion of the Blood, p. 183,) maintains that no proof can be adduced that the curvature of the aorta is rendered more straight during the systole of the heart.

‖ Sur le Mouvement du Sang, p. 124.

distention of the auricle, as any one may easily satisfy himself by repeating the experiment. Besides, the distention of the auricles by the blood flowing along the veins is too gradual for this sudden and rapid impulse of the heart; nay more,—the impulse may be observed when no blood is flowing into the auricles. Sabatier* believed that this impulse depends upon two causes,—1st, principally upon the distention of the auricles, more particularly the left; and, 2dly, upon the curvature of the large arteries. Apparently, however, perceiving the necessity of there being a sudden distention of the auricles to produce this, he supposed that this was effected by the auriculo-ventricular valves. He argued that, as these valves during the diastole of the heart form a cone stretching from the base towards the point of the ventricle, which is full of blood when the systole commences, when the valves are carried upwards to obstruct the auriculo-ventricular orifices, this blood is pushed before them into the auricles, producing a reflux into the auricles, which, with the blood flowing along the cavæ and pulmonary veins, causes a sudden distention of the auricles, which pushes the ventricle forwards.† Meckel appears to have adopted the opinions of Sabatier. We need not repeat our objections to this explanation. Dr. Alison, perceiving the insufficiency of all these explanations, has for a considerable time past suggested in his lectures, that this might be explained by the arrangement of the fibres, "more particularly by the irregular cone which they form, being *flattened posteriorly*, and by the consequent greater mass of fibres on the anterior surface." More lately Mr. Carlisle ‡ has also attempted to explain this by the greater length of the anterior fibres of the heart than of the posterior. As the shape of the ventricles is an oblique cone, and as they have their longest sides in front, he argues, "that it is a law of muscular contraction that fibres are shortened during their contraction in proportion to their length when relaxed. For instance, if a fibre one inch long lose by contraction one-fourth of its length, or one quarter of an inch, a fibre two inches in length will lose one inch by contractions of equal intensity. The apex then does not approach the base in the line of the axis of the ventricles, but is drawn more to the side of the longer fibres, that is, towards the front, thus producing the tilting forwards." We believe that it may be proved on mechanical principles, that though the anterior and left surfaces of the ventricles are considerably longer than those on the posterior and right, yet during their contraction, when they are drawn towards their fixed attachments, if the fibres are of equal thickness, the apex will be drawn up nearly in the diagonal of the two forces, and that if any tilting upwards of the apex take place, this will be only to a small extent, and be quite insufficient to account for the impulse felt at the chest. We must therefore look to some other circumstances besides a mere difference in length of the two surfaces to account for this. Mr. Alderson* has ingeniously attempted to apply the law of action and reaction between bodies,—one of considerable importance in mechanical philosophy, and upon which Barker's centrifugal mill has been constructed. Unfortunately, however, for this explanation, the axes of the large arteries and the direction in which the apex is tilted do not by any means accord. Dr. Hope's supposition that "the retropulsion of the auricular valves" may assist in producing this impulse, "as these act on a column of blood which offers a greater resistance than the weight of the heart, the action is reflected on the organ itself and impels it forwards," is, on the other hand, completely opposed to the law that action and reaction are the same. As well may a man attempt to propel a boat by standing in the stern, and push with an oar against the prow. Dr. Filhos attributed the impulse to the spiral turns of the fibres at the apex of the heart attempting to straighten themselves during their contraction, and so raise themselves suddenly and throw themselves forwards. The objections to this explanation are so palpable that they must occur to every one. Since the tilting of the apex of the heart forwards is observed after the blood has ceased to flow through its cavities, it is obvious that we must look for the cause of this in the arrangement of the muscular fibres themselves, though it may be difficult to point out that particular arrangement. It appears to me that the distribution of some of the strong bands of fibres, the course of which I have already described when treating of the muscular tissue of the heart, may satisfactorily account for it. We there pointed out that several strong bands of fibres arise from the base of the septum between the ventricles, pass downwards and form part of the septum, then emerge from the anterior longitudinal groove (*fig.* 6, *d*), and wind round in a spiral manner to form both the anterior and posterior part of the lower portion of the heart. On entering the apices of the ventricles, (principally the left,) the fibres are scattered over their inner surfaces, and while a great number of them go directly to be inserted into the tendinous rings, others form part of the columnæ carneæ. We have thus strong bands of fibres attached by one extremity (their septal extremity) to the base of the ventricles at a point pretty far posterior, while at the other extremity many of the fibres are loose, or at least only attached to the tendinous rings through the media of the chordæ tendineæ and valves, which must admit of a certain degree of contraction of these fibres before they become tense. At each systole of the heart when these fibres act, it is evident that the tendinous rings must form the fixed points towards which all these fibres contract; and since they are by one extremity all closely and directly connected to a

* Traité complet d'Anatomie, tom. ii. p. 230.

† Dr. Bostock has failed of his usual accuracy in detailing the opinion of Sabatier on this question.

‡ Transactions of British Scientific Association, vol. iii. Dublin Journal of Medical Science, vol. iv.

* Quarterly Journal of Science, &c. vol. xviii. p. 223.

fixed attachment, viz. the tendinous rings, while by their other extremity part only are directly attached to the tendinous rings, the other part being loose, or at least only connected to the tendinous rings through the lax chordæ tendineæ and valves, it must follow that the force with which the contraction takes place towards the septal extremity must preponderate over the other. If these bands of fibres had been as closely connected to the tendinous rings at the one extremity as at the other, then the force of the contraction towards both would have been equal; but since this is not the case, the apex must be carried forwards at the same time that it is drawn upwards towards the base. This forward motion may also probably be assisted by another arrangement of the same fibres which we have been describing; for some of these muscular bands are attached by their inner extr mity to the anterior part of the left auriculo-tendinous ring, so as to form loops, the greater part of which lie more in front than behind the axis of the heart, and may have a tendency, when in a state of contraction, to draw the apex forwards and upwards. Now when we remember that by this elevation of the apex forwards, the heart, before placed obliquely, now becomes more horizontal, and consequently more approximated to the walls of the chest,—the more particularly as the transverse diameter of the chest diminishes rapidly as we proceed from below upwards, we believe that we have here sufficient to account for this impulse against the chest. As the proximity of the apex of the heart to the chest is affected by the position of the body, as we have already pointed out, this circumstance ought to be attended to in judging of the strength of the impulse of the heart.

What parts of the heart most irritable.—The inner surface of the heart is considerably more irritable than the outer. In experiments, when the heart has become quiescent, and refuses to obey a stimulus applied to the outer surface, it frequently contracts readily for a short time after this when air is introduced into its cavities, or when any other stimulant is applied to its inner surface. After death the different cavities of the heart generally lose their contractility in the following order, the left ventricle, the right ventricle, the left auricle, and last of all the right auricle.* And as the heart is generally the part of the body which shews the latest evidences of contractility, the right auricle has long received the name of *ultimum moriens.* Haller supposed that the greater persistence of contractility in the right side of the heart over the left might depend on the circumstance that the right side of the heart generally contains a greater or less quantity of blood after death, while the left side is generally empty. In this manner the inner surface of the right side of the heart is subject after death to the presence of a stimulant from which the left side is comparatively free. He put this opinion to the test by performing repeatedly the following experiment.* He emptied the right side of the heart by the section of the pulmonary artery and venæ cavæ, having previously retained the blood of the left side by passing a ligature around the aorta. The experiment succeeded many times: the right auricle remained perfectly immoveable, and the only motion which the right side retained arose from the connexion of its fibres with those of the left ventricle. The left auricle retained its movements for a certain time, the ventricles during a longer period, sometimes even for two hours. He adds, we thus transfer from the right auricle to the left ventricle the property of being the last living part in the body, in preserving for it during a longer period the irritation produced by the contact of blood. These experiments of Haller certainly shew that the left side of the heart will continue to contract longer than the right where it is subjected to a stimulant of which the other is deprived; but they do not entitle us to conclude that the persistence of their contractility is the same when placed under similar circumstances. We have every reason for believing that the right auricle is the part of the heart which last loses its contractility. Indeed Haller himself confesses, that if any part of the heart remains longer contractile than another, it is the right auricle. Nysten,† who performed a number of experiments upon the comparative persistence of the irritability in the different contractile parts of the body in the human species, after decapitation by the guillotine, and when the heart was consequently emptied of its blood, obtained the following results upon the order in which the different parts of the heart lose their contractility: —1st, the left ventricle, the contractility of which is annihilated much more quickly than that of the other organs; 2d, the right ventricle, the movements of which generally continue more than an hour after death; 3d, the two auricles, the right being of all the parts of the heart that which preserves for the longest time its contractile power.

The stimulant used in these experiments was galvanism. The greater persistence of the contractility in the right auricle over the other parts of the heart has been observed by other experimenters, after it had been cut from the body, and consequently without any contained blood. The particular part of the auricle which last loses its contractility varies in different cases. Sometimes the appendix is found contracting when the rest of the auricle is quiescent; at other times, and perhaps more frequently, those parts of the auricle around the entrance of the venæ cavæ retain their contractility longest.

* There is occasionally considerable variety observed in the order in which the different cavities lose their contractility after death. The left ventricle has been seen to contract after the right auricle; and Haller has observed in experiments upon cats the irritability of the left auricle first cease. In experiments upon dogs I have seen the ventricles contract after the auricles had ceased to do so.

* Sur le mouvement du sang, p. 172. Similar experiments were performed by Walther with the same results: Experimenta de vivis animalibus, p. 11, as quoted by Burdach.

† Recherches de Physiologie, &c. p. 321.

Harvey and some of the older anatomists observed the movements of the venæ cavæ to continue in some of the lower animals after the auricles had ceased to move. The apex of the ventricles frequently remains longer contractile than the rest of the ventricle. Haller suggested that this might depend on the remaining blood gravitating to the apex, and there acting as a stimulant.

Duration of contractility after death.—In the cold-blooded animals the heart may be made to contract fourteen, twenty, thirty-four hours, or even longer after death. In warm-blooded animals the heart remains contractile for a much shorter period after death than in cold-blooded animals. Haller found the heart contractile in a warm-blooded animal in one case four hours after death, and in another seven hours. He sometimes observed it to cease before the vermicular motion of the intestines. Wepfer found it irritable in a dog six hours after death. Nysten, who attended particularly to this subject, found in one of his experiments on the human subject, that the ventricles refused to contract upon the application of galvanism one hour after decapitation, while the auricles continued contractile for seven hours five minutes after death.* In another case the right auricle was still contractile eight hours after death;† and in a subsequent case which he relates, it remained contractile in the neighbourhood of the entrance of the superior cava sixteen hours and a half after death.‡ In the Mammifera, Nysten found that the left ventricle often refused to contract thirty minutes after death; that the right ventricle retained its contractility two hours, and sometimes longer, while the right auricle was not quiescent upon the application of the galvanism until eight hours after death.

He found it to vary in birds according to the degree of muscular activity which they enjoyed during life. In those of high flight, and which exercise great muscular contractility during life, and have a rapid circulation, as the sparrow-hawk, the irritability of the heart and other muscles becomes much more speedily exhausted than in those the movements of which are comparatively slow and feeble, as in most domestic fowls.§ Nysten supposes that the explanation of the greater persistence of contractility of the right ventricle over the left lies in the circumstance that the left acts with greater vigour during life, thus referring it to the important general law which he has established by his experiments upon the comparative excitability of the muscular tissue in the various classes of animals, that the duration of the contractility after death is in the inverse ratio of the muscular energy developed during life.|| Before we could admit this explanation, it would be necessary to show, what we believe it will be found impossible to do, that the left ventricle, apart from its greater quantity of muscular fibre, exerts greater strength or exhibits more energetic contractions during life than the right ventricle. In young animals, immediately after birth, the contractility of the heart continues longer after death than in the adult animal. We would expect this to be most apparent in those which are born with their eyes shut, as puppies and kittens, and in those birds which are hatched without feathers, since these animals at that period of life approach in their physiological conditions to the cold-blooded animals. There is a curious circumstance stated by Mangili, and confirmed by Dr. Marshall Hall, connected with the hybernation of animals, that if those mammalia which hybernate are killed while under a state of lethargy, the heart and other muscles remain contractile for a longer period than when they are killed in a state of activity, thus resembling, when under the influence of this lethargy, in this as in many other respects, the physiological condition of the cold-blooded animals. The contractions of the heart may frequently be renewed by the application of warmth after they have apparently ceased. I have repeatedly observed the fact which has been stated by Haller and Nysten, that when any of the cavities of the heart become congested with blood, their contractility becomes arrested, and, in their opinion, extinguished.* I have also found that unloading the right side of the heart soon after the congestion has taken place, which can be done in many cases by opening the external jugular vein, acts as a valuable adjuvant under certain circumstances in renewing the heart's action. These it would be out of place to discuss here; but I may state that it appears to me to be principally useful in certain cases of poisoning, in asphyxia, and after the accidental entrance of air into the veins. Since the introduction of a considerable quantity of air into the veins produces death by mechanically arresting the movements of the right side of the heart, we believe that circumstances may occur in which the surgeon may be justified in introducing a tube into one of the large veins passing into the upper part of the chest, and suck-

* Op. cit. p. 316.

† Page 318.

‡ In these experiments all the other parts of the body lost their contractility before the right auricle.

§ Op. cit. p. 349.

|| Dr. Marshall Hall (Phil. Trans. 1832) has more lately laid it down as a general law that the irritability of the heart and other muscles is in the inverse ratio of the oxygen consumed in respiration. Various experimenters distinctly show that as we descend in the scale of animals the quantity of oxygen consumed diminishes, and that Birds consume more than Mammalia. Dr. Edwards has also shown that the young of the Mammalia deteriorate the atmospheric air less rapidly than the adult animals; and the experiments of Mangili and Prinella prove that hybernating animals, when in a state of lethargy, consume exceedingly little oxygen, so that there is evidently some relation between irritability and the quantity of oxygen consumed in respiration; but for the proof that the irritability is exactly in the inverse ratio of the respiration, we must wait for Dr. Marshall Hall's promised experiments.

* Haller supposed that this was effected, as must be if allowed to continue for any length of time, by the too great distension of the muscular fibres, in the same manner as distension of the bladder produces paralysis of its fibres.

ing the frothy blood from the right side of the heart. It is also necessary to remember this circumstance in experimenting upon the length of time during which the heart remains contractile after death, as the division or non-division of the large veins at the root of the neck in laying open the thorax may considerably modify the results.*

For the probable force exerted by the heart, the share which the heart has in carrying on the circulation, and the probable quantity of blood expelled at each contraction, see the article CIRCULATION.

Frequency of the heart's action.—The frequency of the heart's action is considerably modified by age, condition of the other functions of the body at the time, by mental emotions, and by the original constitution of the individual. Its movements are influenced by very slight muscular exertion, and the extent of this appears to vary at different times of the day. In the fœtus its movements are rapid, being about 140 in the minute. At birth it is from 130 to 140; at one year 115 to 130; second year 100 to 115; third 90 to 100; seventh 85 to 90; fourteenth 80 to 85; middle age 70 to 75; in very old age 50 to 65. The heart's action generally sympathises powerfully with the other organs of the body, and this has always been regarded as a most important and necessary guide in the detection and cure of diseases.

It becomes strong and rapid in some cases of inflammation, while in others it becomes rapid and feeble. It becomes quicker after eating and slower during sleep. It is much increased in frequency during bodily exertion. In cases of great general debility it becomes very quick and feeble. It becomes more rapid and weaker during inspiration, slower and stronger during expiration.

It is an important fact that when the contractility of the heart is much enfeebled by extensive injuries of the central organs of the nervous system or of the other parts of the body, (as when a limb is extensively crushed,) its contractions are not only much weaker, but are also greatly increased in frequency. It is also worthy of remark that such injuries do not produce convulsive movements in this organ. The effect which severe injuries and certain inflammatory affections have in greatly debilitating or even destroying the contractility of the heart is a fact of great practical importance, as it not only explains the cause of the most alarming symptoms in such cases, but also points out the most appropriate remedies to avoid the chief tendency to death. To this cause, for example, we are to attribute the rapid and feeble pulse, in concussion of the brain, in extensive mechanical injuries, the shock after operations, extensive burns, peritonitis, &c. It is very fortunate that the contractions of the heart become more frequent when its contractility becomes enfeebled. If the heart under these circumstances had required, as we would *à priori* expect, the presence of a greater quantity of blood to stimulate it to contraction, instead of a smaller quantity, as is actually the case, what would have been the consequence? It is evident that since the resistance, under ordinary circumstances, which the heart has to overcome in contracting, is, according to a well-known hydrostatic law, in proportion to the extent of the area of the inner surface of the cavities of the heart at the commencement of their contraction, (each square inch of surface, according to the experiments of Hales, having a pressure upon it nearly equal to four pounds,) the more frequent contractions, where there is a smaller quantity of blood present in the heart at the commencement of each contraction, will not demand the same degree of muscular force for their performance, as if these had been less frequent. If, when the contractility of the heart became debilitated, the presence of a greater quantity of blood than usual in its interior had been necessary to stimulate it to contraction, and if the area of the inner surface of the cavities of the heart be in proportion to the quantity of blood contained there, it is apparent that the movements of the heart would have been much more rapidly and frequently arrested when its contractility became enfeebled, than they are under the actual arrangement.

The influence of mental emotions upon the movements of the heart requires no illustration, for this is so universally experienced that in common language the heart is considered to be the seat of the affections and passions, and this has had a powerful influence upon the phraseology of all languages.

In sanguine temperaments the heart generally contracts more frequently than in phlegmatic temperaments. In women it is also generally a little quicker than in men.

It varies very much in different classes of animals.

Burdach* has given the following table collected from numerous sources, as an approximative valuation of the frequency of the heart's action in various animals.

Number of pulsations in a minute.†

In the Shark	7
Mussel	15
Carp	20
Eel	24
Snake	34
Horse	36
Caterpillar	36
Bullock	38

* Edinburgh Medical and Surgical Journal, 1836. When I performed these experiments, I was not aware that I had been anticipated to a certain extent by Mr. Coleman. (Wilson on the Blood, &c. p. 131.) It is very possible that the sinuses upon the inferior cava and hepatic veins in the seal may, besides answering other purposes, have the effect of preventing this mechanical distension of the right side of the heart.

* Physiologie, vol. iv. p. 251.

† We cannot consider the number of pulsations of the heart in a minute given in the above table as by any means quite satisfactory. The number of pulsations in the ox and horse is given on the authority of Vetel in Froriep, Notizen, t. xxiv. p. 112. Other observers state the number of pulsations in a minute at from 38 to 52 in the horse, and from 64 to 70 in the ox.

Ass	50
Crab	50
Butterfly	60
Goat	74
Sheep	75
Hedgehog	75
Frog	77
Marmot	90
Locust	90
Ape	90
Dormouse	105
Cat	110
Duck	110
Rabbit	120
Menoculus Caster	120
Pigeon	130
Guinea-pig	140
Hen	140
Bremus terrestris	140
Heron	200
Menoculus pulex	200

For the effects of the respiration upon the contractions of the heart, and the influence of the circulation of dark blood upon its irritability, see ASPHYXIA.

The cause of the motion of the heart.—The motion of the heart, and the constancy and regularity of its movements, are circumstances so remarkable that they could not fail early to excite a deep interest among medical philosophers when they had once turned their attention to the explanation of vital phenomena. When we contemplate the heart commencing its movements at an early period of fœtal existence, and never resting from its apparently unceasing toil until the latest moments of life, and when we remember the uniform and regular manner in which all its actions are accomplished—all conspiring for the proper performance of the deeply important functions assigned to it, we are at first impressed with the idea that it is regulated by laws different from similar textures of the body, and altogether peculiar to itself. It must have been under the influence of similar impressions that the older medical philosophers approached this subject, and it is in this manner only that we can account for many of the strange speculations on the heart's action which they have left recorded.

We find one sect attempting to explain it by a peculiar innate fire. Sylvius, the head of the chemical sect, had recourse for its explanation to an effervescence excited by the intermixture of the old and alkaline blood with the acid chyle and acid pancreatic lymph.* Descartes supposed that a constant succession of explosions occurred in the heart from steam generated there, which propelled the blood through the body. Stahl got at once out of the difficulty by affirming that the heart was more particularly under the guidance of the anima or soul. But we cannot here dwell longer on these obsolete and to us in the present time almost incredible opinions, and the only use to which they are now applicable is to serve as beacons to keep us, in all our inquiries into the phenomena of living bodies, within the strict path of facts and observation, and to forcibly impress upon us into what strange and fatal errors even the brightest intellects may fall, when they leave the inductive method of investigation, and wander into the alluring but dangerous regions of hypothesis. And the effects of these errors are only the more to be dreaded as they are often clothed in the most seductive ingenuity. It ought also still more forcibly to inculcate upon us the important truth, which, though generally in our mouths, is not unfrequently forgotten in practice,—that as the material world and all which it contains have been placed by the Author of Nature under arbitrary and fixed laws, it is impossible to extend our knowledge of these by theorizing in the closet, and that this can only be effected by the patient interrogation of Nature herself.

It was not until the time of Senac and Haller that accurate notions began to be entertained on the nature of the heart's action.

The cause of the movements of the heart is distinctly referable to the same laws which regulate muscular contractility in other parts of the body, only modified to adapt it for the performance of its appropriate functions. Like all the other muscles it is endowed with irritability, which enables it to contract upon the application of a stimulus. The ordinary and natural stimulus of the heart is the blood, which is constantly flowing into its cavities. The greater irritability of the inner surface over the outer is evidently connected with the manner in which the stimulus is habitually applied. When the blood is forced on more rapidly towards the heart, as in exercise, its con tractions become proportionally more frequent; and when the current moves on more slowly, as in a state of rest, its frequency becomes proportionally diminished. If the contractions of the heart were not dependent upon the blood, and their number regulated by the quantity flowing into its cavities, very serious and inevitably fatal disturbances in the circulation would soon take place.

As the heart continues to contract often for a very considerable time after the venæ cavæ have been tied, and after the blood has ceased to pass through its cavities, or after it has been removed from the body, this has been supposed by some to indicate that there is something in the heart's structure or in its vital properties which enables its movements to proceed independent of all other circumstances. But in all these cases a stimulus has been applied in some form or other to the heart. If the heart has been allowed to remain in its place, though the circulation of the blood may have come to a stand, part of it may yet remain in the different cavities of the organ; or if the pericardium has been opened, the impression of the external atmosphere may act as a stimulus. The experiments of Walther and Haller formerly mentioned upon the comparative irritability of the

* In the same manner Borelli says, "Constat ex dictis immediatam causam motivam cordis esse ebullitionem fermativam tartarei succi sanguinei excitatam à commistione succi spiritnosi à nervis instillati." De Motu Animalium, p. 97.

two sides of the heart, and the different results obtained when the one side of the heart was emptied of blood, and when it was retained in the other, are sufficient to shew the effect which the presence of blood in the cavities of this organ has upon the continuance of its action after the circulation has ceased. If the heart has been removed from the body and emptied of its blood, it must naturally follow that its different cavities will be filled with atmospheric air; and it has been well ascertained that this acts as a very powerful stimulant upon the inner surface of the heart.* Every circumstance connected with these experiments is in exact conformity with the opinion that the movements of the heart are only called into action by the application of a stimulant. Thus, when the irritability of the heart becomes more languid, and when the blood or the atmospheric air in its cavities becomes insufficient to raise it to contraction, strong and energetic movements may still generally be excited by having recourse to a more powerful stimulant, such as the prick of a scalpel or the application of galvanism. Since the heart is highly endowed with irritability, various other mild fluids besides the blood are capable of exciting it to contraction. As every organ, however, has its irritability adapted for the function which it is destined to perform, so we find that the heart, the central organ of the circulation, is most fitly called into action by the blood, its appropriate and natural stimulant.

In examining the nature of the irritability of the heart, and contrasting it with that of the voluntary muscles, we must not compare its contractions with those excited by volition in the muscles of voluntary motion, for these last are evidently modified by the nervous influence for an obvious purpose; but let us observe both when placed under similar circumstances, and irritated by the application of the same stimulant applied to the muscles themselves, and we will find that they only differ in this,—that in the voluntary muscles each successive application of the stimulant is generally followed by a single contraction, while in the heart it is followed, except when the contractility is much impaired, by several consecutive contractions alternated with relaxations. This tendency to successive contractions is also observed, though not to the same extent, in the muscular coat of the intestines.

We must admit, however, that the contractions of the heart proceed under circumstances where it is difficult to point out the presence of any sufficient stimulus, and where, to account for their continuance, we are almost obliged to have recourse to the supposition, that there is some innate moving power in the heart itself. It has been stated, for example, that the movements of the heart will proceed under the exhausted receiver of an air-pump. I have repeatedly placed under the bell-glass of an air-pump the heart of a frog when removed from the body and emptied of its blood, and I could never satisfy myself that the frequency or strength of its contractions was at all affected by the withdrawal or renewal of the air; and though it might be urged that the air is only rarefied, not entirely removed, in the best exhausted receiver of an air-pump, and that consequently in such experiments a stimulant still existed in the presence of the rarefied air, yet I would not consider this explanation of the continuance of its contractions by any means satisfactory. In these experiments there is another source of stimulation present which ought to be taken into account, for, as I shall afterwards shew, the slightest movement of the heart, such as that caused by its contraction, upon the surface upon which it is placed when removed from the body, is sufficient, from the great irritability of the organ, to act as a stimulant upon it. If these external stimuli appear to be insufficient to account for the persistence of the contractions of the heart under the circumstances we have mentioned, we may have recourse to another explanation drawn from the mechanical structure of the organ; for it is possible, as has been suggested by Dr. Alison, that from the peculiarly convoluted arrangement of the fibres, the outer may, during the contraction of the organ, pinch or stimulate the inner, and so cause this tendency to repeated contractions from one application of a stimulant. We do not, however, consider that we have succeeded perfectly in accounting for the continuance of the contractions of the heart under all circumstances, but we are unwilling to admit the existence of any peculiar innate and unknown agency in the production of any phenomenon, until it is satisfactorily established that it cannot be accounted for on the known laws which regulate similar phenomena in the same texture in other parts of the body. And it must also be remembered that these movements of the heart have only been observed when its contractility was still comparatively vigorous, and where sources of stimulation were still present. We ought, besides, to be the more cautious in admitting the existence of this innate moving power, since it is in opposition to a well-known law in the animal economy,—that though the various tissues of an organized body are endowed with certain vital properties, yet the application of certain external and internal stimuli is necessary to produce their manifestations of activity. In fact it is from the action and reaction of these tissues and excitants upon each other, that the phenomena of life result.*

* Peyer, Brunner, and Haller have seen the contractions of the heart renewed by blowing air into the cava ascendens. Wepfer and Steno produced the same effect by inflation of the thoracic duct. Enman states that he once observed the renewal of the heart's action in the human subject by blowing air into the thoracic duct. Vide Senac, tom. i. p. 326.

* The remarks which we have made above, illustrating the great length of time which the heart will continue to contract after being removed from the body, and when all communication between the nerves ramified in its substance and the sympathetic ganglia and the central organs of the nervous system have been cut off, when taken along with the equally well ascertained fact, that its contractions

Upon what does this irritability of the heart depend?—This has been one of the most keenly agitated questions in physiology, as a great part of the experiments, and much of the reasoning upon the nature of *muscular irritability*, have been furnished by this organ. As, however, the general doctrines entertained on this subject have already been fully discussed under the article CONTRACTILITY, we shall here confine ourselves to a few of the leading facts connected with it which have a special reference to the heart. The two principal questions on this point since the time of Haller have been, whether does it depend upon nervous influence? or is it a property of the muscular fibre itself independent of the nerves?

We have seen that the nerves distributed upon the heart are the par vagum and sympathetic. Numerous experimenters have removed portions of the par vagum on both sides of the neck without the slightest diminution of the strength of the contractions of the heart. These experiments we have frequently performed with the same results. There can now be no doubt that the sudden death which occasionally follows this operation is not to be attributed to the cessation of the heart's action, as some of the older experimenters believed, but, as Legallois has shewn, it depends upon an arrestment of the movements of the muscles attached to the arytenoid cartilages. Portions of the sympathetic have also been destroyed in the middle of the neck without any effect upon the contraction of the heart, except what could be sufficiently accounted for by the pain of the incisions and the terror of the animal. A portion of both of the sympathetic and pneumogastric nerves may be removed in the neck with the same results; in fact we cannot, in the dog and most quadrupeds, cut the par vagum in the middle of the neck without also dividing the sympathetic. Magendie affirms that all the sympathetic ganglia of the neck, along with the first dorsal, may be removed without any sensible derangement of the parts to which their nerves are distributed. Brachet* supposes that the reason why the excision of the sympathetic ganglia in the neck does not always arrest the heart's action, is because there is another source of nervous influence for the cardiac nerves placed below this in the cardiac plexus or ganglion. He accordingly put this opinion to the test of experiment, and he assures us that the total destruction of the cardiac plexus was followed by the sudden and permanent arrestment of the heart's action. Now when we consider the nature of such an experiment as this, with the chest of the animal laid open, the respiration arrested, and the heart exposed during the time the experimenter is searching and tearing for the plexus placed deep behind the aorta and pulmonary artery, and which would require a considerable time to display even in the dead body when unembarrassed by the movements of the heart, we must be more astonished that the action of the heart had not completely ceased before the experiment was finished, than that it should have continued so long. Besides, even allowing that this experiment could be relied upon, we have sufficient evidence, from the facts stated above, to entitle us to conclude that the heart is not dependent for its movement upon any influence constantly transmitted along its nerves from the central organs of the nervous system,—the brain and spinal marrow. Brachet is himself obliged to admit, from other experiments which he performed, that the division of the sympathetic at the lower part of the neck is not sufficient to arrest the heart's action, so that this experiment is intended to shew that its irritability depends upon the ganglia of the sympathetic itself. The independence of the irritability of the heart upon the brain and spinal marrow can be very satisfactorily proved in another manner. The occurrence of acephalous monsters,* and the experiments of Wilson Philip,† Clift,‡ and Brachet§ demonstrate that the brain or spinal marrow may be naturally wanting; that one or both of them may be removed entirely, or destroyed in small portions at a time, without arresting the heart's action. We may here observe that the experiments of Legallois,|| Wilson Philip, Wedemeyer,¶ Brachet, and many others, in which the action of the heart was arrested by crushing large portions of the brain or spinal marrow, though they do not prove the dependence of the irritability of the heart upon the brain and spinal cord, at least shew, what the effects of mental emotions upon the movements of the heart had already pointed out, that it can be influenced to a great and most important extent through these organs. The advocates for the dependence of the irritability of the heart upon the nerves appear to have pretty generally abandoned the opinion that this is derived from the central organs of the nervous system, and now maintain the doctrine, which was more prominently developed by Bichat, that this is derived from the sympathetic, the ganglia of which, according to him, are independent sources of nervous influence. From the manner in which the sympathetic is distributed upon the heart, it is

may be readily increased or renewed under those circumstances, by mild excitants applied to its inner surface, are completely opposed to the supposition that the heart is called into contraction in a manner similar to those sympathetic movements more lately described under the term excito-motary. Though this mode of explanation may be considered quite legitimate when applied to those sympathetic movements which do not require the intervention of the brain for their performance, such as deglutition, respiration, &c., it is certainly pushing the doctrine far beyond its proper limits to apply it to the explanation of the movements of the heart.

* Du système nerveux ganglionaire, p. 120.

* The heart is generally though not always absent in acephalous monsters.

† Experimental Inquiry into the vital functions.

‡ Phil. Trans. 1815.

§ Système nerveux ganglionaire.

|| Legallois performed these experiments on the spinal cord alone, and supposed he had proved that the movements of the heart were dependent upon that portion of the nervous system.

¶ Physiol. Untersuchungen über das Nervensystem, &c. p. 235.

perfectly impossible to insulate that organ from the nerve and experiment upon it; but we think we are justified in concluding from observations and experiments derived from other sources, that in all probability the contractility of the heart depends upon a property possessed by the muscular fibre itself without any necessary intervention of its nerves. The possibility of exciting or increasing the action of the heart by stimuli applied to its nerves has been mixed up with this question. Though it must be admitted that mechanical and chemical stimulants applied to a considerable surface of the central organs of the nervous system quicken the heart's action, yet experimenters have generally acknowledged that these stimulants applied to the nerves of the heart produce no effect upon its movements. Burdach,* however, maintains that he has quickened the heart of a rabbit deprived of sensation by applying caustic potass to the trunk of the sympathetic, or its inferior cervical ganglion. That the heart can be excited to contraction by the application of galvanism has had many supporters, and many celebrated names are arranged both on the affirmative and negative sides of the question. That the movements of the heart may be increased or renewed by the application of galvanism as the experiment is usually performed, there can be no reasonable doubt; for if one wire is placed upon the nerve and the other upon the heart, the moist nerve will act as a conductor to the electricity, and the effect produced will be the same as if the stimulant had been applied to the substance of the heart itself. Nysten admits that movements of the heart were excited by the galvanism when one of the wires was applied to one of the large arteries from which all the visible filaments of the nerves had been dissected off. Dr. C. Holland,† in a number of experiments, satisfied himself that the tissues of the body conduct galvanism with so much facility, that the heart's action could readily be excited, when one wire was placed upon the heart and the other in the nose, mouth, and even among the moist food in the stomach. I have performed similar experiments with the same results. Humboldt and Brachet assert that they have quickened the movements of the heart by applying both wires to one of the cardiac nerves. If these and the experiments of Burdach could be relied upon, they would be sufficient to prove that the heart could be occasionally stimulated through the cardiac nerves, but the negative experiments on the other side are so numerous, and the sources of fallacy in judging in this manner of the relative quickness of the heart's action between one time and another so obvious, that we must be allowed to distrust them unless they should be confirmed by other accurate observers.

Constancy of the heart's action.—The constancy of the heart's action is more apparent than real. After each contraction a state of relaxation follows. The relative duration of the contraction of the auricles and ventricles, according to Laennec, appears to be as follows:—a third at most, or a fourth or a little less by the systole of the auricles; a fourth or a little less by the state of quiescence; and the half or nearly so by the systole of the ventricles. From this he calculates that the ventricles, when the heart is acting with its usual frequency, rest twelve hours out of the twenty-four, and that in those individuals in whom the pulse is naturally below 50, it must be in a state of relaxation sixteen hours out of the twenty-four.* Now this is a degree of contraction of which many muscles of the body are probably susceptible, such as the muscles which support the trunk when we sit or walk, and which some, as the diaphragm and intercostals, generally perform.

Regularity of the heart's movements.—The regularity of the heart's movements, so essential to the welfare of the animal, has appeared, even to many modern physiologists, to be intimately connected with some peculiarity in its structure. We are inclined, however, to agree with Haller, that this is perfectly explicable on the known laws of muscular contractility in other parts of the body. The regularity of the heart's action was another fertile subject of hypothesis to the older physiologists; and even in the present day we find the term "*organic instinct*" employed to designate it.

The contractions of the heart take place in the order in which the blood flows into its different cavities; and if the blood be the habitual stimulant upon which its movements depend, this is exactly what we would expect.† The blood forced in greater quantity into the auricles by the contraction of the termination of the cavæ and pulmonary veins, stimulates the auricles to contract and propel an additional quantity into the ventricles; and this, acting as a stimulant upon the ventricles, excites them to contract and drive the blood into the arteries, when the same series of pheonomena is renewed and repeated in the same succession.

The continuance of the heart's action after the circulation has ceased, we have already attempted to explain; and if these contractions depend upon the presence of a stimulus, they must evidently be in the same order as in the natural state of the organ, as these have not been interrupted. The continuance of the regular order of the contractions of the heart after its removal from the body can in general, we think, be satisfactorily accounted for by the substitution of a new stimulant for that of the blood; the cavities are then occupied with air instead of blood, and each

* Traité de Physiologie, tom. vii. p. 74, traduit par Jourdan.

† Experimental Inquiry, &c. p. 275.

* We have not here given Laennec's calculations of the relative duration of the contraction and relaxation of the auricles, as they must be founded on false data—on the supposition that the second sound of the heart marked the duration of the contraction of the auricles.

† This was also the doctrine maintained by Senac, op. cit. tom. i. p. 325. Senac, however, was opposed to the doctrine of Haller, that the contractility of the heart was a property inherent in the muscular fibre, and independent of the nerves. Tom. i. p. 451.

contraction of the auricle must force an additional quantity into the ventricle, and this, though small in quantity, may be quite sufficient to excite the ventricles to contraction, when the irritability is not too much impaired.* It is only in this manner, taken along with the greater irritability of the internal surface over the external, that we can explain the observation made by Dr. Knox in the course of his experiments upon the irritability of the heart in fishes, where, when the irritability was nearly exhausted, contractions excited in the auricle were sometimes followed by contractions of the ventricle, when irritation of the outer surface of the ventricle itself produced no effect.† Certainly, under ordinary circumstances, this regularity of the heart, so necessary for the proper performance of its functions, is a marked feature in its action; but that it is not either necessarily connected with its structure or vital properties, but depends solely on the manner in which its stimulant, the blood, is applied, is proved by various facts. 1st. The movements of the auricles and ventricles generally cease at different times after death; and though the auricles much more frequently continue to contract after the ventricles, yet several accurate experimenters have observed the left auricle become quiescent before its corresponding ventricle.‡ 2dly. When the movements of the ventricle have ceased, while the auricles continue to contract, the ventricle may generally be excited to vigorous contractions by the application of a powerful stimulus. 3dly. When the irritability of the heart becomes somewhat languid, two, three, or sometimes six or seven contractions of the auricle may take place before the ventricles are roused to contraction; the evident deduction from which is, that the contractions of the ventricles do not necessarily follow those of the auricles, unless the contractions of the auricles occasion the application of a stimulant to the inner surface of the ventricles sufficient to excite them to contraction. 4thly. The movements of the ventricles and auricles will go on in the same manner, though detached from each other by the knife. 5thly. If we were allowed to argue from final causes in negative cases, we could easily shew that a peculiar endowment, such as we are contending against, would not be of the slightest advantage in securing the regularity and constancy of the heart's movements. It appears, then, quite unphilosophical to call in the agency of some unknown and indefinite principle for the production of these periodic movements, as they have been called, of the different chambers of the heart, when they can be satisfactorily referred to the laws which regulate muscular contractility in other parts of the body. We have here a beautiful example of the manner in which nature produces adaptation of means to an end, not by the creation of new properties, which we, in our ignorance, sometimes erroneously attribute to her, but by the employment of those already in use in the performance of other functions, only modified to accommodate them to the circumstances under which they are placed.

Sounds of the heart.—On applying the ear over the region of the heart, two distinct sounds are heard accompanying its contraction. Though the existence of such sounds seems to have been known to Harvey,* who compares them to the noise made by the passage of fluids along the œsophagus of a horse when drinking, yet, as is well known, it is to Laennec that we owe the first accurate description of the character of these sounds, the order of their succession, and the manner in which they may hereafter be made available for the important purposes of the diagnosis of the diseases of the heart.

The first of these sounds is dull and prolonged; the second, which follows closely upon the first, is sharp and quick, and is likened by Laennec to the flapping of a valve, or the lapping of a dog. After the second sound a pause ensues, at the end of which the sounds are again heard. These three—the first sound, the second sound, and the pause—occur in the same uniform order, and when included along with the movements of the heart, to which they owe their origin, have received the term *rhythm of the heart*. As the dull prolonged sound is synchronous with the impulse of the heart, and consequently with the contraction of its ventricles, Laennec attributed this sound to the contraction of the ventricles. The second sound, which is synchronous with the diastole of the ventricles, he supposed must depend upon the systole of the auricles; and to this he was naturally led by the supposition that their contraction must also produce some sound. From the weight of Laennec's authority, this opinion

* When the heart has ceased to contract, it may frequently be called into pretty vigorous action by opening one of the large veins, and blowing some air into its cavities.

† I have repeatedly attempted to ascertain if the circumstances here described as sometimes occurring in the cold-blooded animals could be observed in the warm-blooded animals, but without success. In one experiment upon the heart of a rabbit, after all the movements of the ventricles had ceased, but *where they could still be readily excited by the application of a stimulant*, we were convinced that contraction of the auricle, when excited by stimulation applied to itself alone, was sometimes followed by contaction of the ventricle even after the ventricle had been *slit open*. But in subsequent experiments upon dogs, we ascertained a source of fallacy which we had overlooked in the other experiment, for we found that a slight movement of the heart on the surface upon which it rests, such as that caused by a very gentle pull at the large arteries, and not exceeding the effects produced by the contraction of the auricle, was, in some of these cases, sufficient to excite contractions of the ventricles.

‡ In one experiment upon a cat, I distinctly observed the right ventricle occasionally pulsate twice for each pulsation of the auricle. In another experiment, I distinctly observed the contractions of the ventricles precede those of the auricles, when the contractility of the heart had become enfeebled. In this case, the pause in the heart's action occurred after the contraction of the auricles.

* Op. cit. cap. v.

seems to have been almost implicitly adopted until the appearance of a paper by the late Professor Turner, in 1829. Professor Turner there recalled to the attention of medical men the observations of Harvey, Lancisi, Senac, and Haller, upon the order of succession in which the cavities of the heart contract, which appear to have been forgotten amidst admiration at the brilliancy of Laennec's progress. He also pointed out from their experiments that if the second sound was dependent upon the contraction of the auricles, it ought to precede instead of following the first sound, and that the pause ought to occur after the first sound, and not after the second. He also adduced, in farther proof of Laennec's error, observations drawn from the effects of disease, when, from some impediment to the passage of the blood from the right auricle into the ventricle, a distinct regurgitation takes place into the large veins at the root of the neck, and showed that in these cases the regurgitation marking the contraction of the auricles occurs without any accompanying sound; that immediately afterwards the impulse is felt attended by the first sound, and that the second sound takes place during the diastole of the ventricles and the passive condition of the auricles. He suggested that the second sound might be accounted for by the falling back of the heart into the pericardium during its diastole, to which "the elasticity of the ventricles at the commencement o the diastole, attracting the fluid by suction from their corresponding auricles, may perhaps contribute." Soon after the appearance of Mr. Turner's paper, Laennec's explanation of the cause of the second sound appears to have been pretty generally abandoned; and numerous attempts, both in this country and in France, have since that time been made to solve this difficulty. Some of these explanations appear to be mere guesses, occasionally at total variance with the anatomical structure of the organ, and at times presenting even as wide a departure from its normal action as that given by Laennec himself. Others, again, have entered upon an experimental investigation of the subject with enlightened views of its anatomy and physiology, have furnished us with much additional information, and lead us to indulge in the pleasing prospect that in a short time the matter will be completely set at rest.

The result of the experiments of Hope and Williams, attested as they have been by various gentlemen well qualified to judge of their accuracy,—also those of Mr. Carlisle, Magendie, Bouillaud, and the Dublin Committee, have satisfactorily determined that the account of the order of the contractions of the heart, and their isochronism to the sounds as stated by Mr. Turner, are perfectly correct. As, however, so many different circumstances attend each movement of the heart, any one of which may be capable of producing these sounds, it became a much more difficult matter, and one requiring great perseverance and accuracy of investigation, to determine upon what particular one or more of these, each sound depends. For accompanying, and synchronous with the first sound, we have the contraction of the ventricles, the collision of the different currents of blood contained there thus set in motion, the approximating of the auriculo-ventricular valves, the impulse of the heart against the chest, and the propulsion of the blood along the large arteries; while attending the second sound, we have the diastole of the ventricles, and the rush of a certain quantity of blood from the auricles into the ventricles, the sudden separation of the auriculo-ventricular valves towards the walls of the ventricles, and the regurgitation of part of the blood in the arteries upon the semilunar valves, throwing them inwards towards the axes of the vessels; so we will find that each of these in its turn has been thought capable of producing the sound which it accompanies, and still has, or until lately had, its advocates and supporters. As the subject is one surrounded with numerous and unusual difficulties, and is of comparatively recent investigation, it has followed, as was to be anticipated, that as new facts and observations are collected, many of the opinions first promulgated on this question have required to be modified or changed; and the scientific candour displayed by several of these authors in renouncing former published opinions is deserving of the highest praise.

Several of the explanations of the cause of the sounds of the heart proceed, however, upon the supposition that the relation of these sounds to the movements of the organ is different from what has been here represented. We shall merely state these without alluding to the arguments adduced in support of them, as we believe that they are founded upon inaccurate observation. Sir D. Barry believed that the first sound was synchronous with the diastole of the auricles, and the second sound with the diastole of the ventricles. Mr. Pigeaux, Dr. Corrigan also until lately, Dr. Stokes, Mr. Hart, and Mr. Beau, have maintained that the first sound is synchronous with the diastole, and not with the systole of the ventricles. According to Mr. Pigeaux, when the auricles contract they project the blood against the walls of the ventricle, and a dull sound (first sound) is produced; on the other hand, whilst the ventricles contract, they project the blood against the thin walls of the great vessels which spring from them, and a clear sound (second sound) is the result. Dr. Corrigan supposed that the first sound was produced by the rush of blood from the auricles into the dilating ventricles, and that the second sound owed its origin to the striking together of the internal surfaces of the ventricles during their contraction, after they had expelled all their blood. Mr. Beau believes with M. Magendie that the first sound arises from the impulse of the heart against the inner surface of the chest, but differs from him in maintaining that this occurs during its diastole, and not during its systole. The second sound he believes to depend upon the dilatation of the auricles. M. Piorry has revived the obsolete and perfectly untenable opinion of Nicholl, that the two ventricles contract at different times, and attributes the dull sound to the contraction of the left ventricle, and the clear sound to the contraction of the right ventricle. Dr. David Williams, while he believes that the first sound depends upon the rush of blood into the large arteries during the systole of the ventricles, attributes the second sound to the musculi papillares, which he considers as forming part of the valvular apparatus, causing the valves to strike against the walls of the ventricles. These musculi papillares do not, in his opinion, contract during the systole of the ventricles, but immediately afterwards, for the purpose of throwing open the auriculo-ventricular valves. In a former part of this article several circumstances are stated adverse to this opinion.

We shall now proceed to the explanation of the cause of these sounds given by those who maintain the views of the rhythm of the heart which we have here adopted, as resting upon the concurrent testimony of numerous accurate observers. These may be divided into those who attribute both sounds *to causes intrinsic to the organ*, or, in other words, to circumstances occurring within the organ itself, and into those who place them *external to the organ*, and depending upon extraneous objects. The only supporters of the latter opinion are Magendie and his followers. Magendie maintains that "in contracting, and for causes long since known, the ventricles throw the apex of the heart against the left lateral part of the thorax, and thus produce the first sound, *i. e.*, the dull sound. In dilating, in a great measure under the influence of the rapid influx of the blood, the heart gives a shock to the anterior paries on the right of the thorax, and thus produces the second sound, the clear sound." In proof of this, he states that on removing the sternum of a swan (an animal selected expressly for the experiment, as it interfered less with the natural action of the heart than in the Mammalia), he found that the movements of the heart produced no sound, while, on replacing the sternum, and allowing the heart to impinge upon its posterior surface as in the natural state, both sounds were again distinctly heard. He adduces several arguments drawn from the action of the heart both in its healthy and diseased state in favour of his opinion; and he ingeniously attempts to get rid of the objection which must instantly suggest itself, that in many cases, such as frequently occur in hypertrophy of the organ, the loudness of the sounds is diminished, while the force of the impulse is increased, by arguing that in these cases this increased impulse depends rather upon a heaving of the chest produced by the heart, which from its increased size is brought close to its inner surface, than upon a distinct impingement upon it, such as takes place in the healthy state. Dr. Hope, M. Bouillaud, Dr. C. J. B. Williams, and the Dublin and London Heart Commitees have, however, distinctly heard both sounds of the heart, after that portion of the chest against which it impinges had been removed. It may, nevertheless, be objected to these experiments, that as the stethoscope was used in many of them, the impulse of the heart against the extremity may have produced an effect similar to its impulse against the parietes of the thorax. M. Bouillaud, having apparently this objection in view, states that the rubbing of the heart during its movements against the extremity of the stethoscope, is easily distinguished from the sounds of the heart; and that he has distinctly heard both sounds, though feebler than through a stethoscope, as was to be expected when nothing but a cloth was interposed between his naked ear and the surface of the heart. Dr. C. J. B. Williams, in his experiments, heard both sounds when the stethoscope was placed over the origin of the large arteries, and where no external impulse could take place; and this observation was repeated by the Dublin Committee. The Dublin Committee heard both sounds through the stethoscope, though feebler after the pericardium had been injected with tepid water; and in another experiment they were also heard when the ear was simply approximated to the organ. From all these experiments, I think there can be little doubt that the movements of the heart, independent of all extraneous circumstances, are attended by a double sound. As the impulse of the heart against the chest must produce some sound, as any one may convince himself by making the experiment in the dead body, and as this occurs during the systole of the heart, or, in other words, during the first sound, it may increase the intensity of that sound. Dr. R. Spittal,* after relating several experiments in which a sound similar to that of the first sound of the heart was heard by tapping gently with the apex of the heart or the point of the finger against the chest, both when empty and when filled with water, and after pointing out several sources of fallacy which he supposes were not sufficiently guarded against in the experiments which we have adduced above as subversive of this view, and which deserve the attention of future experimenters, comes to the conclusion that "it is highly probable that the percussion of the heart against the thoracic parietes during the contraction of the ventricles assists materally in the production of the first sound." He is also inclined to believe "that the act of the separation of the heart from the thorax after its approach, which was found in his experiment to produce a sharp, short sound, somewhat resembling the ordinary sound, may in certain circumstances be an assistant cause to the second sound."† Magendie's explanation of the second sound is completely untenable.

Among those who maintain that these sounds depend upon causes intrinsic to the heart, *the first sound* is referred by Rouanet, Billing, Bryan, and Bouillaud to the rapid approximation of the auriculo-ventricular valves during the systole of the ventricles, to which Bouillaud

* Edin. Med. and Surg. Journal, July 1836.

† Though Dr. Spittal is inclined to believe that the impulse of the heart against the chest has considerable share in the production of the first sound, he does not concur with Majendie in the explanation of the second sound.

adds the sudden separation of the semilunar valves when the blood is forced into the large arteries; by Mr. Carlisle to the rushing of the blood along the inner surface of the large arteries during the systole of the ventricles.* Dr. Hope, in the appendix to the second edition of his work, describes it as consisting, 1st, possibly of a degree of valvular sound; 2d, of a loud smart sound produced by the abstract act of a sudden jerking extension of the muscular walls, in the same manner that such a sound is produced by similar extension of the leather of a pair of bellows; to avoid circumlocution, he calls it the *sound of extension;* 3d, a prolongation and possibly an augmentation of this sound by the sonorous vibrations peculiar to muscular fibre." Dr. C. J. B. Williams has very justly objected to the correctness of the second cause here adduced as aiding in the production of the first sound, as the phrase "sound of extension" is obviously contradictory when applied to a contracting muscle.† Dr. C. J. B. Williams maintains "that the first sound is produced by the muscular contraction itself," the clearness of which is increased by the quantity of blood in the heart "affording an object around which the fibres effectually tighten, whilst the auricular valve, by preventing the reflux of the blood, increases its resistance, and thus adds to the tension necessary for its expulsion." He was first led to the adoption of this opinion by the observations of Erman and Wollaston upon the existence of a sound accompanying every rapid muscular contraction. This opinion he afterwards put to the test of experiment, the results of which we give in his own words. "Experiment 1st, observation 8th; I pushed my finger through the mitral orifice into the left ventricle and pressed on the right so as to prevent the influx of blood into either ventricle; the ventricles continued to contract strongly (especially when irritated by the nail of the finger on the left), and the first sound was still distinct, but not so clear as when the ventricles contracted on their blood. Observation 9th. The same phenomena were observed when both the arteries were severed from the heart." He also found in other observations that the first sound was louder over the surface of the ventricles than over the origin of the large arteries, which is in direct opposition to the opinion of those who believe that this is produced by the rush of blood along the great arteries. That the first sound is not dependent upon the closing of the auriculo-ventricular valves, he also ascertained from observations, in which the closure of these valves was partially or completely prevented, and yet the first sound was still heard. Besides, this sound continues during the whole of the ventricular systole, while the shutting of the valves must take place and be completed at the commencement of the systole." That the collision of the particles of fluid in the ventricles does not produce this sound he was convinced from observations, in which it continued although there was no blood in the ventricles.

Though we must admit that these experiments of Dr Williams prove that part at least of the first sound is caused by the muscular contraction of the ventricles, yet we must consider it still problematical, until we obtain further observations, whether it produces the whole of that sound, for it is very possible that some of the other circumstances attending the systole of the heart may increase its intensity. M. Marc d'Espine has maintained that both sounds depend on muscular movements; the first sound upon the systole, and the second upon the diastole of the ventricles. The Dublin Committee have in the meantime concluded that the first sound is produced either by the rapid passage of the blood over the irregular internal surface of the ventricles on its way towards the mouths of the arteries, or by the *bruït musculaire* of the ventricles, or probably by both these causes. We must wait for further experiments before this question can be fairly settled.*

Second sound.—Later experimenters appear to be more nearly agreed about the cause of the second sound than that of the first sound. M. Rouanet appears to have been the first who publicly maintained the opinion that the second sound was dependent upon the shock of blood against the semilunar valves at the origin of the aorta and pulmonary artery. M. Rouanet himself acknowledges that he owed the suggestion to Dr. Carswell, at that time studying in Paris, who came to that conclusion by a beautiful process of reasoning upon the phenomena which presented themselves in a case of aneurism of the aorta. The same opinion has been supported by Billing, Bryan, Carlisle, and Bouillaud.† It is, however, to Dr. C. J. B.

* As Mr. Carlisle is a member of the Dublin Heart Committee, we must now consider him as concurring with the report of that Committee.

† Medical Gazette, Sept. 1835.

* The London Committee, in their report given in at the meeting of the British Scientific Association for 1836, have adduced some additional experiments in favour of the opinion that the first sound of the heart depends upon muscular contraction. It appeared to them that the sound produced by the contraction of the abdominal muscles as heard through a flexible tube resembles the systolic sound. They, however, admit that though "the impulse is not the principal cause of the first sound, it is an auxiliary and occasional cause, nearly null in quietude and in the supine posture, but increasing very considerably the sound of the systole in opposite circumstances." From the great care with which these experiments appear to have been performed, we believe that we are now fully justified in adopting this explanation of the cause of the first sound. The Dublin Committee, in their report given in at the same time, also detail some experiments which they believe to be confirmatory of their former conclusions. See Sixth Report of British Scientific Association.

† In justice to Dr. Elliott, of Carlisle, I must state that I find, on consulting his Thesis De Corde Humano, published in Edinburgh in 1831, that he states (p. 53) that he believes that the second sound of the heart is dependent upon the rush of blood from the auricles into the ventricles during their diastole, and also upon the sudden flapping inward of the sigmoid valves at the origin of the large arteries by the refluent blood.

Williams that we owe the first direct experiments in support of it. In one experiment he ascertained that the second sound was louder over the origin of the large arteries than over the surface of the ventricles, while it was the reverse with the first sound; that pressure upon the origin of the aorta and pulmonary artery suspended the second sound; and that the second sound disappeared after the auricles had been laid open, although the first continued. In a second experiment* we find the following observations stated:—" Observation 6. A common dissecting hook was passed into the pulmonary artery, and was made to draw back and thus prevent the closure of the semilunar valves; the second sound was evidently weakened and a hissing murmur accompanied it. A shoemaker's curved awl was then passed into the aorta so as to act in the same way on the aortic valves. The *second sound now entirely ceased and was replaced by a hissing.* Observation 7. The hook and the awl were withdrawn; *the second sound returned and the hissing ceased.* Observation 8. The experiment 6th was repeated with the same result, and whilst Dr. Hope listened I withdrew the awl from the aorta. He immediately said, 'Now I hear the second sound.' I then removed the hook from the pulmonary artery; Dr. Hope said, 'Now the second sound is stronger and the murmur has ceased.'" The Dublin Committee have repeated and confirmed these experiments of Dr. Williams. In their experiments one of the valves in each artery was transfixed and confined to the side of the vessel by a needle, and the second sound disappeared; on withdrawing the needles they re-appeared.

As the second sound thus appears to be produced by the *shock of the blood upon the semilunar valves*, its intensity must, in a great measure, depend upon the diastole of the ventricle drawing part of the blood back upon them, but perhaps more particularly upon the elasticity of the large arteries returning suddenly upon their contents during the diastole of the ventricles, when the distending force of the ventricles has been withdrawn. We would therefore expect that the second sound should be louder in those whose aorta retains its elasticity, than in those (a circumstance sufficiently common in old age) in whom, from a morbid alteration of the structure of its coats, the elasticity is either lost or greatly diminished. This is an observation which, as far as I know, has not yet been verified; but my friend Dr. W. Henderson informs me that he is positive from numerous observations that the second sound is louder in young than in older persons; but whether this is in the exact ratio of the change upon the elasticity of the coats of the large vessels he is not at present prepared to say.

* These experiments were performed upon asses, in which the sensation was first suspended by a dose of wourara poison and then maintaining artificial respiration. In this manner the heart continued to act upwards of an hour after the commencement of the artificial respiration.

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THE END.

MARCHANT, PRINTER, INGRAM-COURT, FENCHURCH-STREET.