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ON THE

RELATIONS, STRUCTURE, AND FUNCTION, OF THE VALVES

OF THE

VASCULAR SYSTEM IN VERTEBRATA.

BY

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XLVI.—*On the Relations, Structure, and Function, of the Valves of the Vascular System in Vertebrata.* By JAMES BELL PETTIGREW, M.D. Edin., Assistant in the Museum of the Royal College of Surgeons of England. Communicated by WILLIAM TURNER, M.B. (Plates XXVIII., XXIX.)

(Read 21st March 1864.)

Introductory Remarks.

The rapid advances made of late in the diagnosis of cardiac and other diseases affecting the organs of circulation, render the present inquiry into the normal or healthy condition of the valves of the vascular system, not more important anatomically, than medically. As the nature and composition of the parts in which valves are found in some instances materially influence their action, I have deemed it necessary to advert briefly to the properties and structure of the veins and arteries, when describing the venous and arterial or semilunar valves; and to the arrangement of the muscular fibres in the ventricles, when pointing out the peculiarities of the auriculo-ventricular ones. As, moreover, much information is to be obtained by comparing analogous structures, I have, in the present instance, not confined my observations to any particular form of valve, but have examined in succession the entire valvular arrangements of the fish, the reptile, the bird, and the mammal; my object being to arrive, if possible, at a correct knowledge of the more elaborate varieties as they exist in man, and in the higher mammalia.

In order to simplify the numerous relations and complicated structure of the several valves met with, as well as to obviate the necessity for entering largely into anatomical details, the present paper has been fully illustrated by photographs and drawings from dissections, and from casts representing the valves in action. The photographs, thirty-four in number, were taken for the most part from the specimens while in the fresh or recent state, by Mr AYLING and myself. Of the drawings, twenty-three in number, that marked 33, Plate XXVIII. and the last six of Plate XXIX., are by my friend Dr HENRY SEASON WILSON. The remaining fourteen are by myself. For permission to examine and figure several of the specimens illustrating the peculiarities of the valvular arrangements of the fish and reptile, I am indebted to the kindness of the Council of the Royal College of Surgeons of England. The dissections and casts, which are numerous, were made with a special view to this inquiry, and are preserved in the Museum of the Royal College of Surgeons of England, where they may be consulted.

STRUCTURE OF THE VEINS AND VENOUS VALVES.

Regarding the composition of the veins, there is, as the reader is aware, some difference of opinion, authorities not being agreed either as to the number or nature of the coats. This may in part be explained by the variation in the thickness of the coats themselves, these, according to JOHN HUNTER,[*] becoming thinner and thinner in proportion to the size of the vein, the nearer they approach to the heart. In moderate-sized veins an external, a middle, and an internal coat are usually described; the first consisting of cellular, fibrous, and elastic tissue, interlacing in all directions; the second, of waved filaments of areolar tissue, with a certain admixture of non-striped muscular fibres, which run circularly, obliquely, or even longitudinally;[†] the third, consisting of one or more strata of very fine elastic tissue, minutely reticulated in a longitudinal direction, the innermost stratum (when several are present) being lined by epithelium. Of these layers, the second and third, from the fact of their contributing to the formation of the venous valves, are the most important. The coats of the veins, as has been long known, are tough, elastic, and possessed of considerable vital contractility. Of these qualities, the toughness prevents undue dilatation of the vessel when distended with blood; the elasticity and vital contractility assisting the onward flow of that fluid, and *tending to approximate the segments of the valves*, by contracting in the direction of the axis of the vessel. As the valves of the veins are very ample and very flexible, they readily accommodate themselves to the varying conditions in which they are placed by the elasticity and contractility of the vessel, and by the reflux of the blood.

The valves of the veins vary as regards the number of the segments composing them, and also slightly as regards structure. In the smallest veins, and where small veins enter larger ones (Plate XXVIII. fig. 9 *b*), one segment only is present. In middle-sized veins, as they occur in the extremities, two segments (Plate XXVIII. figs. 3, 4, and 7 *a b*), are usually met with;[‡] while in the larger veins, as in the internal jugular of the horse, three, and even four segments (Plate XXVIII. figs. 1 and 2, *a b c, f g h*), are by no means uncommon.[§]

The segments, whatever their number, are semilunar in shape[||] (Plate XXVIII.

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[*] HUNTER on the Blood, pp. 180, 181.

[†] Dr CHEVERS says, that in the deep as well as in some of the superficial veins of the trunk and neck, the middle coat is composed of several layers of circular fibres, with only here and there a few which take a longitudinal course; while the middle coat of the superficial and deep veins of the limbs consists of a circular layer, and immediately within this of a strong layer of longitudinal fibres.—*Med. Gazette*, 1845, p. 638.

[‡] In the heart of the frog-fish, sun-fish, sturgeon, American devil-fish, python, and crocodile, a semilunar valve, consisting of two segments, guards the orifice of communication between the sinus venosus and the right auricle.

[§] When four segments are present, two are usually more or less rudimentary (Plate XXVIII. fig. 2 *f g*).

[||] JOHN HUNTER in speaking of the form of the venous valves, says, their free edges are *cut off straight*, and are not curved as in the arteries. This, however, is not the case; as may be seen by

figs. 3 and 4 *a b*); the convex border being attached to the wall of the vessel obliquely (Plate XXVIII. fig. 5 *a b*), the crescentic or concave margin, which is free (Plate XXVIII. fig. 4 *c*), and directed towards the heart, projecting into the vessel. When one segment constitutes the valve, and it occurs in the course of a vein, it is placed obliquely in the vessel (Plate XXVIII. fig. 9), its attached convex border (*a*) occupying rather more than a half of the interior. When the segment occurs at the junction of a smaller with a larger vein, its convex border is attached to a half or more of the orifice of the smaller one where it joins the larger, its free margin running transversely to the larger trunk. In such cases the segment *acts as a moveable partition or septum, common alike to both vessels,* but its position and relations are such, that while it readily permits the blood from the smaller vein to enter the larger one, it effectually prevents its return.

When the valve consists of two segments, they are semilunar in shape, and very ample, the vertical measurement of each, being not unfrequently nearly twice that of the diameter of the vessel itself (Plate XXVIII. figs. 3 and 4 *a b*). In such cases both segments are usually of the same size, so that they divide the vessel into two equal parts (*e*). They are placed obliquely with regard to each other (Plate XXVIII. fig. 5 *a b*), their convex borders, which are attached to the interior of the vessel, starting from a common point above (Plate XXVIII. fig. 2 *i*), and gradually diverging (*e*) to curve round and reunite on the opposite side of the vessel (*d*); their concave and free margins inclining towards each other (Plate XXVIII. fig. 12 *e*), and being directed, as in the more simple valve, towards the heart. The free margins of the two segments, like the attached ones, start from a common point (Plate XXVIII. fig. 4 *r*), but such is the shape of the segments, and such the angle at which they are placed with regard to each other, that they do not diverge to the same extent, *but run more or less parallel.** This relation of the segments to each other above, is in part accounted for by the presence of *a fibrous structure* (Plate XXVIII. fig. 4 *r*), *which extends from the wall of the vessel into the interior*, and supports them at a certain distance from the sides of the vessel. The fibrous structure referred to is well seen in the semilunar valves of the pulmonary artery and aorta (Plate XXVIII. fig. 36 *n n'*), and seems to have escaped observation. In a line corresponding to the attached border of each of the segments (Plate XXVIII. fig. 4 *a b*), *the middle and internal coats of the vein are thickened*, as may be ascertained by a vertical section, or by

reference to photographs 1, 2, 3, and 4, Plate XXVIII. The edges referred to are least curved when the valve is distended or in action (Plate XXVIII. fig. 13 *e*), but the curve is never altogether absent.—*Treatise on the Blood*, pp. 181, 182.

* I was much struck, on injecting the external saphenous vein of the human subject from the dorsum of the foot, to find, on dissection, that the free margins of some of the segments were in contact throughout; clearly showing, that when the segments are allowed to float in a fluid, they are so projected against each other, that even the slightest reflux will instantly close them.

introducing coloured plaster of Paris* into the vessel. I particularly direct attention to this circumstance, as the thickenings referred to *form fibrous zones* (Plate XXVIII. fig 6 *h*), *which extend for a short distance into the substance of the segments*, and afford them a considerable degree of support. They further assist in preserving the shape of the segments, and in enabling them to maintain the proper angle of inclination—the said angle inclining the segments towards each other in the mesial plane of the vessel (Plate XXVIII. figs. 3 and 4 *e*). When a valve, consisting of two segments, is situated at the junction of a smaller with a larger vein, one of the segments is usually placed between the two vessels at the point of juncture (Plate XXVIII. fig. 11 *b*), the other on the wall of the smaller vein (*a*). The position of the segments in such instances varies, their long diameter sometimes running parallel with the larger vessel, sometimes obliquely, but more commonly transversely. When the valve consists of three segments (Plate XXVIII. figs. 1 and 8, *a b c*, *r s t*), the segments, as a rule, are unequal in size, one of them being generally a little larger (*t*) than either of the other two (*r s*). They are semilunar in shape, as in the smaller and middle-sized veins, and differ from the latter in being less capacious. The tri-semilunar valves in the veins, may therefore be regarded as intermediate between the fully developed bi-semilunar valves found in the veins of the extremities, and the fully developed tri-semilunar valves which occur at the origin of the pulmonary artery and aorta. The existence of valves in the veins is indicated externally by a dilatation or enlargement of the vessel; the dilatation consisting of one, two (Plate XXVIII. figs. 3, 5, and 12 *h g*), or three (Plate XXVIII. fig. 8 *g a b*) swellings, according as the valve is composed of one two, or three segments. These dilatations or swellings are analogous to the sinuses of VALSALVA in the arteries (Plate XXVIII. figs. 17 and 18 *d*), their direction in the veins of the extremities being from below upwards and from within outwards. They form, with the segment to which they belong, open sinuses or pouches which look towards the heart, and as they extend nearly as far in an outward direction as the segments project inwardly, they give a very good idea of the size and shape of the segments themselves. The only point regarding the dilatations deserving of special attention, *is the gradual thinning in a direction from above downwards, of those portions of the coats of the vessel which enter into their formation.* The thinning referred to, is well seen when vertical sections of the vessel are made, or when the vein is distended with coloured plaster of Paris, as recommended. The swellings present a deeper colour the nearer we approach to the attached border of the segments, the attached borders, on account of their greater thickness, appearing as dense fibrous zones (Plate XXVIII. fig. 5 *a b*, fig. 6 *h*). The object of the swellings is evidently

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* I have derived much information from the employment of this material; its use having enabled me to determine with something like accuracy, the relation of the segments of the valves to each other when in action, and other points connected with the physiology of the heart.

twofold,—*firstly, to cause the blood to act on the segments of the valve from above downwards, and from without inwards, in the direction of the mesial plane, or of the axis of the vessel,* according as there are two or three segments present; and, *secondly, to increase the area over which the pressure exerted by the reflux of the blood extends.* When the vein is opened between the segments, when two are present, each of the segments is seen to form two curves,—one curve giving its concave or free margin (Plate XXVIII. fig. 4 *c*), the other its convex or attached one (*a*); but when the section is carried through the wall of the vein, and through the centre of one of the segments, one curve only is obtained (Plate XXVIII. fig. 3 *g*); and it is useful to remember this, as it shows with what facility the structures entering into the formation of the segments, viz., the lining membrane of the vessel and certain parts of the middle and internal coats, are given off. It also shows how the lower portion of the dilatation (*g*), while it supports a certain quantity of the refluent blood, guides by far the greater quantity on to the valves (*b*), rendering their closure not a matter of accident, but of necessity.

The segments of the venous valves are exceedingly flexible, and so delicate as to be semi-transparent. They possess great strength and a considerable degree of elasticity.* Usually they are described as consisting of a reduplication of the fine membrane lining the vessel, strengthened by some included fibro-cellular tissue, the whole being covered with epithelium. This description, however, is much too general to convey any very accurate impression of their real structure, and the following, drawn up from the examination of a large number of specimens taken from man, the horse, ox, sheep, and other animals, may prove useful.

When one of the segments of a well-formed bi-semilunar valve removed from the human femoral vein, is stained with carmine, fixed between two glasses, and examined with the microscope or pocket lens, the subjoined phenomena are witnessed :—

1*st*, The lining membrane of the vessel covered with epithelium is seen to form the investing sheath of the segment, no breach of continuity being anywhere perceptible.

2*d*, Large quantities of white fibrous tissue, mixed up with areolar and yellow elastic tissue, from the middle and internal coats of the vessel, are observed to extend into the segment. The fibres composing these tissues pursue a definite arrangement.

Thus running along the concave or free margin of the segment (Plate XXVIII. fig. 14 *a*), as likewise on the body, especially where the segments join each other (*b*), are a series of very delicate fibres, consisting principally of yellow elastic tissue. These fibres proceed in the direction of the long diameter

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* HUNTER denies the elasticity of the segments, on the ground that the valvular membrane is not formed of a reduplication of the lining membrane of the vessel, an opinion at variance with recent investigation.—*Treatise on the Blood*, pp. 181, 182.

of the segment, but transversely to the course of the vessel, and may be denominated *the horizontal fibres.*

Running in a precisely opposite direction, and confining themselves principally to the body of the segment, are a series of equally delicate fibres (*c*), having a like composition, and which, for the sake of distinction, may be described as *the vertical series.* These two sets of fibres are superficial, and to be seen properly, a power magnifying from 200 to 250 diameters is required.

Radiating from the centre of the segment (Plate XXVIII. fig. 15 *e*) *towards its attached border* (*i i'*), *and seen through the more delicate horizontal and vertical ones, is a series of stronger and deeper fibres,* composed of white fibrous and yellow elastic tissue, the former predominating. Still stronger and deeper than either of the fibres yet described, and proceeding from the attached border of the segment (Plate XXVIII. fig. 16 *s t*), *is a series of oblique fibres,* continuous in very many instances with corresponding fibres in the middle coat of the vessel. These fibres cross each other with great regularity, and form the principal portion of the segments. They are most strongly marked at the margin of the convex border of the segment, where they form a fibrous zone or ring, which, as has been explained, supports the segment, and carries it away from the sides of the vessel into the interior. I have also detected, in the vicinity of the attached border of the segment, some non-striped muscular fibres. The segment of a venous valve is therefore a highly symmetrical and complex structure, the fibrous tissues composing it, being arranged in at least three well-marked directions ; viz., horizontally, vertically, and obliquely. The great strength which such an arrangement is calculated to impart to the segment is readily understood.

In conclusion, the segment is thinnest at its free margin, and thickest towards its attached border ; the body being a little thicker than the free margins, and where the extremities or narrow portions of the segments join each other, but not so thick as the attached border.

The Venous Valves in Action.

The manner in which the venous valves act, is well seen when the vein is suspended perpendicularly overhead, and water, oil, glycerine, or liquid plaster of Paris, poured into it by an assistant from above ; the vein beneath the valve being cut away, the better to expose the segments to the view of the spectator. When the valve consists of one segment only, the fluid is observed *to force it obliquely across the vessel,* and to apply its free crescentic margin to the interior or convex surface with such accuracy as to prevent even the slightest reflux. When two segments occur in the course of a vein, *they are forced by the fluid simultaneously towards each other in the mesial plane of the vessel* (Plate XXVIII. figs. 3 and 12 *e*), the sinuses (*gh*) behind the segments becoming distended, and directing the

current and regulating to a certain extent the amount of pressure. The closure in this instance is almost instantaneous, and so perfect that not a single drop escapes.   It is effected by *the free margins of the segments, and a large proportion of the sides*, coming into accurate contact, the amount of contact increasing in the inverse of the pressure applied.   If liquid plaster of Paris be used for distending the vein, and the specimen is examined after the plaster has set, one is struck with the great precision with which the segments act (Plate XXVIII. figs. 6 and 11 *a b*), these coming together so symmetrically, that they form by their union *a perpendicular wall or septum* (Plate XXVIII. figs. 6, 11, and 12, *e*) *of a beautifully crescentic shape** (Plate XXVIII. fig. 13 *e*).   This fact is significant, as it clearly proves that the concave or free margins of the segments, and a considerable proportion of the sides, run parallel to each other when the valve is in action, a circumstance difficult of comprehension, when it is remembered that the convex borders of the segments are attached obliquely to the walls of the vessel, and that the segments, when not in action, incline towards each other at a considerable angle.   The very accurate apposition of the segments, when the valve is closed, is to be traced :—

1*st*, *To the direction and shape of the venous sinuses*, which conduct the fluid employed, on to the segments in almost equal quantities.

2*d*, *To the disposition of the free margins of the segments*, which, as was explained, run side by side, and are supported by fibrous structures which carry them away from the sides of the vessel for some distance ; and,

3*d*, *To the amplitude of the segments themselves*, which allows them to come together without difficulty, and when the pressure is applied, to flatten themselves against each other to form the perpendicular crescentic wall adverted to.

In the event of two segments occurring at the entrance of a smaller into a larger vein, one of them being situated at the junction of the smaller vessel with the main trunk (Plate XXVIII. fig. 11 *b*), the other on the wall of the tributary branch (*a*) ; the former, *i.e.*, the common or septal segment, is forced by the fluid in *a slightly outward direction*, the latter *in an opposite or inward direction*, the free margins and sides of the segments being by this arrangement accurately applied to each other to form an impervious wall or septum (*e*) as already described.   When the entrance of a smaller into a larger vessel is guarded by two segments situated on the tributary branch at its orifice, their action is precisely the same as when they are placed in the course of a vein.   When three segments are present, as happens in the larger trunks, the closure is effected in a manner greatly resembling that by which the semilunar valves of the pulmonary artery and aorta

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* In order to see the perpendicular wall formed by the flattening of the sides of the segments against each other when the valve is in action, the vein and the plaster should be cut across immediately above the valve, and the segments forcibly separated by introducing a thin knife between them.   In fig. 13, Plate XXVIII., one of the segments has been quite removed.

are closed; the fluid employed, in virtue of the direction given to it by the venous sinuses, *causing each of the segments* (Plate XXVIII. fig. 8 *r s t*) *to bend or double upon itself at an angle* (*i*) *of something like* 60° ;* the three lines formed by the doubling and union of the three segments dividing the circle corresponding to the wall of the vessel, into three nearly equal parts. In the doubling of the segments upon themselves, *each segment regulates the amount of bending which takes place in that next to it,* and as the free margins of the segments so bent advance synchronously towards the axis of the vessel, *they mutually act upon and support each other.* As the three segments are attached obliquely to the wall of the vessel, while the free margins, after the folding has taken place, are inclined towards and run parallel to each other (*a b*), they form an inverted dome consisting of three nearly equal parts, the margins of the segments, and a certain portion of the sides, when the pressure is applied, flattening themselves against each other to form three crescentic partitions or septa† which run from the axis of the vessel towards the circumference.

The tri-semilunar valve, as will be seen from the foregoing explanation, is closed in a very different manner from the bi-semilunar one. The occlusion of the vessel, however, is not the less complete; the segments, when three are present, *being wedged into each other in a direction from above downwards, and from without inwards;* the first of these movements, by tending to flatten the segments, pressing their margins and sides together: the second, by urging the segments towards the axis of the vessel, impacting them more and more tightly, especially towards their apices or points. As the apices or points formed by the doubling of the segments whilst in action, are composed principally of the flexible and free crescentic margins, and are at liberty to move until the wedging process is completed, a careful examination has satisfied me, *that they rotate to a greater or less extent before the valve is finally closed.* This spiral movement, which is simply indicated in the venous valves, is more strongly marked in the semilunar ones of the pulmonary artery and aorta (Plate XXVIII. figs. 26, 27, and 28, *v, w, x,*) and attains, as will be shown subsequently, a maximum in the auriculo-ventricular valves of the mammal (Plate XXIX. figs. 53 and 54, *m i n, s r*).

By whatever power the blood in the veins advances—whether impelled by the heart alone, or by muscular contractions occurring in different parts of the body, or by rythmic movements which take place in the vessels themselves, or by efforts of inspiration, or by all or combinations of these; there can, I think, be little doubt that this fluid, in its backward or retrograde movement, acts to a great extent mechanically on the valves as described. It ought, however, to be borne in mind that the veins and the valves are vital structures, and that

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* The angle is never precisely 60°, from the fact of the segments varying slightly as regards size.
† The crescentic partitions, as they occur in the semilunar valves of the pulmonary artery and aorta, are shown at *b b′,* of fig. 25, Plate XXVIII.

although a perfect closure may be effected by purely mechanical means in the dead vein, it is more than probable that in the living one, the contraction of the coats of the vessel exercises a regulating influence.

STRUCTURE OF THE ARTERIES AND ARTERIAL VALVES.

The coats of the arteries, as is well known, are thicker than those of the veins, while the layers composing them are more numerous.   The external coat, according to HENLE, consists of an outer layer of areolar tissue in which the fibres run obliquely or diagonally round the vessel, and an internal stratum of elastic tissue; the middle coat in the largest arteries, according to RAÜSCHEL, being divisible into upwards of forty layers.   The layers of the middle coat consist of, pale, soft, flattened fibres, with an admixture of elastic tissue, the fibres and elastic tissue being disposed circularly round the vessel.   The internal coat is composed of one or more layers of fibres, so delicate that they constitute a transparent film, the film being perforated at intervals, and lined with epithelium.   The arteries, as might be expected from their structure, and as was proved by the admirable experiments of JOHN HUNTER, whose beautiful preparations I have had an opportunity of examining, possess a high degree of elasticity and vital contractility, and are extensible and retractile both in their length and breadth; the power of recovery, according to that author, being greater in proportion as the vessel is nearer the heart.   From this it follows that the pulmonary artery and aorta are most liable to change in dimensions.   As, however, any material alteration in the size of the pulmonary artery and aorta might interfere with the proper function of the semilunar valves situated at their orifices, it is curious to note that the great vessels arise from strong and comparatively unyielding fibrous rings.   These rings (particularly the aortic one) are so dense as to be almost cartilaginous in consistence, and Professor DONDERS[*] has lately discovered, that they contain stellate corpuscles similar in many respects to those stellate and spicate corpuscles, found in many forms of cartilaginous tumours.   They have been more or less minutely described by VALSALVA,[†] GERDY,[‡] Dr JOHN REID,[§] and Mr W. S. SAVORY,[||] and merit attention because of their important relations to the segments of the semilunar valves.   The following description of the aortic and pulmonic fibrous rings, has been drawn up chiefly from the examination of a large number of human hearts.   Each ring, as will be seen by a reference to

* " Onderzockingen betrekkeligh den bouw van het menchclijke hart," in " Nederlandsch Lancet" for March and April 1852.
† Opera VALSALVÆ, tom. i. p 129.
‡ Journal Complimentaire, tom. x.
§ Cyc. Anat. and Phy. article " Heart," pp. 588, 589.   London, 1839.
|| Paper read before the Royal Society in December 1851.

Plate XXVIII. figure 30, taken from a photograph of a boiled heart, consists, as was shown by REID, of three convex portions (*r s t*). Each convex portion is directed from above downwards, and from without inwards, and as it unites above with that next to it, the two when taken together form a conical-shaped prominence (*x*), which is adapted to one of the three triangular-shaped inter-spaces occurring between the segments of the valve (Plate XXVIII. fig. 17 *h*). The arterial rings are therefore placed obliquely, the under surface, which gives attachment to many of the fibres of the ventricles anteriorly (Plate XXVIII. fig. 30 *d d'*), resting on the rounded oblique border of the ventricular walls (Plate XXVIII. fig. 17 *e*). The ring surrounding the pulmonary artery, as was pointed out by REID, is broader, but not quite so thick as that surrounding the aorta, and both are admirably adapted for the reception of the large vessels which, as was shown by that author, originate in three festooned borders. These borders, I am inclined to think, consist of two parts,—*an outer* (Plate XXVIII. fig. 17 *r r'*), composed of the outer, and a small portion of the central layer of either the aorta or pulmonary artery; and *an inner* (*t*), composed principally of the central and inner layers. The outer border (Plate XXVIII. fig. 18 *r*), which is the thinner of the two, is attached *to the superior and outer margin* of one or other of the fibrous rings (*g*), chiefly by the serous membranes; the inner (Plate XXVIII. fig. 17 *t*), which projects further in a direction from above downwards, and corresponds to the thickened convex border of the seg-ments (*s*), to the formation of which it contributes, being attached *to the inferior and inner margin* (*g'*). These points are well seen, when a vertical section is made of the aorta or pulmonary artery between the segments com-posing the semilunar valves. In such a section (Plate XXVIII. fig. 17), the vessels are observed to be thickened in a direction from above downwards, the thickening beginning at the point where the segments meet above (*b*), and gradually increasing until the vessels bifurcate (*r' t*). The reverse of this holds true of those portions of the vessels which enter into the formation of the sinuses of VALSALVA (Plate XXVIII. fig. 18 *i*), these being unusually thin, particularly where attached (*r*).* As the thickened portions of the vessels correspond to the fixed margins of the segments (Plate XXVIII. figs. 17 and 35 *b t n*), and extend between them in an arched direction above (*c*), they give the precise boundaries of the sinuses of VALSALVA (Plate XXVIII. figs. 17 and 18 *d*), and furnish the segments with *three fibrous frameworks* analogous, in some respects, to the thickenings which occur in similar situations in the veins. *These frameworks extend for a short distance into the segments* (Plate XXVIII. fig. 17 *b*, and fig. 36 *n*), and assist not only in affording the segments

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* The several points adverted to are seen to advantage in the whale (*Physalus antiquorum*, Gray), the aorta of which I had an opportunity of dissecting for the Museum of the Royal College of Surgeons of England.

the requisite degree of support, but in carrying them away from the sides of the vessel, and in inclining them towards each other at such an angle as insures that their free margins, especially where they unite above (Plate XXVIII. fig. 36 *b c*), shall be more or less parallel when the valve is in action. That the frameworks afford the support here indicated, is proved by the fact, that when liquid plaster of Paris is introduced into the ventricles, and forced through the pulmonary artery and aorta, in the direction of the circulation, the attached borders of the segments do not fall back into the sinuses of VALSALVA (Plate XXIX. figs. 50 and 51 *v w*) to the same extent as the sides and free margins, but project so as to furnish the casts thus obtained, with corresponding depressions (*r s*). The sinuses of VALSALVA are formed above by the dilatations or expansions of the great vessels, and the one occupies a higher position than either of the other two. They are further unequal in size (Plate XXVIII. fig. 26 *w x v*), the highest and smallest occurring anteriorly, that which is intermediate in size being placed posteriorly, while the lowest and largest is directed towards the septum. They correspond in situation and dimensions to the segments behind which they are found, and differ from the venous sinuses in being more capacious, a section of the sinus and its segment (which is likewise very ample) giving a sweep of nearly half a circle (Plate XXVIII. fig. 18 *b i s*). As a result of this amplitude, those portions of the segments which project into the vessel are, during the action of the valve, closely applied to each other throughout a considerable part of their extent (Plate XXVIII. fig. 26 *a b c*); the great size of the sinuses furnishing an increased quantity of blood for pressing the segments from above downwards, and from without inwards, or in the direction of the axis of the vessel. *The sinuses of* VALSALVA *curve towards each other in a spiral direction;* and this ought to be attended to in speaking of the action of the semilunar valves, as the sinuses direct the blood spirally on to the mesial line of each segment (Plate XXVIII. fig. 26 *v w x*), and cause the segments to twist and wedge into each other, as represented at *v w x* of figs. 26, 27, and 28, Plate XXVIII. In order to determine this point, I procured a fresh pulmonary artery and aorta, and after putting the valves into position with water, caused an assistant to drop liquid plaster of Paris into the vessels. The greater density of the plaster gradually displaced the water, and I was in this way furnished with accurate casts of the sinuses and of the valves. The segments of the semilunar valves, unlike the venous ones, are almost invariably three in number.* They differ in size and in position, and in this respect resemble the sinuses of VALSALVA, to the inside of which they are found. Thus the segment which is smallest is situated anteriorly, and occupies a higher position than either of the others; that which is second in

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* Dr JOHN HUGHES BENNETT speaks of a case in which four were present, but whether the additional segment was congenital, or the result of disease, is not easy to determine. "Principles and Practice of Medicine," 1858, p. 550.

size being placed posteriorly, and a little lower than the anterior segment. The remaining segment, which is the lowest, is directed towards the septum. They are flexible, more or less opaque, very strong, and somewhat crescentic in shape (Plate XXVIII. figs. 19 and 20). In structure, the semilunar valves are intermediate between the venous and auriculo-ventricular ones. They consist of a reduplication of the fine membrane lining the vessel, strengthened by certain tendinous bands, and, as was first satisfactorily demonstrated by Mr W. S. SAVORY, of a considerable quantity of yellow elastic tissue.[*] Some of the older anatomists, among whom may be mentioned LANCISCI,[†] SENAC,[‡] MORGAGNI,[§] WINSLOW,[||] and COOPER,[¶] believed that they had detected the presence of carneous or muscular fibres; but HALLER,[**] and many since his time, have gravely doubted the accuracy of their observations. Very recently, Mr MOORE[††] has figured two sets of muscular fibres, which he has termed according to their supposed action, dilators and retractors; and Dr MONNERET[‡‡] has described two similar sets, which, for like reasons, he has named elevators and depressors. I have sought in vain for the muscular fibres in question, and am inclined to think that when found, they have been mistaken for the tendinous bands accidentally stained with blood. The tendinous bands have hitherto been regarded as following three principal directions,—one band being said to occupy the free margin, and to be divided into two equal parts by the nodulus or Corpus Arantii, otherwise called Corpusculum Morgagni, and Corpus sesamoideum; a second band, proceeding from points a little above the middle of the segment, and curving in an upward direction towards the Corpus Arantii; the third band, which is the thickest, surrounding the attached border of the segment. A careful examination of a large number of mammalian hearts, particularly those of man, has induced me to assign to the semilunar valves a more intricate structure. In a healthy human semilunar valve[§§] taken from the pulmonary artery, the following seems to be the arrangement. Proceeding from the attached extremities of the segment above (Plate XXVIII. fig. 19 *b*, fig. 20 *x*, and fig. 29 *a*), and running along its free margin, is a delicate tendinous band, which gives off still more delicate

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* PURKINGE and RAEUSCHEL had detected elastic tissue in the Corpora Arantii, but knew nothing of its existence throughout the other portions of the valves. Of its presence I have frequently satisfied myself.

† De motu Cordis.

‡ Traité de la Structure de Cœur, livre i.

§ Adversaria Anatomica Omnia.

|| Exposition Anat. de la Structure du Corps Humain, p. 592

¶ Myotomia Reformata.

** Elementa Physiologiæ.   Liber iv. sect. 10.

†† Med. Gazette, March 8, 1850.

‡‡ Lancet, Dec. 29, 1850.

§§ It is very difficult to get a perfectly healthy human semilunar valve, especially if the patient is at all advanced in years.   Out of twenty adult hearts examined by me, nearly a half of that number had the valves abnormally thickened.

slips (Plate XXVIII. figs. 20 and 29 *r*), to radiate in a downward and inward direction, *i.e.* in the direction of the mesial line (Plate XXVIII. fig. 20 *c*) and body of the segment. These fine slips interdigitate in the mesial line, and are attached below to the uppermost of a series of very strong fibrous bands which occupy the body of the segment (Plate XXVIII. figs. 20 and 29 *s*). In the interspaces between the slips, the valve is so thin as to be almost transparent. Those portions of the segments included within the delicate fibrous band, running along the free margin and the uppermost of the stronger bands occupying the body, and which are situated to the right and left of the mesial line, are somewhat crescentic in shape (Plate XXVIII. fig. 20 *r*), and have, from this circumstance, been termed lunulæ. They do not form the perfect crescents usually represented in books, the horns of the crescents directed towards the mesial line of the segment (Plate XXVIII. fig. 20 *c*), being much broader than those directed towards the extremities, or where the segments unite above (Plate XXVIII. fig. 20 *b*). The object of this arrangement is obvious. The crescentic portions referred to, are those which, when the segment is folded upon itself during the action of the valve, are accurately applied to corresponding and similar portions of the two remaining segments (Plate XXVIII. fig. 25 *b b′*). If, however, the lunulæ had been symmetrical, in other words, if they had terminated in well-defined horns towards the mesial line, or where the segments fold upon themselves, then the union between the segments in the axis of the vessel (Plate XXVIII. fig. 25 *x*), where great strength is required, *would have been very partial*, and consequently very imperfect.

Proceeding from the attached extremities of the segments at points a little below the origins of the marginal band, and curving in a downward and inward direction, is the first of the stronger bands (Plate XXVIII. fig. 20 *b*). The band referred to essentially consists of two portions, these splitting up into brush-like expansions as they approach the mesial line (*c*), where they interdigitate and become strongly embraced. Other and similar bands, to the extent of three (*s*) or four, usually the latter number, are met with (Plate XXVIII. fig. 29 *v*), and as they all curve in a downward and inward direction, and have finer bands running between them in a nearly vertical direction, they suspend the body of the segment; so that when water is poured upon it, the various parts of which it is composed, radiate from the attached or convex border like a fan; each band dragging upon that above it; the whole deriving support from the thickened convex border. The bands, which are thus six in number, are best seen on that aspect of the segments which is directed towards the sinuses of VALSALVA.* They are thickest at their attached extremities, where they interlace slightly, and are mixed up to a greater or less extent with the pale, soft, flattened fibres, and elastic tissue of the central layer

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* The surfaces of the segments directed towards the axis are perfectly smooth, and so facilitate the onward flow of the blood.

of the vessel itself. They in this manner form a fibrous zone (Plate XXVIII. fig. 17 *b n*), which corresponds to the attached convex border of the segment, and may be regarded as an expansion of the inner of the two divisions (Plate XXVIII. fig. 17 *t r*) into which, as I formerly pointed out, the pulmonary artery and aorta resolve themselves.

As the bands under consideration are exceedingly strong when compared with those occurring in other portions of the segment; and project in an inward direction, or towards the axis of the vessel, when the preparation is sunk in water; their function, as ascertained from numerous experiments on the semilunar valves of a whale (*Physalus antiquorum*, Gray), seems to be the following :—

1st, They carry the body of the segment away from the sides of the vessel, and incline the free margins towards each other, at such an angle, as necessitates the free margins of neighbouring segments, being always more or less in apposition. In this they are assisted by the thickened portion of the pulmonary artery (Plate XXVIII. figs. 17 and 36 *b n*) which projects between the segments (Plate XXVIII. fig. 36 *n n'*) where they unite above, and by the fibrous zones which correspond to the convex border of each segment.

2d, The stronger fibres suspend the body of the segment from above, and permit the reflux of blood to act more immediately upon the mesial line of each segment where thinnest (Plate XXVIII. fig. 20 *c*), *and where least supported;* to occasion that characteristic folding of the segment upon itself, when the valve is in action.

Other bands, intermediate in thickness between those occupying the free margin and the body of the segment, are found towards its lower portion (Plate XXVIII. figs. 20 and 29 *o*). These bands cross and interdigitate to a greater or less extent, and as their prevailing direction is from below upwards, are instrumental in keeping the *lower portions* of the segment, away from the sides of the vessel. Each segment may therefore be described as consisting of three portions—a superior and thinner portion, an inferior and thicker one, and a central portion, which is the thickest of all. It ought also to be remarked that the three portions of the segment corresponding to its mesial line, where the folding occurs when it is in action, are comparatively thinner than the parts to either side of the line in question. The varying thickness of the segments is well seen in the semilunar valve of the whale (Plate XXVIII. fig. 29 *a v n*).

While the foregoing may be considered a literal description of a healthy human semilunar valve, there are modifications to which it is necessary to direct attention. Thus, in some instances, the band occupying the margin of the segment splits up near its origin, as represented at Plate XXVIII. fig. 19 *b*, and maps out a triangular portion (*c*). This portion is very thin, and contains delicate tendinous fibres, which terminate in brush-shaped expansions towards the mesial line. The remaining and stronger bands are similar to those already described, but the difference in the thickness of the several portions of the valve, is not so marked.

In other cases (Plate XXVIII. fig. 21), the marginal band not only splits up and contains a fully developed Corpus Arantii (*d*), but gives off two or more well-marked tendinous slips (*a*) which connect the free margin with the stronger or central portion of the segment (*i*). Radiating from the Corpus Arantii as a centre (Plate XXVIII. fig. 24 *d*), and proceeding along the free margin, I have sometimes detected a series of hair-like fibres (*e*), which are apparently of use in strengthening this the weakest portion of the segment. This is the more probable, since other and similarly delicate fibres proceed from the attached extremities in the direction of the Corpus Arantii. On other occasions, the tendinous bands proceeding from the marginal one (Plate XXVIII. fig. 22 *s*) are abnormally thickened (*t*), and terminate in brush-shaped expansions in the body of the segment (*v*); the body under such circumstances, projecting in an upward direction towards the Corpus Arantii (*d*). In such cases, those portions of the valve (*r r'*) which occur between the thickened bands proceeding from the marginal one, are exceedingly thin, and in some diseased conditions altogether awanting, so that the segment very much resembles one of the segments of the mitral or tricuspid valve, with its chordæ tendineæ. That there is an analogy between the semilunar and the mitral and tricuspid valves, and that the chordæ tendineæ is a further development, seems probable from the fact, that in the bulbus arteriosus of certain fishes, as in the grey and basking sharks (Plate XXIX. figs. 41 and 48), Lepidosteus, &c. (Plate XXIX. fig. 40 *b*), the semilunar valves are furnished with what may be regarded as rudimentary chordæ tendineæ, (Plate XXIX., fig. 48. *a*), while in the auriculo-ventricular valves of fishes, which have hitherto been regarded as semilunar, but which exhibit some of the peculiarities of the mitral valve of the mammal, chordæ tendineæ in various stages of development occur.

A scheme of the arrangement of the tendinous bands in the semilunar valves has been given at Plate XXVIII. fig. 23, and shows the segments to be not only bilaterally symmetrical, but to be constructed on a plan which secures the greatest amount of strength with the least possible material; the bands mutually acting upon and supporting each other. Thus the bands marked *a* and *d*, which represent the central portion of the segment, split up into brush-shaped expansions, one portion of each curving in an upward direction (*b e*), and representing the tendinous slips proceeding from the marginal one (*r*); the remaining portions curving in a downward direction (*f c*), and giving the inferior set of fibres which curve from below, towards the body of the segment (*a d*). The Corpus Arantii is rarely present in a perfectly healthy semilunar segment; nor will its absence occasion surprise, when it is remembered that its presence materially interferes with the folding of the segments upon themselves, when the valve is in action. That its existence is not necessary to the perfect closure of the valve, is proved by its complete absence in a great number of cases. In the semilunar valve of the

whale, where one would have naturally expected it in perfection, I could not detect even a trace of it.

What has been said of the semilunar valves of the pulmonary artery, may with equal propriety be said of those of the aorta; the only difference being that the segments are stronger and more opaque, to harmonise with the greater strength of the left ventricle.

The Arterial or Semilunar Valves in Action.

As the manner in which the semilunar valves are closed, does not seem to be well understood, the following experiments conducted with various fluids and liquid plaster of Paris, may prove interesting:—

When the aorta is cut across two inches or so above the aortic semilunar valve, and water introduced, the segments, if watched from beneath, are seen to act with great alacrity, the smallest segment (Plate XXVIII. figs. 26, 27, and 28, *w*), which is situated highest, *descending with a spiral swoop*, and first falling into position ; the middle-sized segment (*x*), which is placed a little lower, *descending in like manner, and fixing the first segment by one of its lunulæ or crescentic surfaces* (Plate XXVIII. fig. 26 *a*); the third and largest segment (*v*), which occupies a lower position than either of the others, *descending spirally upon the crescentic margins* (*b c*) *of the other two, and wedging and screwing them more and more tightly into each other*. The spiral movement, as has been already explained, is occasioned by the direction of the sinuses of VALSALVA, which curve towards each other, and direct the blood in spiral waves upon the mesial line of each segment (*w x v*).

It is well seen when liquid plaster of Paris is used, as the plaster, on setting, enables the experimenter to examine the relations of the segments to each other at leisure. Figures 27 and 28, Plate XXVIII., have been taken from specimens so prepared. On removing one of the segments in such specimens, it is found to be folded upon itself (Plate XXVIII., fig. 27 *w*), and to present two semilunar surfaces, each of which is accurately applied to a corresponding and similar surface of that segment of the valve which is next to it (Plate XXVIII. fig. 25 *b b'*). The union, therefore, between any two of the segments of a semilunar valve, is analogous in many respects, to that occurring in a venous valve consisting of two segments. There is, however, this difference ; in a venous valve, *the segments, simply flatten themselves against each other in the mesial plane of the vessel*, to form a perpendicular crescentic wall (Plate XXVIII. figs. 11 and 13 *e*); whereas in thes emilunar valves, the segments in addition *curve into each other*, and so form three perpendicular crescentic walls, each of which radiates from the axis of the vessel (Plate XXVIII. fig. 26 *r s o*). In the venous valve, moreover, those portions of the segments which come into apposition *form systemetrical crescents* (Plate XXVIII. fig. 13 *e*);

whereas in the semilunar one, the surfaces referred to, are *non-symmetrical*; in other words, the horns of the crescents forming the lunulæ, are broader towards the mesial line of the segments (Plate XXVIII. fig. 20 c) than where they meet above (b). As a result of this want of symmetry in the lunulæ or opposing surfaces of the semilunar valves, the apices or central portions of the segments come together in the axis of the vessel *throughout a considerable space* (Plate XXVIII. fig. 25 x), and form a union of the most perfect description. The extent of the union increases in the inverse of the pressure applied (compare dotted lines, Plate XXVIII. fig. 25 *m m'* with plain ones *b b'*), and is rendered very secure from the segments being wedged into each other in a direction from above downwards and from without inwards (Plate XXVIII. fig. 26 *v w x*). Retzius,[*] who figures the manner of closure of the semilunar valves, does not seem to have been aware of this fact, for he represents the segments as coming together in the axis of the vessel at three points, an arrangement which could scarcely fail to occasion a certain amount of regurgitation. If the closure of the semilunar valves be watched from above, other phenomena are observed. When, for example, the aorta and semilunar valve of the whale were sunk in water and permitted to remain undisturbed, the thicker portions of each segment were seen to project in an upward and inward direction, the free margins being by this arrangement brought more or less closely into contact, and supported on a level corresponding to the top of the sinuses of VALSALVA. When, however, the preparation was raised in the vessel, so that the water acted from above on the central and more unsupported portions of the segments; the free margins, together with the more moveable parts of the bodies, descended to the extent of fully an inch and a half. In so doing, the free margins of the segments were projected against and accurately applied to each other, clearly showing that the fluid, because of its weight and the spiral downward and inward direction communicated to it by the sinuses of VALSALVA, is sufficient to effect the closure. When the closure was taking place, the segments fell into position in rotation, but at so nearly the same interval of time, that they mutually regulated the amount of downward and inward movement; and so prevented each other from protruding too far into the interior of the vessel. When the hand was introduced into the aorta, which the great size of the specimen[†] readily permitted, and one of the segments was pushed in an outward direction, it was found to apply itself to the sinus of VALSALVA behind it, with more or less accuracy; the extremities of the segments, where they unite above, projecting to form three ridges, which are *spirally inclined with reference to each other*, and are no doubt useful in directing the blood into the aorta proper. From the foregoing description of the venous and arterial semilunar valves in mam-

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[*] Om Mekanismen af Semilunar Valvlernes tillolutning.

[†] In this case, the aorta had a girt of 27 inches; the average size of the segments being 9 inches by 7.

malia, it will be evident that there is nothing, either in their structure or relations, to betoken any great degree of activity on their part. That these structures are, on the contrary, principally passive, seems certain from the fact, that a stream of water or other fluid directed upon them from above as recommended, at once closes the orifices which they guard.

STRUCTURE OF THE BULBUS ARTERIOSUS OF THE FISH, AND OF THE VENTRICLE OF THE FISH AND REPTILE ; SEMILUNAR AND OTHER VALVES FOUND THEREIN.

The semilunar valves in the bulbus arteriosus of the fish, and the auriculo-ventricular valves in the fish and reptile, differ from the venous and arterial ones, in being, for the most part, connected either directly or indirectly, or exposed in some way to the influence of muscular contractions. In order the better to understand the position which these valves occupy in the gradually ascending scale of valvular arrangements, a brief description of the bulbus arteriosus, of the fish, and of the ventricle of the fish and reptile, is necessary. In the ventricle of the fish, the fibres, as I have pointed out elsewhere,* consist of three layers ;— an external layer, in which they proceed from base to apex, and occasionally interdigitate and become strongly embraced ; an internal layer, in which they are aggregated into fascicular bundles, and have a more or less vertical reticulated arrangement ; and a central layer, in which they run transversely, or at right angles to the fibres of the external and internal layers. These layers are connected to each other by certain fibrous bands, which run in a direction from without inwards. Rising from the base of the ventricle anteriorly is a muscular structure of a more or less bulbous form, the so-called bulbus arteriosus (Plate XXIX. figs. 38, 39, 40, 41, and 48), the arrangement of the fibres in which, resembles that in the ventricle itself. The ventricle of the fish, and the bulbus arteriosus contract in every direction, and in this respect they are analogous to the veins and arteries, which, as JOHN HUNTER showed, are extensible and retractile, both in their length and breadth. One point to be noted in the ventricle of the fish, is the absence of musculi papillares ; the auriculo-ventricular valves being so placed, that certain of the fasciculi constituting the internal layer, run parallel to them, and extend, in not a few instances, into their substance. The effect of this arrangement is to modify the action of the valves in question ; and I direct attention to the circumstance, because of the purely mechanical views entertained by some with regard to them ; views which to me appear inconsistent with the nature of the textures involved. The arrangement of the fibres in the ventricle of the reptile is nearly the same as that in the fish. There is, however, this difference, and it is worthy of mention as bearing directly upon the structure and function of the auriculo-ventricular valves in this

* On the Arrangement of the Muscular Fibres, in the Ventricles of the Vertebrate Heart, with Physiological Remarks.—*Phil. Trans.*, vol. 154, pp. 445–47.

class of animals.   The fibres of the external and internal layers pursue a slightly spiral course.   The spiral direction of the fibres here indicated is so marked in the ventricles of the bird and mammal, as to influence not only the position of the musculi papillares and carneæ columnæ, but also the shape of the ventricular cavities, and the closure of the mitral and tricuspid valves.   In the bulbus arteriosus of the fish, the valves as a rule, may be said to be fairly within the range of muscular influence, and it is interesting to note that in this structure, the segments vary both as regards number, size, and shape.   Thus, in the frog-fish (*Lophius piscatorius*), the origin of the bulbus arteriosus is guarded by a semilunar valve, consisting of two ample and very delicate segments (Plate XXIX. fig. 47 *a*), resembling those found in the middle-sized veins (Plate XXVIII. fig. 3 ; compare with *a b*); while in the sun-fish (*Orthagoriscus mola*, Schneider), the same aperture is guarded by a semilunar valve, consisting of three segments (Plate XXIX. fig. 43 *a b c*); the segments being analogous in every respect to those found in the largest veins (Plate XXVIII. fig. 1 ; compare with *a b c*).   As the valve in these cases is situated between the bulbus arteriosus and the ventricle, and surrounded by a fibrous ring similar to that occurring at the origin of the pulmonary artery and aorta, it is not affected by the structures between which it is situated to any great extent.   The semilunar valves in the frog-fish and sun-fish, may therefore be regarded as connecting links between the venous and arterial ones in the bird and mammal ; and that more complex system of analogous valves, which is found in the bulbus arteriosus of the fish generally.   In the bulbus arteriosus of the skate (*Raia batis*), the segments occupy the whole of the interior of the bulb, and are arranged in three pyramidal rows of five each (Plate XXIX. fig. 38 *a b c*).   As the segments in this instance are very small, and altogether inadequate to the obliteration of the bulbus cavity, they must be looked upon as being useful only in supporting the column of blood in its onward progress ; it being reserved for the segments at the termination of the bulb, which are larger and more fully developed, to effect the closure.   The action of the segments in the bulbus arteriosus of the skate, is rendered more perfect by the pressure from without, caused by the contraction of the bulb itself (*d*).   In the bulbus arteriosus of the sturgeon (*Accipenser sturio*), the segments are arranged in three rows of eight each (Plate XXIX. fig. 39 *a*).   They are more delicate, and less perfectly formed than in the skate.   In the bulbus arteriosus of the American devil-fish (*Cephalopterus giorna*), they increase to thirty-six, are more imperfect than in any of the others, and are supported by three longitudinal angular muscular columns.   As these segment-bearing columns, from their shape, project into the cavity, so as almost to obliterate it during the contraction of the bulb, they in this way bring the free margins of the segments together.   The orifices of the bulbus arteriosus, however, are not closed by the imperfect segments referred to ; these being guarded by two well-formed and fully developed tri-semilunar

valves, the one of which is situated at the beginning, the other at the termination of the bulb. In the bulbus arteriosus of the grey shark (*Galeus communis*), we have a slightly different arrangement, the two rows of segments of which the valve is composed being connected to each other by means of tendinous bands, resembling chordæ tendineæ (Plate XXIX. fig. 48 *a*). In the bulbus arteriosus of the Lepidosteus (Plate XXIX. fig. 40 *b*), and that of the basking shark (*Selachi maxima*, Cuv.), (Plate XXIX. fig. 41 *b*), the same arrangement prevails; the segments being stronger and less mobile, and the tendinous bands which bind the one segment to the other, more strongly marked than in the grey shark. As the tendinous bands referred to are not in contact with the wall of the bulbus arteriosus, but simply run between the segments, and are in some instances, as in the basking shark, very powerful (Plate XXIX. fig. 41 *b*), they must be regarded in the light of sustaining or supporting structures; their function being probably to prevent eversion of the segments. Other examples might be cited, but sufficient have been adduced to show, that the nature, as well as the number and arrangement of the segments, is adapted to the peculiar wants of the structure in which they are situated; and it ought not to be overlooked, that when a multiplicity of segments are met with in an actively contracting organ, the two act together or in unison.

If we now direct our attention to the auriculo-ventricular valves of the fish and reptile, similar modifications as regards the number of the segments, and the presence or absence of chordæ tendineæ and analogous structures, present themselves. Thus in the heart of the serpent (*Python tigris*), the two crescentic apertures by which the blood enters the posterior or aortic division of the ventricle, are each provided *with a single semilunar valve*. The same may be said of the aperture of communication, between the left auricle and ventricle of the crocodile (*Crocodilus acutus*) and of the sturgeon (*Accipenser sturio*, Linn.) In the heart of the Indian tortoise (*Testudo Indica*, Vosmaer), the left auriculo-ventricular orifice is guarded *by a single membranous fold*, the right orifice having in addition *a slightly projecting semilunar ridge*, which extends from the right ventricular wall, and may be regarded as the rudiment of the fleshy valve which guards the same aperture in birds (Plate XXIX. fig. 45 *g h*). In the heart of the bulinus, frog-fish, American devil-fish, grey shark, and crocodile, the auriculo-ventricular orifice is guarded by a semilunar valve consisting *of two cusps or segments;* while in the sturgeon, sun-fish, and others, it is guarded *by four, two larger and two smaller.*

So much for the number of the segments constituting the auriculo-ventricular valves in fishes and reptiles; but there are other modifications which are not less interesting physiologically. In the bulinus, frog-fish, and crocodile, the segments of the valves are attached to the auriculo-ventricular tendinous ring, and to the sides of the ventricle, and *have no chordæ tendineæ*. In the sun-fish

(Plate XXIX. fig. 43 *f*), the valve is destitute of chordæ tendineæ likewise; but in this instance the muscular fibres are arranged *in the direction of the free margin of the segments of the valve*, and no doubt exercise an influence upon them. In the grey shark the membranous folds forming the segments, *are elongated at the parts where they are attached to the ventricular walls*, these elongated attachments being more or less split up, so as to resemble *chordæ tendineæ*.

In the American devil-fish the semilunar valve consists of two strong well-developed membranous folds, which, like the preceding, are attached by elongated processes to the interior of the ventricular wall; *these processes consisting of distinct tendinous slips*, which are attached *to rudimentary musculi papillares*.

In the sturgeon (Plate XXIX. fig. 37), *three tendinous chords* (*b*) *from rudimentary musculi papillares*, are seen to extend into the half of each of the segments; while in the left ventricle of the dugong, *six chords, proceeding from tolerably well-formed musculi papillares, are distributed to the back, and six to the margins of each of the segments*. It is, however, in the bird and mammal, particularly the latter, that the musculi papillares are most fully developed, and the chordæ tendineæ most numerous—the number of tendinous chords, inserted into each of the segments, amounting to eighteen or more (Plate XXVIII. fig. 33 *r r′, s s′*). As the auriculo-ventricular valves are attached either to the interior of the ventricle, or to the musculi papillares or carneæ columnæ, it is plain that the contraction of the ventricle must influence them to a greater or less extent. That, however, the presence of muscular substance in no way interferes with the efficiency of the valves, is proved by the fact, that some valves are partly muscular and partly tendinous, a few being altogether muscular. Thus, in the heart of the cassowary, the right auriculo-ventricular orifice is occluded by a valve, which is partly muscular and partly tendinous; the muscular part, which is a continuation of two tolerably well-formed musculi papillares, extending into the tendinous substance of the valve, where it gradually loses itself. In the right ventricle of the crocodile (Plate XXIX. fig. 42 *r*), a muscular valve, resembling that found in the right ventricle of birds, exists.

In birds the muscular valve (Plate XXIX. figs. 45 and 46 *g h i*) is usually described as consisting of two parts, from the fact of its dependent or free margin (*g*) being divided into two portions by a spindle-shaped muscular band (*h*), which connects it with the right ventricular wall (*j*). As, however, the wall consists of one continuous fold towards the base (*i*), and the two portions of the margin are applied during the systole not to each other but to the septum (*e′ e″ e‴*), it is more correct to say that the valve is single; the spindle-shaped muscular band representing the musculus papillaris of the right wall of the ventricle with its attached chordæ tendineæ.* In the serpent, the opening between the right

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* For the relations, structure, and function, of the muscular valve in birds, see paper already referred to.   Phil. Trans. vol. 154, pp. 470-1-2.

and left ventricle, occurs as a spiral slit in the septum (Plate XXIX. fig. 44 *r*), and is guarded by two projecting muscular surfaces, which are rounded off for this purpose. The opening into the left ventricle also occurs as a muscular slit (*s*); and the orifices of many of the venous sinuses are closed by purely muscular adaptations; the fibres in such instances running parallel to the slit-like opening (Plate XXVIII. fig. 10), and being continuous with two or more bundles of fibres (*b c*), which supply the place of musculi papillares. From the great variety in the shape and structure of the auriculo-ventricular valves, and from the existence in almost all of tendinous chords, which connect them with actively contracting textures, there can, I think, be little doubt, that they possess an adaptive power peculiar in a great measure to themselves; this power being traceable to the contractile properties residing in muscle.

As it would greatly exceed the limits of the present paper, to give a detailed account of the structure of the numerous auriculo-ventricular valves, to which allusion has been made, I have selected for description the auriculo-ventricular valves of the mammal, and those of man more particularly. Before, however, entering upon this the most difficult part of the present investigation, a brief account of the arrangement of the muscular fibres in the ventricles seems indispensable; these, as has been explained, modifying the action of the valves to a very considerable extent.

ARRANGEMENT OF THE MUSCULAR FIBRES IN THE VENTRICLES OF THE MAMMAL—SHAPE OF THE VENTRICULAR CAVITIES, &c.

The fibres of the ventricles in the mammal, as I have ascertained from numerous dissections,[*] are arranged in seven layers; three external, a fourth or central, and three internal. The fibres constituting these layers in the left ventricle, to which these remarks more particularly apply, pursue a spiral direction; the external fibres becoming more and more oblique, in a direction from left to right downwards, as the central layer is approached—the internal fibres becoming more and more vertical, in a direction from right to left upwards, as it is receded from. The fibres, therefore, of corresponding external and internal layers, cross each other. The fibres of the several layers are further arranged in two sets; the two sets, forming each of the external layers, being continuous at the apex and at the base, with two similar sets belonging to a corresponding internal layer. This arrangement of the fibres renders the ventricles bilaterally symmetrical, and in part accounts for the great precision with which the heart acts, and for its rolling movements. Its bearing on the action of the organ is obvious, for as muscular fibres contract in the direction of their length, the more vertical external and internal fibres, diminish the ventricular cavities from above downwards, and from

* Of these upwards of an hundred are preserved in the University of Edinburgh Anatomical Museum, where they may be examined. For a detailed description of the specimens, and for accurate representations thereof, see Phil. Trans. vol. 154, pp. 445–500, Plates 12 to 16.

below upwards; the downward movement preceding the upward by an almost inappreciable interval of time. In that brief space, however, which elapses between the downward and upward movements, the ventricles, owing to the contraction of the more circular fibres, are visibly diminished from without inwards; and it is important to note this circumstance, as the auriculo-ventricular orifices are, at this instant, reduced in size, and the mitral and tricuspid valves, consequently liable to a certain amount of displacement. The ventricular wall of the left ventricle, as was known to GERDY and other investigators, is thickest at the upper part of its middle third (Plate XXVIII. fig. 35 j), and tapers towards the apex (w) and base (v') respectively; and it is interesting to observe that the thickest part of the ventricular wall, corresponds with the widest portion of the ventricular cavity, whence the blood is projected into the aorta; a fact of some significance, since the contractions at this point are necessarily more intense than at any other. As the two sets of fibres composing the first external layer are continuous at the left apex with the two sets of fibres forming the carneæ columnæ and musculi papillares, and these structures, especially the latter, bear an important relation to the segments of the bicuspid valve, with which they are connected by the chordæ tendineæ, a more minute description than that given of the other layers, is requisite for clearness. On looking at the left auriculo-ventricular opening (Plate XXVIII. fig. 30 b), the fibres of the first layer are seen to arise from the fibrous ring surrounding the aorta (a), and from the auriculo-ventricular tendinous ring (n) in two divisions; the one division (d) proceeding *from the anterior portions of the rings*, and winding in a spiral nearly vertical direction, from before backwards, to converge and enter the apex *posteriorly;* the other set (Plate XXVIII. fig 30 f) proceeding *from the posterior portions of the rings*, and winding in a spiral direction from behind forwards, to converge and enter the apex *anteriorly.* Having entered the apex, the two sets of external fibres are collected together, and form the musculi papillares and carneæ columnæ; the one set, viz., that which proceeded from the auriculo-ventricular orifice anteriorly and entered the apex posteriorly, curving round in a spiral direction from right to left upwards, and forming *the anterior musculus papillaris* (Plate XXIX. fig. 50 y), *and the carneæ columnæ next to it;* the other set, which proceeded from the auriculo-ventricular orifice posteriorly, and entered the apex anteriorly, curving round in a corresponding spiral direction, and forming *the posterior musculus papillaris* (Plate XXIX. figs. 50 and 51 x), *and adjoining carneæ columnæ.* As the external fibres converged on nearing the apex, so the internal continuations of these fibres radiate towards the base; and hence the conical shape of the musculi papillares. I am particular in directing attention to the course and position of the musculi papillares, as they have hitherto, though erroneously, been regarded as simply vertical columns, instead of more or less vertical *spiral* columns.* The necessity for in-

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* Plate XXIX. fig. 49, $x\,y$, gives the spiral track of the musculi papillares.

sisting upon this distinction will appear more evident when I come to speak of the influence exerted by these structures on the segments of the bicuspid valve. It is worthy of remark, that while the left apex is closed by two sets of fibres, the left auriculo-ventricular orifice is occluded during the systole by the two flaps or segments constituting the bicuspid valve (Plates XXVIII. and XXIX. figs. 28 and 51 *m n*). The bilateral arrangement, therefore, which obtains in all parts of the ventricle and in the musculi papillares, extends also to the segments of the valve in question. What has been said of the arrangement of the fibres in the left ventricle, applies with slight modifications to the fibres of the right one; and many are of opinion (and I also incline to the belief) that the tricuspid valve, is in reality bicuspid in its nature (Plate XXVIII. fig. 34 *m n;* and Plate XXIX. fig. 51 *g'h*). The shape of the ventricular cavities of the heart of the mammal greatly influences the movements of the mitral and tricuspid valves, by moulding the blood into certain forms, and causing it to act in certain directions. It is seen to advantage when the ventricles are filled with wax or plaster of Paris, and the ventricular parietes removed to expose the casts or moulds thus obtained (Plate XXIX. figs. 50 and 51).

The form of the left ventricular cavity, which I regard as typical, is that of a cone twisted upon itself (Plate XXIX. fig. 49); the twist or spiral running from left to right of the spectator, and being especially well marked towards the apex.[*] The cone tapers slightly towards its base (*b*), and the direction of its spiral corresponds with the direction of the fibres of the carneæ columnæ and musculi papillares (Plate XXIX. fig. 50 *x y*). As the two spiral musculi papillares project into the ventricular cavity, it follows that between them, two conical-shaped spiral depressions or grooves, are found (Plate XXIX. fig. 49 *q j*). These grooves, which are especially distinct, are unequal in size; the smaller one (Plate XXIX. figs. 49 and 50 *j*) beginning *at the right side of the apex*, and winding in an upward spiral direction, to terminate *at the base of the external or left and smaller segment of the bicuspid valve* (Plate XXIX. figs. 50 and 51 *n*); the larger groove (Plate XXIX. fig. 49 *q*) beginning *at the left side of the apex*, and pursuing a similar direction, to terminate *at the base of the internal or right and larger segment* (Plate XXIX. fig. 51 *m*).

Running between the grooves in question, and corresponding to the septal aspect of the ventricular cavity, is yet another groove, larger than either of the others (Plate XXIX. fig. 51 *q*). The third or remaining groove winds from *the interior of the apex posteriorly*, and conducts *to the aorta* (*a*), which, as the reader is aware, *is situated anteriorly*. The importance of these grooves physiologically cannot be over-estimated, for I find that in them the blood is arranged or moulded *into three spiral columns*, and that towards the end of the diastole and the beginning of the systole, the blood in the two lesser ones is forced in two spiral streams upon the segments of the bicuspid valve, which are in this

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[*] In this description the heart is supposed to be placed on its apex.

way progressively elevated towards the base, and twisted and wedged into each other, until regurgitation is rendered impossible (Plate XXIX. fig. 51 *m n*). When the bicuspid valve is fairly closed, the blood is directed towards the third and largest groove, which, as has been stated, communicates with the aorta. The spiral action of the mitral valve, and the spiral motion communicated to the blood when projected from the heart, is due to the spiral arrangement of the musculi papillares and fibres composing the ventricle, as well as to the spiral shape of the left ventricular cavity. These points are determined in the following manner:— When a cast of the interior of the left ventricle is made, by introducing liquid plaster of Paris into the left ventricular cavity, by means of a tube inserted into the aorta and reaching to the left apex, it is found, on cutting away the parietes of the ventricle, that the segments of the mitral valve are borne up on the plaster,* and wedged into each other on a level with the ventricular orifice. It is further found, that the two spiral streams of plaster (now spiral columns) which closed the segments of the mitral valve, merge towards the base, into the third column, communicating with the aorta. That portion, therefore, of the left ventricular cavity (Plate XXIX. figs. 50 and 51 *o*), which corresponds to the conus arteriosus or infundibulum of the right one (Plate XXIX. fig. 50 *i*), is conical in form. It is moreover furnished with three conical-shaped spiral depressions, which in the cast appear as conical-shaped *spiral prominences* (*p o*), and are continuous with the three spiral columns of plaster proceeding from the apex of the ventricle. As the apices of the three conical-shaped infundibuliform prominences referred to are directed between the three segments of the aortic semilunar valve, the blood from this arrangement must on its onward progress throw the semilunar segments hastily apart, by causing them to fall back upon the spirally disposed sinuses of VALSALVA (*k w v*). The spiral channel, which is thus provided for the blood, is not confined to the heart, but extends for a short distance into the great vessels. As the semilunar valves are closed by a reverse movement to that by which they are opened, it is not difficult to perceive how the spiral action of the segments constituting them is induced.

What has been said of the left ventricular cavity and aorta, applies, with slight alterations, to the right ventricular one and the pulmonary artery (Plate XXIX. figs. 50 and 51 *c i*), the cone formed by the right cavity being flattened out and applied to or round the left.

INTRICATE STRUCTURE OF THE MITRAL AND TRICUSPID VALVES IN MAMMALIA; RELATIONS OF THE CORDÆ TENDINEÆ TO THE SEGMENTS AND TO THE MUSCULI PAPILLARES.

The auriculo-ventricular valves are composed of segments, which differ in size, and are more or less triangular in shape. They are much stronger than

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* In order to see the spiral movement of the segments to advantage, the plaster ought to be made very thin. Should any difficulty occur, the experimenter is recommended to use water until he is familiar with the phenomena to be observed.

the segments of the semilunar valves, which in some respects they resemble in structure as well as function. They are very dense, and quite opaque, unless at the margins and apices, where they are frequently remarkably thin. They unite at the base where thickest, to form a ring, which is attached to one or other of the fibrous rings surrounding the auriculo-ventricular orifices (Plate XXVIII. fig. 30 *n n'*). The auriculo-ventricular rings, which are consequently intimately related to the segments, have been variously described, the majority of investigators regarding them as highly developed structures, which afford attachment, not only to the valves, but to all the fibres of the auricles and ventricles. A careful examination of the rings in question in boiled hearts, has led me to a different conclusion. They afford attachment to the fibres of the auricles (Plate XXVIII. fig. 35 *y d*), and to the valves (*m n*), *but to almost none of the fibres of the ventricles* (*v*). They are most fully developed anteriorly, and on the septum, where they form a dense fibrous investment. The left ring, like everything else pertaining to the left ventricle, is more fully developed than the right; but neither the one nor the other can compare in breadth, or thickness, with either of the arterial rings (*a k*). The influence, therefore, which they exert on the dilatation and contraction of the auriculo-ventricular orifices (Plate XXVIII. fig. 30 *b l*) must be immaterial. The position of the segments in the auriculo-ventricular orifices, and their relation to the musculi papillares, is deserving of attention. On looking into the auriculo-ventricular orifice of the left or typical ventricle, when the clots which usually fill the ventricular cavity have been removed, it is found to be partially obliterated, by two principal segments; the one of which is larger than the other (Plate XXVIII. fig. 28 *m*). The larger segment, which is obliquely suspended between the auriculo-ventricular and aortic openings, occupies a somewhat *internal and anterior position;* while the smaller one (*n*), which runs parallel to it, occupies a more or less *external and posterior position.* Between the principal segments, two smaller accessory segments, are usually found. In the right ventricle, the principal segments are three in number, and are of different sizes,—the smallest running parallel to the septum; the largest being placed anteriorly and inclined to the right side; the one which is intermediate in size occupying a more posterior position. These, also, have smaller accessory segments placed between them. The segments, whatever their size, are attached by their bases to the auriculo-ventricular tendinous rings (Plate XXVIII. fig. 30 *n n'*), and, by their margins and apices, to the spiral musculi papillares (Plate XXVIII. fig. 28 *a b c d*), by means of the chordæ tendineæ.

The segments of the mitral valve, to which the following description, drawn from an extensive examination of mammalian hearts,* more particularly applies,

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* Of the hearts examined may be mentioned those of man, the elephant, camel, whale (*Physalus antiquorum*, Gray), mysticetus, horse, ox, ass, deer, sheep, seal, hog,, porpoise, monkey, rabbit, and hedgehog.

consist of a reduplication of the endocardium, or lining membrane of the heart, containing within its fold, large quantities of white fibrous tissue, and, as was pointed out by Mr W. S. Savory, and after him, by Professor Donders,* of a moderate amount of yellow elastic tissue. The white fibrous tissue greatly preponderates, and is derived principally from the chordæ tendineæ, which split up into a vast number of brush-shaped expansions, prior to being inserted into the segments. The fibrous or tendinous expansions, which assume the form of bands, may consequently be regarded as prolongations of the chordæ tendineæ. They are analogous, in many respects, to similar bands in the semilunar valves; the only difference being, that in the semilunar valves, the bands referred to, instead of being free, as in the present instance, are involved in the valvular substance. (Compare fibrous bands marked in Plate XXVIII. fig. 20, with chordæ tendineæ and brush-shaped expansions, marked s in Plate XXVIII. fig. 33). As each of the segments composing the bicuspid or mitral valve, like the left ventricle itself, is bilaterally symmetrical, it will be convenient, when speaking of these structures, to describe, in the first instance, only the half of one of the segments; and in order to do this the more effectually, it will be necessary to consider each musculus papillaris, as essentially consisting of two portions;† *a superior and external portion* (Plate XXVIII. figs. 28 and 33 *a*), which gives off two, usually three chordæ tendineæ (*s*) to *that half of the anterior segment* of the mitral valve (*m*) which is next to it; and *an inferior and internal portion* (*b*), which also gives off three tendinous chords; these being inserted into the adjacent *half of the posterior segment* (*n*). The three tendinous chords which proceed from the superior external portion (Plate XXVIII. fig. 31 *r*), subdivide, and are inserted, by the brush-shaped expansions spoken of, into the half of the anterior segment posteriorly, in nine different places.‡ Of these, three are inserted into the mesial line of the segment (Plate XXVIII. figs. 31, 32, and 33, *r*), viz., into the base (*g*), central portion (*f*), and apex (*e*); three into the basal, central, and apicial portion of the free margin (Plate XXVIII. fig. 33 *s'*); and three into intermediate points between the mesial line and the margin (*r'*). On some occasions, as in the mitral valve of the whale, a slightly different arrangement prevails; three chordæ tendineæ being inserted into the mesial line of the segment at the base, at the centre, and at the apex; an additional chord *going to the free margin near the apex;* three into intermediate points between the mesial line and the margin; a second additional chord *going to the central*

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* Professor Donders describes the yellow elastic tissue as being most abundant in the upper surface of the segments.

† The musculi papillares in the human and other hearts (Plate XXVIII. figs. 28, 31, and 33, *ab, cd*) either bifurcate, or show a disposition to bifurcate at their free extremities, so that the division of the chordæ tendineæ into two sets is by no means an arbitrary one.

‡ The number of insertions vary in particular instances. In typical hearts, however, it is remarkably uniform.

portion of the margin. A third and independent chord, *goes to the base of the margin.* In the whale, as will be observed, the arrangement is virtually the same as that first given; the insertions being nine in number,—three into the mesial line, three into the free margin, and three into intermediate points. The tendinous chords pursue different directions prior to insertion; the three which are inserted into the mesial line of the segment, and are the longest and strongest (Plate XXVIII. figs. 31, 32, and 33 *r*), being less vertical than those which are inserted nearer the margin (*r'*); these in turn being less vertical than the ones inserted into the margin, which are the shortest and most delicate. The basal chord of each set, on the contrary, is more vertical than that beneath it, or nearer the apex (*x*); the apicial chords being more or less horizontal. As there is a disposition on the part of the higher and more central chordæ tendineæ (Plate XXVIII. fig. 31 *g*) to overlap, by their terminal brush-shaped expansions, those below and to the outside of them, the segment is found to diminish in thickness from the base (*z*) towards the apex (*x*) and from the mesial line towards the periphery or margin; the basal and central portions of the segment being comparatively very thick, the apicial and marginal portions very thin (Plate XXVIII. fig. 32 *v x*); so thin, indeed, that in some hearts, particularly in the right ventricle, they present a cobwebbed appearance. As the marginal portions form the counterparts of the lunulæ in the semilunar valves, and are those parts of the segments which come into accurate apposition when the valve is in action, they are, from this circumstance, entitled to consideration. When a perfectly healthy mitral valve from an adult, or, still better, from a fœtus at the full time or soon after birth, is examined, the portions referred to are found to be of a more or less crescentic shape (*vide* that part of the mitral valve to which the chordæ tendineæ marked *r'*, fig. 33, Plate XXVIII., are distributed), and so extremely thin, that the slightest current in the fluid in which they are examined causes them to move like ciliæ. The physiological value of this delicacy of structure, and consequent mobility, is very great; as the most trifling impulse causes the marginal parts of the segments, which are naturally in juxtaposition, to approach towards or recede from each other. The half of one of the segments of the mitral valve may be regarded as consisting of a reduplication of the endocardium or lining membrane of the heart, supported or strengthened in all directions by nine or more tendinous brush-shaped expansions; these expansions being arranged in three vertical rows of three each (Plate XXVIII. fig. 33), with much precision, and according to a principle which is seldom deviated from. In addition to the reduplication of the lining membrane and the tendinous expansions referred to, Lancisi,* Senac,† and Kürschner‡ have ascertained that there is a

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* De Motu Cordis.   † Traité de la Structure du Cœur, livre i. p. 76.
‡ Wagner's Handwörterbuch, art. "Herzthäjtigkeit."

slight admixture of true muscular fibres.* As the tendinous expansions of the half of the segment described, bifurcate or split up, and run into similar expansions from the other or remaining half of the same segment, to become strongly embraced in the mesial line; a complete segment may be described as consisting of a reduplication of the endocardium or lining membrane, enclosing in its fold certain muscular fibres, and eighteen or more tendinous expansions; the chordæ tendineæ, on which these expansions are situated, proceeding from the anterior and posterior musculi papillares equally (Plate XXVIII. fig. 28 *a c*), and pursuing different directions, to meet in the mesial line and form angles (Plate XXVIII. fig. 32) which become more and more obtuse in a direction from above downwards. When, therefore, a segment is examined by being held against the light, or by the aid of a dissecting lens or microscope, it is found to consist of tendinous striæ running transversely, obliquely, and more or less vertically; the striæ of opposite sides being so disposed that they mutually act upon and support each other; an arrangement productive of great strength, and one which secures that the segments shall be at once tightened or loosened, by the slightest contraction or relaxation of the musculi papillares. The intermediate accessory segments of the mitral valve, resemble the principal ones, in structure and general configuration. They are, however, comparatively speaking, very thin; and the chordæ tendineæ inserted into them differ from those inserted into the principal segments, in having a more vertical direction, and in being longer and more feeble. The description given of the bicuspid valve, applies, with trifling alterations in particular instances, to the tricuspid, if allowance be made for an additional large segment, and three or more accessory segments. With regard to the smallest of the three large segments forming the tricuspid, I have to observe, that in all probability, it is simply an over-developed accessory segment; the so-called tricuspid valve being in reality a bicuspid one (Plate XXVIII. fig. 34 *m n*). Nor is this to be wondered at, when it is stated† that the right ventricle, is a segmented portion of the left, and partakes of its bilateral symmetry even in matters of detail. The opinion here advanced is by no means new, but it appears to me that the point has not been sufficiently investigated, and we are in want of statistics regarding it. In ten human hearts which I examined for this purpose, no less than four had well-marked bicuspid valves in both ventricles; and on looking over a large collection of miscellaneous hearts in the Museum of the Royal College of Surgeons of England, I found that nearly a third of them had the peculiarity adverted to; if indeed that can be called peculiar which seems to me to be typical. When two principal segments, with two or more accessory segments, occlude the right auriculo-ventricular orifice, as happens in Plate

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* According to Mr SAVORY's observations, the muscular fibre is found more particularly at the upper or attached border of the valves.

† Phil. Trans., vol. cliv., pp. 464–67.

XXVIII. fig. 34 *m n*, the distribution of the chordæ tendineæ (*o p*) in the segments is the same as that given when describing the bicuspid of the left ventricle; but when there are three principal segments, with as many or more accessory segments, the distribution is varied to meet the exigencies of the case; there being a tendency in each of the chordæ tendineæ to divide into three; one of the chords so divided being inserted by one of its slips into the mesial line of the segment at the base posteriorly; by another into the margin of the segment, likewise at the base; and by the remaining slip into a point intermediate between the mesial line and the margin. Other chords, similarly divided, are inserted at intervals in a direction from above downwards, or from base to apex (Plate XXVIII. fig. 34 *o*), the insertions in each case proceeding from the mesial line towards the margin. In some instances, though more rarely, a mixed arrangement prevails; the insertions of the three tendinous slips running from the mesial line of the segment towards the margin, and from the base to the apex indiscriminately; but whatever the arrangement on the one side of a segment, it is, as a rule, the same on the other, so that one of the segments of a true tricuspid valve is as symmetrical in its way as a segment of a bicuspid one. The musculi papillares in the right ventricle of a typical heart, are two in number, as in the left. When, therefore, the right auriculo-ventricular opening is closed by a tricuspid valve, an additional origin is required for the chordæ tendineæ; and in such a case these chords spring from the two musculi papillares, and from the right side of the septum behind the fleshy pons, either from a rudimentary papillary muscle, or from carneæ columnæ, or from the smooth wall of the septum. The number of papillary muscles in the right ventricle (and the same remark applies to the left, although not to the same extent) vary somewhat; the two typical ones being frequently seen to bifurcate at their free extremities, and others to spring up in their vicinity. On these occasions the origins of the chordæ tendineæ are increased, but this does not materially affect their insertion, which is remarkably uniform. The tricuspid valve, differs from the bicuspid as regards actual strength, the segments being comparatively thinner. This delicacy of structure, extends to the chordæ tendineæ and to the musculi papillares, in fact, to everything pertaining to the right ventricle; the walls of which, as is well known, are only half the thickness of those of the left ventricle. The comparative feebleness of the tricuspid valve, is no doubt traceable to the smaller amount of force it is called upon to withstand, the pulmonic circulation being less vigorous than the systemic. From the foregoing description, it will be seen, that the chordæ tendineæ are inserted into every portion of the bicuspid (Plate XXVIII. figs. 31, 32, and 33) and tricuspid valves; and as they freely decussate with each other in all directions, by means of their terminal brush-shaped expansions, and are of infinite variety as regards length and strength; those at the base and posterior aspect of each segment being long and exceeding strong; while those

at the margins and towards the apices are short, and in some instances as delicate as hairs, it follows that every part of the valves in question, bears a graduated relation to, and is under the control and domination of, the conical-shaped spiral musculi papillares, whose power to contract is now well established.*   It is therefore my impression, and my belief is shared by others, that the chordæ tendineæ ought to be regarded as the satellites of the actively contracting musculi papillares, under whose guidance they have to perform, not only a very important, but a very delicate function, and one which could not by any possibility, be accomplished by a simply mechanical arrangement.

The Mitral and Tricuspid Valves of the Mammal in Action.

The theories which have long divided the attention of physiologists with regard to the action of the mitral and tricuspid valves, are two in number; one sect maintaining, that the valves *are acted upon mechanically by the blood*, as if they were composed of inanimate matter; the other believing, that *they form part of a living system*, their movements being traceable to their connection with the musculi papillares, which are actively contracting structures.

In the mechanical theory, the segments of the valves are supposed to be *passively* floated up by the blood, which acts upon them from beneath during the systole, and brings their edges or free margins into such accurate apposition as enables the segments completely to occlude the auriculo-ventricular orifices.   In these movements *the musculi papillares and carneæ columnæ* are said *to take no part;* the chordæ tendineæ acting *mechanically*, like so many stays, to prevent eversion of the segments in the direction of the auricles.

In the vital theory, on the other hand, the segments of the valves are supposed to be from the first *under the control of the musculi papillares;* these structures, by contracting, drawing the lips or free margins of the segments closely together in the axis of the auriculo-ventricular openings, to form two impervious cones, the apices of which project downwards into the cavities of the ventricles.

In these movements, it is maintained, *the blood takes no part*, the chordæ tendineæ, which are regarded as the proper tendons of the musculi papillares, acting as adjusters or adapters of the segments; † a function which their varying length and strength readily enables them to perform.

I need scarcely add, that these theories are diametrically opposed to each

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* Dr JOHN REID states from experiment, that the carneæ columnæ act simultaneously with the other muscular fibres of the heart, and that the *musculi papillares* are proportionally more shortened during their contraction than the heart itself taken as a whole.   He attributes this to the more vertical direction of the musculi papillares, and to their being free towards the base and in the direction of the ventricular cavities.—*Cyc. of Anat. and Phy.*, art. " Heart," p. 601.   London, 1839.

† In one specimen which I dissected, the chordæ tendineæ contained a large amount of muscular fibre, and were so thickened as to resemble rudimentary musculi papillares.

other. The vital theory which was espoused by MAYO and BOUILLAUD,* has been defended with great ability by Dr JOHN REID,† who says, that if the lips of the valves were merely floated up to the orifice, a greater quantity of the blood would regurgitate into the auricles during the systole of the ventricle than if the lips were assisted or brought together by an active force. This author alludes to, and very properly attaches considerable importance to the fact, that the musculi papillares to which the valves are attached by the chordæ tendineæ, contract with the other portions of the ventricular walls. He also points out the uniform position and course of the musculi papillares and chordæ tendineæ, and shows, as bearing directly upon the question, how the chordæ tendineæ in the left ventricle pass from each musculus papillaris to both lips of the mitral valve. One statement, however, made by him requires to be noticed. When speaking of the mitral valve he says, that the lip of the posterior or smaller segment though it may be drawn inwards so as to meet that of the larger and more moveable one, *is so bound down as to be scarcely capable, in most cases, of being floated up on a level with the orifice.* I have examined a large number of hearts, young and old, human and otherwise, with a view to determine this point, and in no instance do I remember an example where the peculiarity adverted to was observable. The anterior or larger segment, from its attachments and shape, naturally rises higher, just as the anterior and septal segments of the tricuspid valve for similar reasons, rise higher than the posterior segment; but in every case, the posterior or smaller segment rises sufficiently high, not only fairly to meet the anterior and larger one, but if a sufficiency of pressure is exercised, to protrude in an upward direction, so as to form a convexity which encroaches upon the left auricular space.

In the valvular controversy, as in most others, a certain amount of truth is to be found on either side; and I have to express my conviction, that both theories (conflicting though they appear) are virtually correct as far as they go, but that neither the one nor the other is sufficient of itself to explain the gradual, and to a certain extent self-regulating process, by which the auriculo-ventricular valves are closed and kept closed. On the contrary, I believe that the closure is effected partly by *mechanical* and partly by *vital* means. In other words, that the blood towards the end of the diastole and the beginning of the systole forces the segments in an upward direction, and causes their margins and apices to be so accurately applied to each other as to prevent even the slightest regurgitation; whereas, during the systole, and towards the termination of that act, the valves are by the contraction of the musculi papillares, dragged down by

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* These investigators proposed to call the musculi papillares the tensor, elevator, or adductor muscles of the valves.
† *Op. cit.* pp. 361, 362.

the chordæ tendineæ into the ventricular cavities to form two dependent cones; this downward movement of the segments permitting the blood in the auricles to descend into the ventricles, so as to relieve the congestion of the former.

Granting that the foregoing hypothesis is correct, there is yet another point *as to the manner of the closure,* to which I am particularly anxious to direct attention, as it is of primary importance, and appears to me, by some unaccountable means, to have hitherto escaped observation.   I refer to the spiral form assumed by the blood in the ventricular cavities, which, as has been already partially explained, causes it, towards the end of the diastole and the beginning of the systole, to act in *spiral waves* mechanically (Plate XXIX. fig. 49 *j q*) on the segments, with the effect of *twisting and wedging them into each other in a spiral upward direction* (Plate XXIX. fig 51 *m n*, and figs. 53 and 54 *m i n, r s*).   I allude, also, to the spiral course pursued by the musculi papillares (Plate XXIX. figs. 49 and 50 *x y*); these structures, as the systole advances, contracting in such a manner as occasions the spiral descent of the segments into the ventricular cavities (Plate XXIX. figs. 52 and 55 *m n, r s*), to form *two spiral dependent cones,* the apices of which are directed towards the apices of the ventricles.   As the decrease of the blood in the ventricles is followed, as has been stated, by a corresponding increase in the auricles; the blood in the latter assists in keeping the free margins and apices of the segments from being everted by the uniform pressure exercised on them by the blood in the former, during the systole.   From this account of the closure of the auriculo-ventricular valves, it will be perceived that the valvular segments form two moveable partitions or septa, which rise and fall during the action of the heart, in the same way that the diaphragm rises and falls during the respiratory efforts. The advantages arising from such an arrangement are very great.   *When the ventricles are full of blood,* and the auricles empty or comparatively so, the valvular septa are convex towards the base of the heart, and protrude into the auricular cavities. When, however, *the auricles are full of blood,* and the ventricles all but drained of it, the valvular septa descend so as to protrude in a downward or opposite direction.   Certain portions, therefore, of the auriculo-ventricular cavities are common alike to the auricles and to the ventricles; and it is important to note this fact, as the valvular septa by their rising and falling, at one time increase the size of the ventricular cavities while they diminish the auricular ones, and *vice versa*.   The principal object gained by the descent of the segments into the ventricles is the diminution of the ventricular cavities towards the base; the dependent cones formed by the valves fitting accurately into the conical-shaped interspaces situated between the slanting heads of the musculi papillares and the auriculo-ventricular tendinous rings.   As the musculi papillares, on the contraction of the ventricles, mutually embrace and twine round each other, the obliteration of the ventricular cavities is by this arrangement rendered very complete.   "That the ventricles empty themselves during the systole, is rendered probable

from analogy, for on watching the hearts of cold-blooded animals, they are found towards the end of the contractile act to become quite pale, not, as Harvey supposed, from the blood being pressed out of the parietes, but from the blood in their cavities seen through their transparent sides being almost entirely expelled." An important inference to be deduced from the spiral nature of the ventricular fibres and ventricular cavities and *the undoubted spiral action of the auriculo-ventricular valves* is the effect produced on the blood as it leaves the ventricles, that fluid being unquestionably projected by a wringing or twisting movement, which communicates to it *a gliding spiral motion.* This view is favoured by the spiral inclination of the sinuses of VALSALVA to each other, these structures gradually introducing the blood so projected into the vessels. How far the rotatory movement referred to, extends into the arteries, is difficult to determine; but when the smooth cylindrical nature of the vessels, and the great velocity and force with which the blood travels, is taken into account, there is every reason to suppose that the distance is considerable.

The Mechanical and Vital Theories of the Action of the Mitral and Tricuspid Valves considered.

That the theory which attributes the closure of the auriculo-ventricular valves to the mechanical floating up of the segments from beneath by the blood, forced by the auricles[*] into the ventricles, distending equally in all directions,[†] is of itself inadequate to explain all the phenomena, is, I think, probable from analogy and the nature of things; for if a merely mechanical arrangement of parts was sufficient for the closure of the gradually contracting auriculo-ventricular orifices, then, it may be asked, why were these apertures in birds and mammals not furnished with sigmoid or semilunar valves similar in all respects to those met with in the veins and arteries? The answer to this question is no doubt to be found in the nature of the structures in which the valves are situated, as well as in the circulation itself. In the veins, as is well known, the movements of the blood are sluggish—the contraction of the vessels being feeble, and not consequently calculated to interfere to any great extent with the closure of the valves. In the arteries, where the circulation is more vigorous, and the contractions of the vessels more decided, the valves are surrounded by dense fibrous rings, which protect them alike from the contractions of the ventricles, and the contractility

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[*] According to HARVEY, LOWER, SENAC, HALLER, and others, the auricles contract with a very considerable degree of energy.

[†] "In a quantity of fluid submitted to compression, the whole mass is equally affected and similarly in all directions."—*Hydrostatic Law.* Dr GEORGE BRITTON HALFORD attributes the closure of the auriculo-ventricular valves entirely to the pressure exercised by the auricles on the blood forced by them into the ventricles. That, however, this is not the sole cause, will be shown further on.

and elasticity of the vessels. In the bulbus arteriosus of fishes, where the area of activity of the valves is not thus circumscribed, and where they are exposed to the influence of muscular contraction, *the segments are not only increased in number, but chordæ tendineæ*, in the shape of tendinous bands, *begin to make their appearance.* In the auriculo-ventricular valves of fishes and reptiles, *chordæ tendineæ in various stages of development occur*, these being attached to the interior of the ventricle *to more or less fully developed musculi papillares ;* the musculi papillares, which occur only in the reptilia, being in no instance so well marked *as in the ventricles of the aves and in the mammalia.* As we thus rise in the scale of being, and the requirements of the circulation become greater, it will be observed *that the relation of the segments to actively contracting structures,* becomes more and more defined. In the ventricle of the fish, as I pointed out, the fibres proceed in wavy lines from base to apex, and from apex to base, from without inwards and circularly; so that the organ contracts and dilates very much *as one would shut and open the hand.* In the reptilia, the external and internal fibres pursue a slightly spiral direction—*the ventricles rotating more or less when in action.* In the cold-blooded animals, moreover, as every one is aware, the circulation is languid or slow, so that an arrangement of valves similar in some respects, though more complex than that which exists in the veins and venous sinuses and in the arteries, amply suffices. In the hearts, however, of the warm-blooded animals, where the ventricles are composed entirely of spiral fibres, and where the circulation, on account *of the sudden twisting and untwisting of the fibres is very rapid*, a system of valves, which will act with greater rapidity and precision, is absolutely necessary. But functional precision implies structural excellence; and hence that exquisite arrangement of parts in the auriculo-ventricular valves of mammals, whereby every portion of every segment (by reason of the ever varying length and strength of the chordæ tendineæ) bears a graduated relation to the musculi papillares and carneæ columnæ. Although the partial closing of the valves during the diastole may be, and is occasioned by the uniform expansion of the blood owing to the force exercised upon it by the contraction of the auricles, still it must be evident to all who reflect, that this cause is not of itself adequate to the complete closure, and for a very obvious reason. The blood, which is the expanding force, derives its power solely from the contraction of the auricles, and enters the ventricular cavities by the auriculo-ventricular orifices. Once in the ventricles, however, the blood has no inherent expansive power, by which it can of its own accord entirely shut off or close, the apertures by which it entered. This act, as I shall show presently, requires for its consummation, the force exercised by the contraction of the ventricles at the commencement of the systole. Admitting, however, that the expansion of the blood was adequate to the closure of the auriculo-ventricular valves at one period,—say at the end of the ventricular diastole,

when the ventricles are full of blood and the auriculo-ventricular orifices widest,—it is scarcely possible that it could keep them closed towards the end of the systole, when the auriculo-ventricular orifices are greatly diminished in size and the blood itself all but ejected. A regulating and motor power, therefore, in addition to the blood, for adapting the different portions of the segments of the valves to the varying conditions of the auriculo-ventricular orifices and cavities during the systole, seems requisite. Such a power, in my opinion, resides in the conical-shaped spiral musculi papillares with their proper tendons—the chordæ tendineæ.

That the theory which ascribes the closing of the auriculo-ventricular valves, entirely " to the contraction of the musculi papillares," is likewise of itself insufficient, appears for the following reasons :—

1st, If the valves which, at the commencement of the ventricular diastole, hang free in the ventricular cavities, and are undoubtedly floated mechanically upwards, so as to have their edges approximated by the blood towards the termination of that act, were dragged upon at the instant of contraction from above downwards, or in an opposite direction to that in which the force by which they were brought together acts, the segments of the valves, instead of being further approximated, would inevitably be drawn asunder, and regurgitation to a fatal extent supervene.

2d, By such an arrangement as Dr HALFORD has satisfactorily shown, the cavities of the ventricles would not only be materially diminished at a very inconvenient time,* but a certain amount of the force required for the expulsion of the blood from the ventricular cavities, would be expended in closing the valves. While, therefore, it seems essential for the approximation of the auriculo-ventricular valves, that they should first ascend with the ascending columns of blood occasioned by the injection of the ventricles by the auricles, so as to have their margins gradually and accurately approximated, in order that when the contraction of the ventricles takes place, they may be instantly closed,† thereby effectually preventing regurgitation ; so, for their continued closure, it seems necessary,

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* Dr HALFORD states his belief, " that the segments of the valves are forced even beyond the level of the auriculo-ventricular orifices, and in this way become convex towards the auricles, and deeply concave towards the ventricles." In his zeal for the enlarged accommodation of the ventricles, he forgets that the auricles are equally entitled to consideration, and that it is unfair to give to the one and take from the other ; for if, as he argues, the segments of the valves form a convex partition, whose convexity throughout the entire systole of the ventricle points in the direction of the auricles, the space beyond the level of the orifices is appropriated from the auricles without compensation. As, however, such an arrangement could not fail materially to inconvenience the auricles, when *they are fullest* of blood, we naturally turn to the ventricles for redress. The additional space required is, as I have already shown, supplied by the descent of the segments of the bicuspid and tricuspid valves towards the end of the systole when the ventricles are almost drained of blood.—*On the Time and Manner of Closure of the Auriculo-ventricular Valves.* Churchill, London, 1861.

† The margins of the segments of the valves at the end of the ventricular diastole are so close as to be nearly in contact. The slightest amount of pressure, therefore, suffices for the instantaneous closure. As, moreover, regurgitation is prevented in proportion to the rapidity with which the closure is effected, the efficiency of this arrangement is at once apparent.

in the second place, that they should descend with the rapidly decreasing columns of blood occasioned by the uniform and continued contraction of the ventricles and musculi papillares, in order that they may adapt themselves to the reduced size of the auriculo-ventricular orifices, and in order that the ventricular cavities may be diminished towards the base, as well as in every other direction. My belief consequently is, that the valves, like the ventricles themselves, have a passive and an active state; and another which, while it is neither strictly passive nor active, may, for the sake of distinction, be regarded as the neutral state. The passive state, corresponds to the diastole of the ventricles; the active state, to the systole; and the neutral or intermediate state, to that brief period which embraces the termination of the diastole and the commencement of the systole.*   As, however, the action of the valves, is, to a certain extent, dependent upon, and induced by the action of the ventricles, the following slight differences as regards time, are to be noted.   The passive state of the valves corresponds to that period in which *their segments are floated mechanically upwards, and their margins partially approximated* (Plate XXIX. figs. 52 and 55 *mn, rs*) by the blood forced by the auricles into the ventricles, during the dilatation of the latter; the neutral state, to that almost inappreciable interval which succeeds the sudden contraction of the ventricles, in which the blood set in motion is arranged in spiral columns, and acts in such a way as not only instantly closes the valves (Plate XXIX. figs. 53 and 56 *mn, rs*), but *screws and wedges the segments thereof, into each other,*† *in an upward spiral direction* (Plate XXIX. figs. 54 and 57 *mn, rs*).   The active state, corresponds to the period occupied by the progressive contraction of the ventricles.   During this period, *the valves are dragged forcibly downwards by the contraction of the musculi papillares, in an opposite direction to that by which they ascended; and are twisted into or round each other, to form spiral dependent cones.* In the active stage, as in the neutral, the blood acts from beneath, and keeps the delicate margins and apices of the segments of the valves, in accurate contact. That the foregoing is the true explanation of the gradual approximation and continued closure of the auriculo-ventricular valves, there can, I think, be little doubt, both from the disposition and structure of the parts, and from experiment.   If, *e.g.*, the coagula be carefully removed from perfectly fresh ventricles, and two tubes of appropriate calibre be cautiously introduced past the semilunar valves, and securely fixed in the aorta and pulmonary artery,‡ and the preparation be

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* In speaking of the closure of the valves, it is of great importance to remember, that the action, although very rapid, is a strictly progressive one, and necessarily consists of stages. In this, however, as in many other vital acts, it is often very difficult (if not indeed impossible) to say precisely where the one stage terminates and the other begins.

† This act takes place just before the blood finds its way into the aorta and pulmonary artery, the amount of pressure required for shutting and screwing home the auriculo-ventricular valves being less than that required for raising the semilunar ones.

‡ Strictly speaking, the tubes should be introduced into the auriculo-ventricular orifices, as it is through these apertures that the blood passes during the dilatation of the ventricles. As, however,

sunk in water until the ventricular cavities fill, it will be found, when one of the tubes,* say that fixed in the aorta, is carefully blown into, that the segments of the bicuspid valve roll up from beneath in a spiral direction (Plate XXIX. figs. 52 and 55 *rs*), in a progressive and gradual manner; each of the two larger or major segments, by folding upon itself, more or less completely, in a direction from within outwards, forming itself into a provisional or temporary cone, the apex of which is directed towards the apex of the left ventricle (*first stage, in which the crescentic margins and apices of the segments are slowly approximated by the uniform expansion of the blood forced into the ventricle by the auricle*). As the pressure exerted by the air is gradually increased, and the action of the valve is further evolved, the segments, folded upon themselves as described, *are gradually elevated, until they are on the same plane with the auriculo-ventricular fibrous ring;* where they are found to be wedged and screwed into each other, and present a level surface above (Plate XXIX. figs. 53 and 56 *rs*).

At this, the second stage of the closure, the crescentic margins of the segments are observed to be accurately applied to each other, *to form two perpendicular crescentic walls*, which accord in a wonderful manner with similar walls formed by the union of the semilunar valves; in fact, the manner of closure is, to a certain extent, the same in both; the segments in either case, being folded upon themselves by the blood, and presenting delicate crescentic margins, which are flattened against each other, in proportion to the amount of pressure employed. When the crescentic margins of the segments, are so accurately applied to each other as to become perfectly unyielding, and the distending process is carried beyond a certain point, the bodies or central portions of the segments bulge in an upward or downward direction as happens; the segments of the mitral valve, protruding into the auricle (Plate XXIX. figs. 54 and 57 *rs*); those of the semilunar one, into the ventricle (Plate XXVIII. figs. 27 and 28 *v wx*).

This completes the first and second stages of the process, by which the mitral or bicuspid valve is closed; but the more important, as being the more active and difficult, is yet to come. *This consists in adapting the segments of the valve, to the gradually diminishing auriculo-ventricular orifice; and in dragging them down into the left ventricular cavity*, to diminish the ventricle towards the base. By this act, the segments, as has been shown, are made to form a spiral dependent cone, an arrangement which renders the obliteration of the ventricular cavity towards the base, a matter of certainty.

The third stage of the closure of the mitral valve, entirely differs from the

the insertion of tubes, however small, into the auriculo-ventricular openings would necessarily prevent the complete closure of the valves, there is no good reason why the plan recommended in the text should not be adopted.

* Thin metallic tubes with unyielding parietes are best adapted for this purpose, as they can be readily fixed in the vessels, and the amount of pressure exercised by the breath on the valves asily ascertained.

first and second stages; inasmuch as the chordæ tendineæ, on the contraction of the musculi papillares, drag the segments in a downward direction, to adapt them to the altered conditions of the auriculo-ventricular orifice, and ventricular cavity. That this downward movement, actually takes place, is proved as follows. If a portion of the fluid be withdrawn by applying the mouth to the tube in the aorta, so as to create a certain amount of suction, the segments of the bicuspid valve, are found gradually to descend in a spiral direction (Plate XXIX. figs. 52 and 55 *r s*); forming, as they do so, a spiral cone, whose apex becomes more and more defined in proportion as the suction is increased; the water in the interior keeping the margins of the segments, accurately in apposition, and thereby maintaining the symmetry. If, again, the musculi papillares, be cut out of the ventricular walls and made to act in the direction of their fibres, *i. e.*, in a spiral direction from left to right downwards; they will be found, in virtue of being connected by the chordæ tendineæ more or less diagonally to either segment of the bicuspid valve, to act simultaneously on that side of the segment which is next to them; the musculus papillaris marked *a b* in fig. 31, Plate XXVIII., acting spirally on the margin and apex (*x*) of the larger or anterior segment, in the direction of the arrow near it; that marked *c d*, acting spirally on the margin and apex (*v*) of the smaller or posterior segment, in a precisely opposite direction. (Compare direction of arrows marked *a* and *d*.) The effect of these apparently incongruous movements, on the segments, is very striking.

The space which naturally exists between the segments (Plate XXVIII. fig. 31 *v x*; fig. 28 *m n*), and which corresponds to the distance between the points of origin of the two sets of chordæ tendineæ (*a* and *b*), is gradually but surely diminished, and the segments twisted into or round each other.

This arrangement, I may observe, while it facilitates the spiral movement adverted to, absolutely forbids any other.

It is rendered perfect by the pressure exercised on the delicate margins of the segments by the spiral columns of blood as already explained.

One complete closure of the mitral or bicuspid valve, may therefore be briefly stated, as follows:—

The segments, are first floated gently and gradually upwards, by the uniform expansion of the blood forced into the left ventricle, during the diastole, by the contraction of the left auricle. *This is a purely mechanical act, and during its performance the valve, and chordæ tendineæ, are entirely passive.* When, however, the ventricle suddenly contracts, the margins of the valve, which were in apposition, although not in actual contact, are rapidly approximated (the left auriculo-ventricular opening being instantly closed*); and the two spiral columns

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* Regurgitation (as has been already stated) is prevented in the inverse of the rapidity with which the closure takes place.

of blood set suddenly in motion by the ventricular systole, *force the segments of the valve, in an upward spiral direction, rendering them more and more tense until they reach the level of the ventricular orifice ; at which point, they are twisted and wedged into each other ;* the chordæ tendineæ limiting the amount of upward motion, to prevent retroversion and regurgitation. As, however, the blood finds its way through the aorta, which it does the instant the segments of the valve are screwed home,* *the segments gradually but rapidly descend in an opposite direction to that by which they ascended, their descent being occasioned, regulated, and minutely graduated by the contraction of the musculi papillares aided by the chordæ tendineæ and by the ascending spiral columns of blood ;* an arrangement which insures that the delicate margins of the segments, are always closely and accurately applied to each other ; for the chordæ tendineæ and the blood in the auricles acting from above, while the spiral columns of blood in the ventricles act from beneath, the delicate margins in question, are effectually prevented from falling towards the ventricular walls.† This downward action of the valve, musculi papillares, and chordæ tendineæ, which is of essential importance in adapting the former to the diminishing condition of the left auriculo-ventricular orifice and ventricular cavity, continues until the blood is completely ejected, and the segments of the valve are twisted or plaited into each other to form a dependent spiral cone, whose apex, is directed towards the apex, of the ventricle. By the time this happens, *i. e.*, by the time the blood is ejected from the ventricle, and the cone in question fairly formed, the left auricle is distended ; and due advantage being taken of the extra space afforded by the descent of the valve, the blood assumes a spiral and conical or wedge-shaped form, which is the best possible for pushing aside the segments, already in the most favourable position for falling away from the ventricular axis, towards the ventricular walls. The same phenomena are repeated with unerring regularity, with each succeeding action of the heart. What has been said of the manner of closure of the mitral or bicuspid valve, applies, I need scarcely add, with slight modifications to the tricuspid.

RESUME.

The points which have been more particularly dwelt upon in the present investigation, and on which the writer has endeavoured to throw additional light, are these :—

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* When the segments of the mitral valve are screwed home, the whole force of the ventricular contraction is expended in raising the aortic semilunar valve, and until the screwing home has taken place, the latter action is impossible, as the ventricle up till this point is compressible.

† The serious results which might arise from the segments of the valve falling towards the ventricular walls, or away from the axis of the cavity, is especially prevented by the attachments of the chordæ tendineæ ; the principal and more internal chordæ tendineæ (Plate XXVIII. fig. 33 *r s*) being, as I have shown, attached to the backs or more external surfaces of the segments, an arrangement which makes their rapid approximation towards the ventricular axis inevitable.

First, An attempt has been made to point out the intimate structural relation, existing between the veins, and venous valves; how the segments of the venous valves are composed principally of white fibrous and yellow elastic tissue, arranged in at least three well-marked directions; and how the segments are so disposed, that their free margins, unless when the blood is actually passing between them, are always more or less in apposition. An attempt has also been made, to demonstrate the nature of the apposition, by the employment of plaster of Paris, injected while in the fluid state into the distal and proximal extremities of the vessels. In the veins, as was pointed out, *the closure is to a great extent mechanical;* the segments, when two are present, being forced together in the mesial plane of the vessel, by the contraction of its walls, but principally by the weight of the refluent blood.

Secondly, The structure and relations of the arterial or semilunar valves, particularly in man, have been examined afresh; a more precise description than that hitherto given of the segments in systematic treatises on anatomy having been essayed. The great vessels have further been shown to bifurcate at their origins, and to be greatly thickened between the segments, which they support and incline towards each other—an arrangement calculated to bring the free margins of the segments more or less closely together, unless when pushed aside by the advancing column of blood during the systole. The sinuses of VALSALVA have, in addition, been shown to vary in size; the one curving towards the other in a spiral direction, and causing the blood to act in spiral waves upon the segments of the semilunar valves, which by this means are twisted and wedged into each other, when the reflux occurs. In the arteries, the action of the semilunar valves, as has been explained, *is for the most part mechanical*, the strong fibrous rings situated at the aortic and pulmonic orifices, tending to counteract the inconvenience, which might be supposed to result from an excess of vital contractility in the vessels, and the ventricles. The arterial semilunar valves, may be said to differ from the bi-semilunar venous ones, in having their segments wedged together by a spiral movement, which in the venous valves, is little more than indicated.

Thirdly, The bulbus arteriosus of fishes, has been shown to be a contractile organ, and to contain in its interior a system of valves, the segments of which, are, as a rule, more numerous than in either the veins or arteries. They have, in some instances, tendinous bands, resembling chordæ tendineæ, running between them; and are for the most part, arranged in tiers; so that the blood which is not caught by the one set, falls into, and is supported by the next. The action of these valves, as will readily be inferred, *is partly mechanical, and partly vital;* for the contraction of the bulb must be regarded as contributing to the closure. They are, therefore, an advance upon the valves of the veins and arteries, both as regards their number, and the manner of their closure.

Fourthly, In the reptiles, as has been demonstrated, *the valves are partly tendinous, and partly muscular;* while in the right ventricle of the bird, *they are altogether muscular.* Here, then, may be witnessed the first trace of a self-regulating power—*actively contracting muscular fibre*, taking the place of *non-contractile fibrous tissue.*

In the auriculo-ventricular valves, there is immense variety; these including most of the forms referred to, and others exhibiting a still higher degree of differentiation. They are, for the most part, characterised by the presence of chordæ tendineæ, which connect them with the interior of the ventricles, or the structures arising therefrom; viz. the carneæ columnæ and musculi papillares. The auriculo-ventricular valves, therefore, differ from the semilunar valves proper. In some instances, only one semilunar flap is present; and this may be either *altogether fibrous*, or *partly fibrous and partly muscular, or altogether muscular.* In a second, there are two flaps or segments, so arranged *that their long diameters correspond to the direction of the muscular fibres lining the ventricular cavity; the segments being continuous with the muscular fibres referred to.* In a third, the two segments are attached to the interior of the ventricle *by rudimentary chordæ tendineæ.* In a fourth, two accessory or smaller segments, are added to the two principal ones; *the whole being attached by well developed chordæ tendineæ to rudimentary musculi papillares.* In a fifth, which is the most perfect form of valve, as it exists in man and in the higher mammalia, the segments are from four to six in number, *most exquisitely and symmetrically formed, and attached by minutely graduated chordæ tendineæ to highly developed carneæ columnæ and spiral musculi papillares.*

The action of the auriculo-ventricular valves, owing to the want of uniformity in the number, structure, and relations of their segments, is varied. It is, however, on all occasions, carefully adapted to the wants of the circulation, and to the configuration of the ventricles and ventricular cavities; these cavities, as has been pointed out, adapting or moulding the blood, and causing it to act in given directions. Thus in the fish, where the circulation is slow, and where the ventricle is conical in shape, and composed of fibres interlacing in all directions, the segments, where two are present, are forced towards each other by the uniform expansion of the blood, and by the contraction of the ventricles, in a manner analogous to that by which the segments of the bi-semilunar venous valves are approximated by the retrogressive movements of the slowly advancing venous blood, assisted to a slight extent by the vital contractility of the vessels.

In the reptile, where the circulation is also languid or slow, the shape of the ventricle, owing to the fibres pursuing a more or less spiral direction, is that of a cone slightly twisted upon itself. As the spiral arrangement extends also to the valves, their action may be aptly compared to that which obtains in the valves of the largest veins, and in the arteries. It is, however, in the

auriculo-ventricular valves of the bird and mammal, that the spiral action of the segments becomes most conspicuous; the nature of the action being unavoidably determined, by the unmistakably spiral arrangement of the muscular fibres composing the ventricles, and by the spiral nature of the musculi papillares and ventricular cavities. As, however, the action of these valves, has been already explained at great length, further allusion to them at this stage is unnecessary.

The valves of the vascular system of the vertebrata, as will be perceived from this summing up, form a progressive and gradually ascending series; the valves in the veins exhibiting a lower type than those in the arteries; the valves in the arteries, being less fully developed than the valves occurring in the bulbus arteriosus and in the auriculo-ventricular orifice of the fish; the valves in the fish, being less highly differentiated than the valves in the reptile and bird; these again falling short both in complexity and adaptive power to those met with in the mammal. In the mammal the valvular arrangements may be said to culminate.

Description of the Plates.

PLATE XXVIII.

Figs. 1 and 2. External Jugular Veins of Horse inverted. Show valves, consisting of two (*d e*), three (*a b c*), and four (*f g h*) segments. (See pp. 763, 764.)

Fig. 3. Section of External Jugular Vein of Horse. Shows valve, consisting of two segments (*a b*), with dilatations (*g*), corresponding to the sinuses of VALSALVA, in the arteries. (See pp. 763, 764, 767.)

Fig. 4. External Jugular Vein of Horse opened. To show the relations of the segments (*a b*) above (*r e*). (See p. 763.)

Fig. 5. Portion of Femoral Vein distended with plaster of Paris. Shows dilatations (*h g*) in the course of the vessel corresponding to the position of the valve. (See p. 765.)

Fig. 6. Shows Venous Valve, consisting of two segments (*a b*), in action. (See p. 767.)

Fig. 7. The same, not in action. (See p. 763.)

Fig. 8. Venous Valve from External Jugular of Horse, consisting of three segments. (See p. 764.)

Fig. 9. Venous Valve, consisting of one segment, situated at the entrance of a smaller into a larger vein. (See p. 763.)

Fig. 10. Venous Sinus from Auricle of Heart of Sturgeon. (See p. 782.)

Fig. 11. Femoral Vein distended with plaster of Paris. Shows venous valves in action, where a smaller vessel enters the larger one (*a b*), and in the main trunk (*a' b'*). (See pp. 767, 768.)

Fig. 12. Vertical Section of Vein distended with plaster of Paris. Shows the nature of the union between the segments (*e*). (See p. 767.)

Fig. 13. The same, the section being carried between (*e*) instead of across or through the segments. (See p. 767.)

Figs. 14, 15, and 16. Show the Structure of the Venous Valves. (See p. 766.)

Fig. 17. Section carried through Pulmonary Artery and Right Ventricle of Human Heart, between the segments of the semilunar valves (*s*). Shows the variation in the thickness of the vessel (*a b*), and how it bifurcates (*r r'*) at its origin. (See p. 770.)

Fig. 18. A similar section, carried through the middle of one of the segments (*s*). Shows how the Pulmonary Artery (*a b*) behind the segments diminishes in thickness in a direction from above downwards (*i*). See p. 770.)

Figs. 19, 20, 21, 22, 23, and 24, Show the Structure of the Semilunar Valves in the Human Pulmonary Artery.   (See pp. 772, 773, 774, 775.)

Fig. 25. Human Semilunar Valve distended with plaster of Paris, and one of the segments (*g*) removed, to show the precise shape of the lunulæ, or opposing surfaces (*b b'*), between which union takes place when the valve is in action.   (See pp. 776, 777.)

Fig. 26. Shows the spiral relation of the Sinuses of VALSALVA to the segments (*v w x*) of the semilunar valve in the Human Pulmonary Artery, and how the segments are spirally wedged into each other, and fixed by six non-symmetrical semilunar surfaces, to form three perpendicular crescentic walls (*r s o*).   Seen from beneath.   (See pp. 776, 777.)

Fig. 27. Shows the Semilunar Valves in the Heart of the Sheep (*v w x*) distended with plaster of Paris, or as they appear in action, together with the spiral nature of that action.   (See pp. 776, 777.)

Fig. 28. Shows the same in the Aorta (*v w x*) of the Human Heart, and in addition, the bifid nature of the musculi papillares (*a b, c d*), and the distribution of the chordæ tendineæ to both segments of the mitral valve (*m n*).   (See pp. 776, 777, 787, 788, 789.)

Fig. 29. Vertical Section carried through the Aorta and through the middle of one of the segments of the Semilunar Valve of the Whale.   Shows the variation in the thickness of the vessel (*c e*), and the structure of the semilunar valve (*a r s' o*).   (See pp. 770, 773, 774.)

Fig. 30. Shows Arterial and Auriculo-ventricular Orifices, with their fibrous rings (*x v n n'*).   (See pp. 769, 770.)

Fig. 31. Human Mitral Valve, Chordæ tendineæ, and Musculi papillares inverted.   Shows the bifid nature of the musculi papillares (*a b*), and the threefold distribution of the chordæ tendineæ (*s*).   (See pp. 786, 787, 788, 788.)

Fig. 32. Shows Structure of the Mitral Valve in the Sheep.   (See pp. 786, 787, 788, 789.)

Fig. 33. Anterior Segment of Human Mitral Valve.   Shows the threefold distribution of the chordæ tendineæ, from above downwards, and from the mesial line towards the margin of the segments.   (See pp. 786, 787, 788, 789.)

Fig. 34. Example of Mitral Valve in the Right Ventricle of the Human Heart.   (See pp. 789, 790, 791.)

Fig. 35. Vertical Section, carried through the aorta (*a a'*) semilunar valve (*s s' s''*), left auricle (*d d', y y'*), the segments of the mitral valve (*m m', n n'*), and the left ventricle (*v v'*), of the Human Heart.   Shows the greater thickness of the aorta, where the segments of the semilunar valve unite above (*b b', c c'*), and its greater tenuity behind the centre of each segment (*o*) ; also how a portion of the aorta (*p*) is continued into the larger or anterior segment of the mitral valve (*m m'*).   It also shows the relation of the left auricle (*y y', d d'*) to the aorta (*a a'*), mitral valve (*m m', n n'*), and left ventricle (*v v'*).

> *r r'*, Openings of coronary arteries.
> *n n'*, Segments of semilunar valve uniting above.
> *x x', e e'*, Auricle terminating by wedge-shaped process in mitral valve.
> *z z'*, Left coronary artery.
> *t t' t''*, Convex, or attached borders of segments of semilunar valve.
> *g*, Septal wall of left ventricle.
> *h h'*, Chordæ tendineæ.
> *i i'*, Musculi papillares.
> *w'*, Apex of left ventricle.   (See pp. 770, 771).

Fig. 36. Left Ventricle of Human Heart laid open to show the semilunar (*s s'*) and mitral (*m*) valves *in situ*.   (See pp. 770, 771.)

PLATE XXIX.

Fig. 37. Portion of Heart of Sturgeon.   Shows auriculo-ventricular valve (*a*) with three chordæ tendineæ (*b*) proceeding from it.   (See p. 781.)

Fig. 38. Ventricle and Bulbus Arteriosus of Skate laid open.   Shows several rows of semilunar valves (*a b c*) increasing in size in a direction from below upwards.   (See p. 779.)
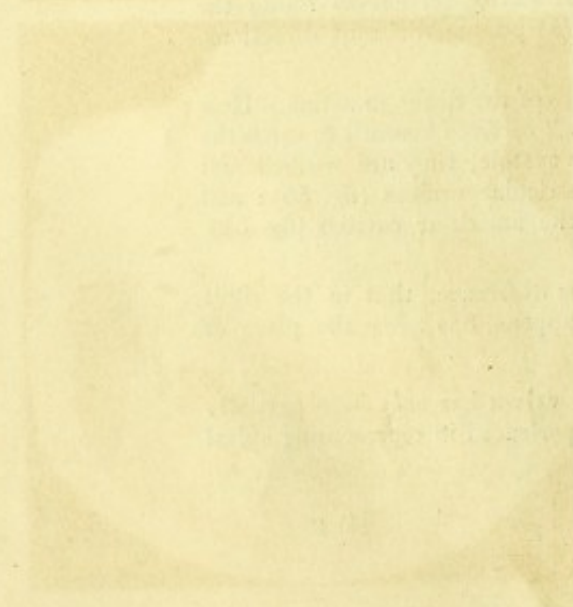
Fig. 39. Bulbus Arteriosus and Ventricle of Sturgeon,—the former displaying five rows of semi-lunar valves (a), the latter an auriculo-ventricular valve (b), with numerous tendinous bands running into it. (See p. 779.)

Fig. 40. Bulbus Arteriosus and Portion of Ventricle of Lepidosteus. Shows the great thickness of the bulb (a), and of the valves (b) contained within it, and between which tendinous bands run. (See p. 780.)

Fig. 41. Portion of Bulbus Arteriosus of Basking Shark. Shows the great thickness of the bulb (a) and of the valves (b), and how the latter support each other. (See p. 780.)

Fig. 42. Heart of Crocodile. Shows spiral semi-muscular, semi-tendinous valve (r), situated between right auricle (a) and ventricle (x). (See p. 781.)

Fig. 43. Bulbus Arteriosus and Ventricle of Sun-fish. Shows three semilunar valves (a b c) at orifice of bulb, and an auriculo-ventricular valve (f), consisting of two segments. (See pp. 779, 781.)

Fig. 44. Heart of Serpent (*Python tigris*). Shows muscular semilunar valve at orifice of left superior cava (s); also spiral muscular slit (r), occurring between the ventricles. (See pp. 781, 782).

Fig. 45. Heart of Emu, showing spiral muscular valve (g h), occurring in right auriculo-ventricular orifice. (See p. 781.)

Fig. 46. Heart of Swan, with right and left ventricles laid open. Shows spiral muscular valve of right ventricle (i), and mitral valve (v) of left, and how one portion of the former (j) corresponds in position to the anterior musculus papillaris (y) of the latter. (See p. 781.)

Fig. 47. Heart of Frog-fish. Shows three sets of semilunar valves ; one occurring where the large veins join the auricle (c) ; a second, where the auricle opens into the ventricle (b) ; the third being situated at the orifice of the bulbus arteriosus (a). (See p. 779.)

Fig. 48. Bulbus arteriosus and portion of Ventricle of Grey Shark. Shows semilunar valves, with tendinous chords running between them (a) ; also, auriculo-ventricular valve (g). (See pp. 779, 780.)

Fig. 49. Wax cast of Left Ventricle (b) and portion of Right Ventricle (a) of Deer. Shows spiral nature of the left ventricular cavity,—the spiral course or tracks of the musculi papillares (x y), and how between these, two spiral grooves (j q) occur, which direct the blood on to the segments of the mitral valve in spiral waves. (See pp. 784, 785.)

Fig. 50. Plaster of Paris cast of Right and Left Ventricles of Zebra. Shows infundibulum or conus arteriosus (i) of right ventricle, and analogous portion of left ventricle (p o) ; also three prominences on each (d e k r v), corresponding to the sinuses of VALSALVA. It also shows the double cone formed by the left ventricular cavity, the one apex pointing towards the apex of the heart (j), the other towards the aorta (h). (See pp. 784, 785.)

Fig. 51. Same cast seen posteriorly. Shows the mitral (m n) and tricuspid (g h) valves in action, and how the blood, when these are closed, assumes a conical form (o) for pushing aside the segments of the semilunar valves, and causing them to fall back upon the sinuses of VALSALVA (v w). It also shows how the right ventricular cavity (c) curves round the left one (x), and how the pulmonary artery (b) and aorta (h) pursue different directions. (See pp. 784, 785.)

Figs. 52, 53, and 54. Show the Mitral (r s) and Tricuspid (m i n) Valves of the Sheep in action. How the segments, acted upon by the spiral columns of blood, *roll up* from beneath towards the end of the diastole (fig. 52) ; how, at the beginning of the systole, they are wedged and twisted into each other, on a level with the auriculo-ventricular orifices (fig. 53) ; and how, if the pressure exerted be great, they project into the auricular cavities (fig. 54). (See pp. 796, 797, 798, 799, 800, 801.)

Figs. 55, 56, and 57. Show the same in the Human Heart, with this difference, that in the right ventricle, a true mitral valve (m n), as not unfrequently happens, has taken the place of the tricuspid. (See pp. 796, 797, 798, 799, 800, 801.)

Note.—The spiral *downward* movement of the mitral and tricuspid valves has only been partially represented (figs. 52 and 55) owing to the great difficulty experienced in representing spiral cavities.

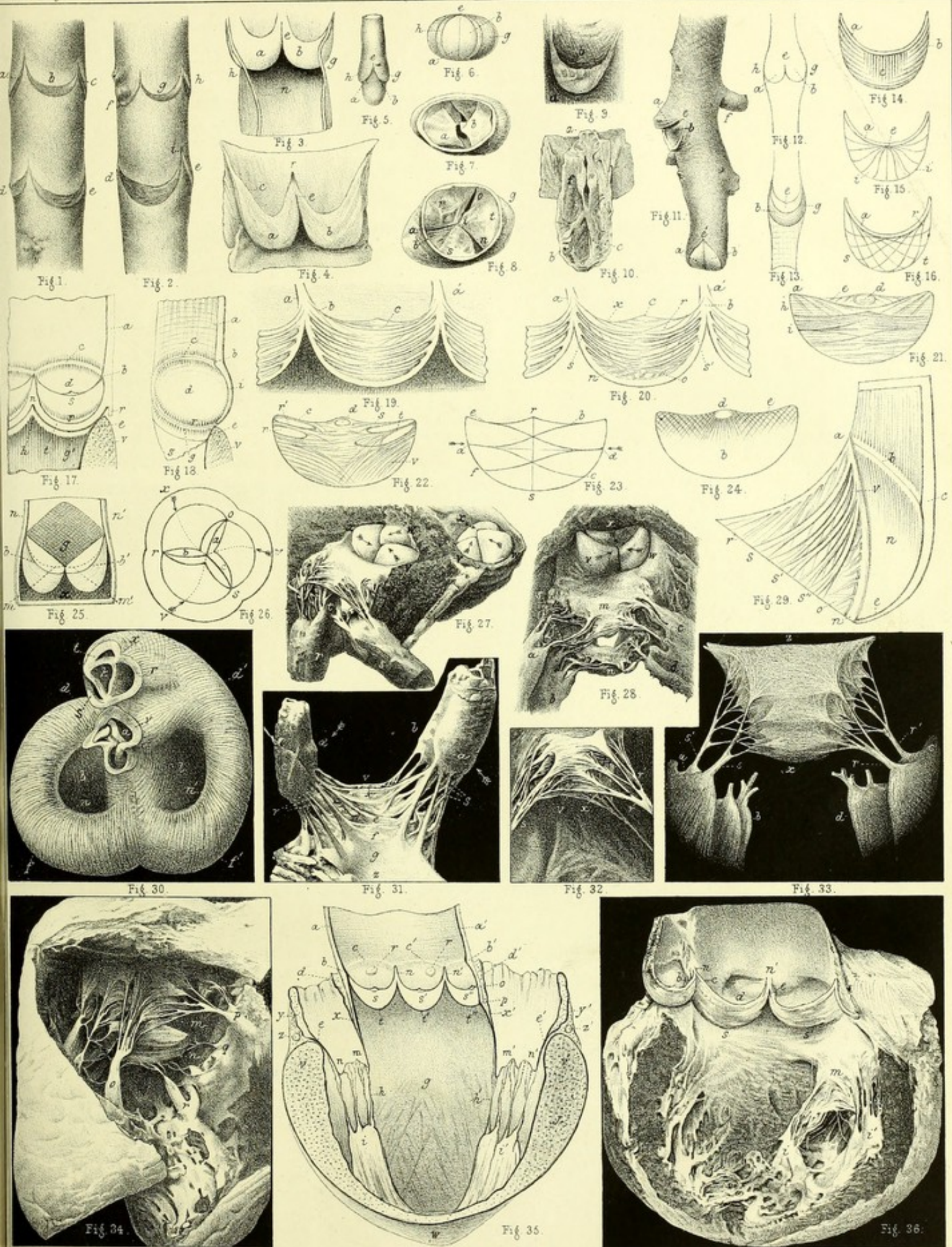Plate XXVIII.

Fig.1.

Fig. 2.

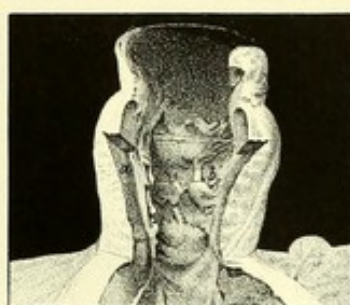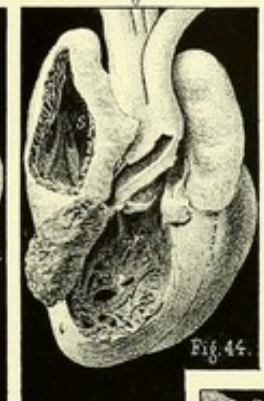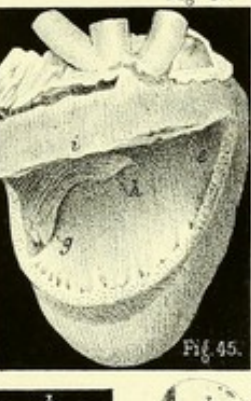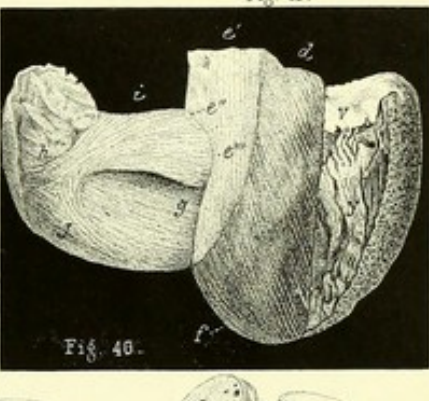Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.
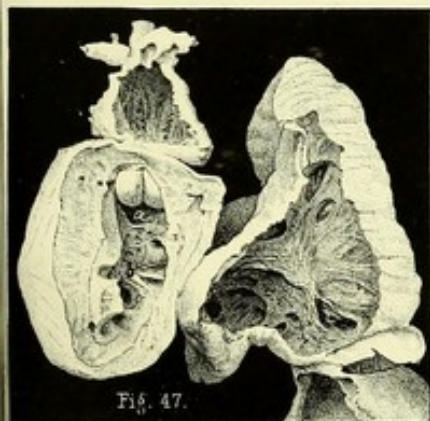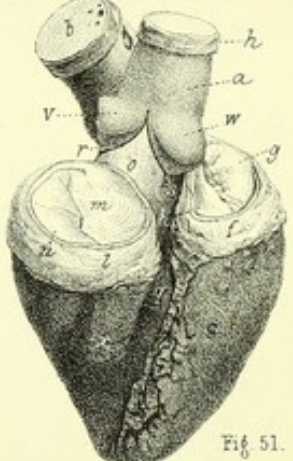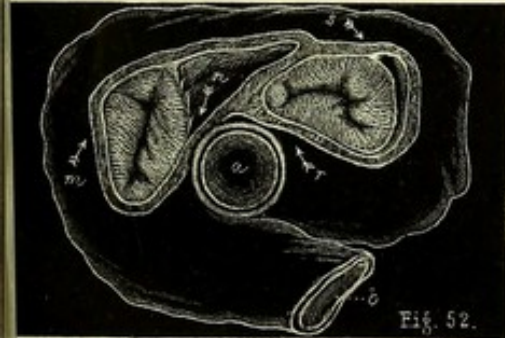
Fig. 7.

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Fig. 33.

Fig. 34.

Fig. 35.

Fig. 36.

Plate XXIX.

Fig. 37.

Fig. 38.

Fig. 39.

Fig. 40.

Fig. 41.

Fig. 42.

Fig. 43.

Fig. 44.

Fig. 45.

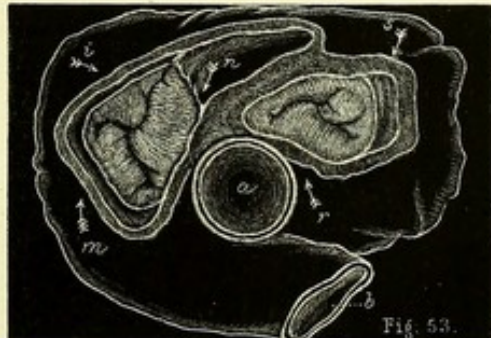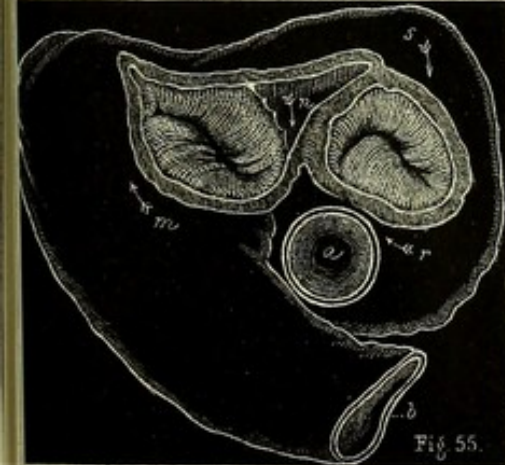Fig. 46.

Fig. 47.

Fig. 48.

Fig. 49.

Fig. 50.

Fig. 51.

Fig. 52.

Fig. 53.

Fig. 54.

Fig. 55.

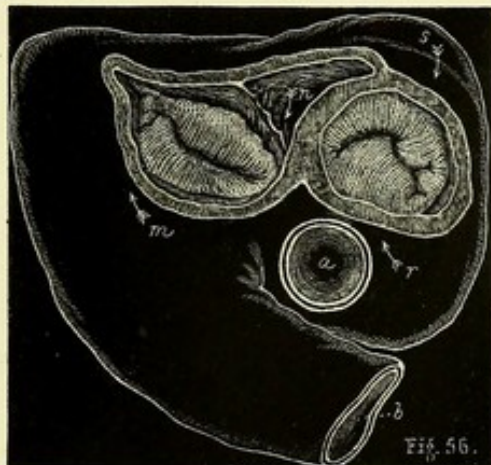Fig. 56.

Fig. 57.