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OF

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BY

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FOUR CHIEF ORIFICES OF THE HEART

ARE CIRCULAR IN FORM AND CONSTANT IN AREA DURING THE ENTIRE PERIODS OF SYSTOLE AND DIASTOLE.

By HERBERT DAVIES, M.D., Cantab, F.R.C.P.

In a paper which I had the honour of reading before the Royal Society in the early part of 1870, I attempted to establish the existence of a law which determines the relative magnitude of the areas of the four chief openings of the heart, and I also sought to show the reasons why the orifices differed from each other in size. I took as the basis of my calculations the facts given by Drs. Peacock, Reid, and others, and I assumed—

1st. That the four openings during the time the blood traverses them are circular in form; and

2nd. That the area of each orifice is unchanged—constant—during systole and diastole.

I propose in this communication to show that these assumptions were correct.

1. All anatomical writers agree in describing the orifices of the aorta and pulmonary artery to be circular in circumference. I have therefore only to prove that the tricuspid and mitral apertures are also circular, although stated in anatomical works to be elliptic in form. And, in the first place, I may recall the fact that all the canals of the body, and all the outlets through which fluid has to pass, are (with a few exceptions) circular in

form, for the obvious reason that the *largest quantity* of fluid can pass with the *least amount* of friction through a circular opening, and therefore with the least expenditure of power on the part of the organ propelling or expelling the fluid. If, for instance, we compare the perimeters of a square, ellipse, and circle, each of which contains an area of one square inch, we shall find that they are—

4
3·85 } inches respectively.
3·54

The ellipse being taken in this case, for the sake of example, as having its long axis double the length of that of the short axis, or as 1·6 to ·8 inches. An elliptic mitral orifice (on the above supposition of the length of axes), containing one square inch, would have a perimeter ·31, or nearly one-third of an inch longer than the perimeter of a mitral opening containing exactly the same area, but of a circular form. The openings of the two different forms would be of exactly the same size in area, but the circumferences bounding these equal areas would be very different in length. The elliptic would evidently expose a much larger frictional surface, and be, therefore, less favourable for the transit of blood than an opening of an exactly circular form enclosing the same area within its circumference. It would be interesting to discover why the longitudinal and straight sinuses in the cranium have a triangular form. It is clear that the arrangement is not merely for the purpose of packing, for we find that the small veins which empty themselves into the longitudinal sinus enter that channel at an angle, and in a direction opposed to the current which flows through it, showing, as it were, that great velocity is not required in the stream of the sinus. The aortic and pulmonic apertures are admitted, as I have already stated, on all hands to be circular in form. It might be, therefore, fairly asked why Nature, which economises force in all

parts of the body, should adopt *oval* apertures for the admission and *circular* openings for the exit of the blood of the ventricles, especially as the incoming tricuspid and mitral currents possess small velocities and momenta, and require every favourable condition possible to secure their reception into their respective ventricles during the period of diastole.

Again, whatever may be the forms of these orifices—as observed *post-mortem*—when the heart is lax and empty there must be, I believe, every probability that volumes of blood, which traverse them *during life* and exert centrifugal pressure on their circumferences, will inevitably tend to throw the *effective* openings into a circular shape. That such is the case is well seen in Dr. Pettigrew's specimen, marked 929 B, in the Museum of the Royal College of Surgeons. The chambers of the heart in this specimen have been filled with fluid plaster of Paris, which, in hardening, has preserved the circular form of the orifices.

Specimen 928 C, in the same Museum, clearly exhibits the naturally circular openings of the tricuspid and mitral orifices in the heart of the *Bison Europæus*. The walls of the apertures are so thick and firm that they preserve their circular shape *post-mortem*.

If we stuff a sheep or bullock's heart with cotton and boil it for many hours, and detach—as we can most easily—the auricles from the ventricles, we shall find in this rude experiment the apertures to be very nearly circular in shape.

Lastly, in employing the spherical balls devised by Dr. Peacock for the measurement of the orifices, the apertures are found to be well fitted by them.

These considerations will, I think, be sufficient to establish the truth of my statement that the tricuspid and mitral orifices when *in function* are circular in form.

I will now proceed to the reasons which show that the areas of the orifices are constant—that they do not alter in superfices during the systole or diastole of the ventricles.

1. The rings which surround the auriculo-ventricular openings are formed of white fibrous (tendinous) tissue. Being naturally inelastic, they are consequently unaltered in their perimeter by any normal eccentric pressure to which they are exposed by the passage through them of the auriculo-ventricular volumes of blood. In my former paper on this subject, I have shown that the force with which these incoming volumes enter the ventricles is small; and it is evident, therefore, why the tendinous boundaries of the auriculo-ventricular openings are feebly developed.

2. The muscular fibres around these orifices are in no way found to be arranged in a circular form, and cannot possibly, therefore, act in the manner of a sphincter to close the openings. The fibres which constitute the walls of the ventricles are formed of seven strata—three of which are external and oblique, one central and transverse, and three internal and oblique. The first and seventh strata are alone inserted into the auriculo-ventricular rings, and converge in a direction almost at right angles to their planes, while the inner and subjacent strata have no connection with, or insertion into, them, but are continuous beneath them. The masterly dissections of Dr. Pettigrew establish the truth of this description. It is clear, therefore, from this arrangement of the fibres that the systolic contraction of the ventricles can have neither power nor influence to diminish the superficial areas of the tricuspid and mitral apertures.

3. The muscular walls of the auricles, according to an able paper by Mr. Savory, of St. Bartholomew's Hospital, are found to terminate by two attachments. The larger and outer portion (the looped fibres of Quain and Sharpey) is closely inserted into the fibrous auriculo-ventricular ring, while the inner and thinner portion can be traced between the surfaces of the valves terminating more or less abruptly by attachment to the tendinous tissue. The former offers no arrangement of fibres capable of contracting or in any degree altering the capacity of the inlets,

and the latter fibres are probably of use, as suggested by Valentin, to assist in raising the tricuspid and mitral curtains in ventricular diastole, in order that the blood may freely pass behind them and close them by recoil pressure.

It follows, therefore, that neither on the ventricular nor the auricular side is there any muscular arrangement existing capable of affecting the areas of the auriculo-ventricular apertures. In fact, the existence of valvular curtains would, I think, lead one *à priori* to expect that they alone are requisite and sufficient to close the apertures. *Where sphincter muscles are found, valves are absent.* We find no valves at the pylorus, anus, and orifice of the bladder in man, and the right auriculo-ventricular orifice in birds, which, being entirely *muscular* in structure, exhibits no trace of a curtain. I propose at some future time to enter into the consideration of the probable reasons why the heart of the bird differs in the shape of its tricuspid orifice from that of the mammal. If the tricuspid and mitral orifices could be contracted by muscular action and closed, as the neck of the bladder is, by a sphincter, no valvular curtains would be required. The two forms of arrangement for closure are incompatible with one another.

Again, looking at the result, it is manifest that auricular action, if capable of diminishing the area of the orifice, would only tend to impede the flow of the blood from the auricle to the ventricle, and thereby oppose the attainment of the very object which it has mainly to accomplish. And it is equally clear that any contraction of the area of the orifice by ventricular systole would not assist in the expulsion of the ventricular contents, inasmuch as the curtains are *inelastic*, and cannot diminish in superficial area under any effort of the papillary muscles which regulate their position and tension. The obliteration of the ventricular chamber is effected only by the contraction of its muscular walls, during which process the auriculo-ventricular curtains are drawn down by the papillary muscles in the shape of a cone

which, in its gradual descent, becomes filled with blood from the auricle. The pressure *on* the ventricular surface of the cone continues, of course, much greater than the pressure of the blood contained *in* the cone until the end of the systole, when it becomes zero, and allows the constituent portions of the cone to separate from each other under the pressure of its fluid contents. And thus is the onward current of blood favoured from one chamber to the other, and a sudden shock to the flow into the auricle prevented during the contraction of the ventricle. The *persistent* opening of the auriculo-ventricular orifice during the descent of the valve, so well described by Pettigrew, forms evidently an important part of the arrangement.

There is, therefore, I believe, great reason for believing that the areas of the tricuspid and mitral openings are as unaffected in systole and diastole as are the areas of aortic and pulmonic apertures. The rings which surround the latter are very strong, and capable of resisting the pressure of the volumes of blood which pass through them in systole; and unless the orifices maintained their constant areas, their valves, *which are inextensible*, would be unable at all times to adapt themselves to the opening which they have rigorously to close. The same line of argument is applicable to the auriculo-ventricular apertures and their curtains. The respective areas of these openings must be constant, in order that the inextensible valves belonging to them may be able to adapt themselves at all times to them.

As an additional illustration in proof of the constancy of the areas, I may refer to some recent experiments made by Drs. Sibson and Broadbent on the living dog.

In Fasciculus VII. of the "Medical Anatomy," Sibson says:—

"When I observed the heart acting vigorously under water, after being cut out, it seemed to me that the circumference of the shut valve (mitral) did not lessen with the diminution of the ventricle towards the end of systole. It would appear that the pressure

of the blood, by filling the sacculi on the under surface, unfurls, flattens out, and enlarges the valve, so as to maintain it almost of full size to the end of systole."

If, then, it be true that all the chief orifices of the heart are circular in form when in action, and that their respective areas are constant during systole and diastole, certain objections which have been raised to the truth of the statements made in my former paper are removed, and the correctness of the formula which I have discovered, viz. :—

$$\frac{\text{Area of Tricuspid}}{\text{Area of Mitral}} = \frac{\text{Area of Pulmonic}}{\text{Area of Aortic}}$$

becomes more fully established.

And if it be also true—as it undoubtedly is—that equal volumes of blood must pass synchronously through the pulmonic and aortic openings, and that the two ventricles exert very unequal pressures upon these equal volumes of blood in systole, it must follow, if the velocities are unequal, that equal times of efflux can be only obtained by the areas of the aortic and pulmonic orifices being inversely as the velocities of the streams which traverse them. During the period of each systole, the left ventricle has not only to sustain and neutralise the pressure of the aortic column, but also to send forth nearly five cubic inches of blood into that vessel. The latter is by far the smallest portion of its task, as shown in an able paper written by Dr. Andrew Buchanan, of the University of Glasgow, upon the "*Effective* Force of the Heart;" but the principle, the formula, for the truth of which I am contending (the result of the correlation of the forces of the *two hearts*), does not involve the *objects* for which the forces of the two ventricles are put forth. It is sufficient to know that the velocities are unequal, that they result from the operation of unequal forces in equal times upon equal masses of blood, to be convinced that the areas of the openings must be inversely as the velo-

cities of the streams which pass through them. An American reviewer of my paper clearly puts it:—"Dr. Davies' observations relate only to the relation between the *size of the orifices*, and to the *average velocity* of the blood through these orifices, and he deals with vis viva only on attempting, as it were, to confirm the latter."*

M. Onimus, in the "Journal de l'Anatomie" (1865), has attempted to show that the auriculo-ventricular openings are completely closed in systole by muscular (sphincter) action; but the investigations of more recent anatomists completely negative the existence of such an arrangement of fibres, and with respect to one of these openings he himself says:—"Si, pour l'orifice auriculo-ventriculaire, on peut admettre des fibres circulaires formant des sphincters, pour l'orifice gauche, cette expression n'est pas très-juste, car cette dénomination suppose un muscle annulaire, et nous avons vu qu'une partie de cet orifice était complètement fibreux." In fact, the dissection of a heart which has been boiled for some hours will readily show that the fibres at the auriculo-ventricular openings have an almost vertical direction, and that their action would tend rather to keep the openings dilated than closed during the ventricular systole. I cannot believe, also, that any trust can be placed upon the very rude experiment, described by M. Onimus, of passing a finger through a wound made in the wall of the auricle of a living animal, so that it may reach and be *pushed* into the ventricle through the tricuspid orifice. Fatal and sudden syncope would undoubtedly result, and interfere with the experiment.

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* The *American Journal of the Medical Sciences*, Oct. 1870, p. 503.

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