LECTURES ON THE HEART,

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LECTURES ON THE HEART.

Lecture I.

Gentlemen,—Having concluded the Descriptive Anatomy of the Heart, I will now consider its functions, glancing, for instruction's sake, at the same organ in the lower animals. Before you are representations of the heart of the reptile, bird, and mammal. The first looks a cumbrous instrument, the second nearly a simple cone, the third, which has chiefly to occupy our attention, a form intermediate between that of the reptile and the bird. Each is enclosed in a case of fibro-serous structure called the pericardium, in which, for the more perfect and smooth movements of the heart, a varying quantity of fluid is contained.

The Pericardium not only encloses the heart, but it facilitates and regulates its movements. If you lay bare the heart of a mammal, you will be surprised how smoothly all goes on; but immediately the pericardium is laid open, the heart, seeming to lose all guiding power, takes on a tumultuous action. This is less seen in the bird; most so in the reptile. You will remember its attachments in man to the tendon of the diaphragm below and to the large vessels above; but in reptiles, such as the alligator and snapping turtle, it is not only attached to a considerable height above the origin of the large vessels, but it sends inwards strong folds to become attached to the ventricle, where, therefore, the heart's shape is most irregular, and its action most sluggish and heaving, these bridles and a larger quantity of fluid are found. Again, in disease, such as inflammation, we find a tumultuous action of the organ immediately following the injury to the pericardium.

The Auricle.—The functions of the auricle are three: 1st, to receive the blood returning to the heart by the veins; 2nd, to fill the ventricle; 3rd, and following from the hydraulics of its second function, to raise and close the segments of the auriculo-ventricular valve.

Let us consider each of these functions. But first look at the auricle of the reptile, mammal, and bird. In the reptile it is large, two being needed to one ventricle; each is so separate from the ventricle that its only connexion is the small round orifice leading into the ventricle. The auricles are so large in the Surinam toad as only to permit the apex of the ventricle being seen.*

Look now at the auricle of the mammal. It is much smaller than that of the reptile, and separating it from the ventricle a mere sulcus; still it has these dog's-ear appendages, whence indeed the name of this division of the heart.

And now that of the bird. It is small, has no dog's-ear appendages, and is not separated from the ventricle by any well-marked sulcus.

1. That of receiving the blood returning to the heart by the veins.

This function is best seen in the heart of the reptile, say, for example, that of the turtle, in which the pulsations are not more on the average than twelve per minute, and in which also inspiration is very irregular and prolonged. During such an inspiration both auricles become greatly distended, and blood flows from them into the single ventricle, the distension of which is however completed by the action of the auricle. In the intervals of these deep inspirations the auricles do not become so distended; and their second function, that of filling the ventricle, is more obvious.

In the mammal the number of pulsations in the minute is greater than in the reptile; in man, say 72. Here the auricles are filling during the pause, or rather during the intervals of ventricular contraction, when being full their contents are forced into the ventricle. There are cases, however, in which, from obstruction to the cardiac or pulmonary circulation, as, for instance, in mitral disease with regurgitation, long-standing phthisis, emphysema, the auricles are compelled to act, as indeed they do naturally in the reptile, the part of reservoirs for the impeded and slowly-circulated blood; but in health in the mammal the three functions of the auricle are pretty evenly maintained.

In the bird, so rapid is the circulation, so forcible the ventricle contraction, that little need is there of any further force being imparted to the venous currents in order to distend the ventricles; still some is required, and hence a rapid auricular precedes an equally rapid ventricular contraction. During those wonderful performances of fine songsters, as the nightingale, canary, &c., as also during submersion in aquatic birds, the auricles must act principally as reservoirs or terminal sinuses to the venous circulation.

The third function which I have assigned to the auricle and upon which I especially insist, that of raising and closing the auriculo-

* See Museum, Royal College of Surgeons of England.

ventricular valves, will be fully discussed when speaking of the mechanism of those valves.

I called your attention to the muscular structure of the auricles; now, would it be believed, some deny that the ventricles are filled by the auricles, asserting that they draw in the blood in the same way as an elastic ball fills itself with air. Let us then magnify the subject; and we have the heart of a whale which, instead of four ounces, discharges with each stroke of the heart from ten to fifteen gallons of blood, the aorta being one foot in diameter. Surely, then, if the arguments of these people be just, such ventricles can well take care of themselves. Not at all, they require auricles of enormous contractile power, the musculi pectinati being of the size of branches of an ordinary shrub. Facts like these bewilder, but do not convince, mere theorists.

The Ventricle differs greatly amongst reptiles: thus in frogs and serpents it is single, in the turtle and chameleon it is very imperfectly divided into two, but in alligator lucius I have failed to find any communication between the ventricles, whilst it occurs in the crocodile. In conjunction with the perfect septum existing in the alligator, I have further remarked, as in a mammal, the dark colour of the right, and florid hue of the left, auricle.

In the bird and mammal it is double.

The functions of the ventricle are three:

1st. To receive the blood from the auricle.
2nd. To raise the semilunar valves.
3rd. To circulate the blood through arteries, capillaries, and veins, back to the auricles.

The first is obvious to all. Of the second, I will speak when treating of the valves hereafter.

That the ventricle is equal to its second function has been abundantly proved. Dr. Hales ascertained a century ago that "if any artery of a large animal like a horse be made to communicate with an upright tube, the blood will ascend in the tube to a height of about ten feet above the level of the heart, and will then continue rising and falling a few inches with each pulsation of the heart. Now a column of ten feet indicates a pressure of about four and a half pounds on a square inch of surface: this, therefore, is the force of the heart urging the blood along the arteries and through the capillaries into the veins."* You will find a *resumé* of Hales's experiment in that admirable work "Todd and Bowman's Physiological Anatomy," as also of those of Volkmann and Poisenille. The latter physiologist, by causing the blood from an artery to press upon a column of mercury, estimated the force of the left ventricle at the moment of its contraction as four pounds four ounces. Sharpey's experiments are most interesting, and prove that such a force as estimated by Hales and Poisenille is sufficient for the function which I am assigning to the ventricle. Here is his account: "A syringe

* "Arnott's Physics," 6th edition.

with a hæma-dynamometer (in English, a blood-power measure), to show the amount of pressure used, was adapted to the thoracic aorta of a dog just killed, the abdominal aorta having been previously tied immediately above the renal arteries, and the inferior vena cava opened just as it passes through the diaphragm. Fresh defibrinated bullock's blood was injected with a pressure of three and a half inches of mercury, and passed through the double capillary system of the intestines and liver out of the veins with a full stream. When the pressure was increased to five inches, the blood spirted from the vein in a full jet. When the aorta was not tied above the renal arteries, the same pressure sufficed to drive the blood through the vessels of the lower extremities, and it was made to traverse the capillary system of the lungs by a pressure of from one and a half to two inches of mercury, so as to flow freely through the pulmonary veins. Allowing one pound for every two inches of mercury, it would appear that a pressure of two pounds was sufficient to complete the circulation through the two abdominal capillary systems, and of one pound for the pulmonary circulation "† Again, Magendie laid bare the femoral artery and vein, and applied a ligature to the vein, which he opened below: blood, of course, flowed. He then compressed the artery between the fingers, and the jet of venous blood diminished, and presently ceased. Moreover, it has occasionally happened, that in ligaturing the femoral artery, the vein has unfortunately been wounded, but in every instance, I believe, the hæmorrhage has ceased upon securing the *artery*. Some years ago I saw such an accident happen to one of the most skilful and humane men it has ever been my happiness to know; but because the bleeding ceased when the artery was tied none of those who witnessed the operation would believe the vein itself had been injured, rather that some small branch has been divided. After the company had dispersed, the surgeon took me on one side and asked me what I thought. My reply was, that it was the vein itself which was injured. But why, then, did the bleeding stop directly? Because, sir, you shut off the vis a tergo immediately you ligatured the artery. The man died, and the post-mortem revealed that the femoral vein had been wounded. At that time I had many rabbits undergoing little operations to solve physiological problems, and on the afternoon of the operation referred to, and before the evening visit of the surgeon, I had in four of them, and in a large dog laid bare the femoral artery and vein, on each side, had passed a thread beneath each artery, and then opened the vein; in all cases the blood ran in large gushes, but in every instance ceased immediately the thread beneath the artery was tied. Majendie's experiment was then unknown to me, but here it was ten times independently confirmed All the animals lived, but the man died; my ligatures were outside the vein, the surgeon's had gone through the vessel. No harm ever results from tying the femoral vein, but

† "Todd and Bowman's Physiological Anatomy."

transfixing it and leaving therein a silken thread is a very different thing indeed.

Lastly, you may see beneath the microscope that, with every stroke of the heart, the blood is urged on in the minutest arteries of the web of the frog's foot; and we have just seen that the same influence is extended into the veins.

In confirmation of these views, I have found that where blood has to be sent more than the average distance from the centre of the circulation, the ventricle is of proportionate strength, being of much greater thickness in the young ostrich and emeu than in the lion or man; in the kangaroo than in the eagle; in the alligator than in the turtle; and relatively in the sturgeon and the salmon than in either.

Disease also teaches us the function of the ventricle, for whenever obstruction arises to the arterial current the ventricle endeavours to overcome it; and by constant exertion, like the blacksmith's biceps or the dancing-master's calf, grows, and prolongs life.

We have seen that a great amount of tension exists in the arteries; but much of this is lost in the veins. The blood from a wounded artery is projected many feet, that from a vein a few inches; it escapes from the artery *per saltum*, from the vein in a steady flow. A moment's reflection will convince you that the gradually-increasing size of the veins as they approach the heart, together with the presence of auricles or reservoirs for the returning blood, will account for the loss of tension. The cause of the equable venous current must now engage our attention. When the arteries are injected by the ventricle, they are distended and lengthened, but rapidly return to their former size. To the elastic tissue entering into their structure this is mainly due, but not entirely; for as you have seen the contractile cells of Kölliker largely abound in the arterial coats, and it is certain that an artery will contract to a far greater extent than can be put to the account of mere elasticity. This is best seen in a large artery, say the carotid of a turtle, which when divided I have seen contract so completely as to obliterate its cavity. In fact, I do not think it possible for a reptile to bleed to death. Here is a frog from which all the limbs have been amputated without a vessel having been tied, and yet comparatively he lost not the twentieth part of the blood following a tap on the nose at a wake or a wedding. Your lecturer on surgery will tell you of cases in which a whole limb has been torn off by machinery, and little loss of blood ensuing; but in the case of the reptiles I have alluded to, the vessels were fairly severed, not torn, and their gradual closure actually watched. There is, then, more than elasticity, there is contractility; but for what purpose? Thus writes Dr. Billing in his "First Principles of Medicine," a book for originality of thought and purity of expression unequalled in the whole range of medical literature:—"The arteries keep up a constant contractile pressure on their contents; not as has been commonly supposed an alternate contraction and relaxation, but a continued contractile effort, both longitudinally and transversely, which is overcome by the action of the heart: when there is much blood sent into them, they are distended; and if there be little blood sent into them, as after hæmorrhage, their tendency to contract causes them to close, so as to keep always full, and to preserve a continuous stream of the blood, even during the temporary relaxation of the heart; and the arteries yielding, and adapting themselves to the pressure of the heart, and recontracting on their contents, whilst the heart is relaxed and filling, is the *cause* of the *equability* of the *stream* in the veins. . . . . The most simple mechanical illustration is a double bellows of a smith's forge, which keeps up a constant current of air, though the handle works with intermissions; so that the blast into the fire would be in puffs, if it were not for the weight on the upper part of the bellows, which keeps forcing out the air in a continued current, whilst the hand is drawing back to make another impulse."*

Hales, whose experiments I have quoted, held the same views, and used the fire-engine as his illustration.

Thus we have abundant evidence of the sufficiency of ventricular contraction to commence, sustain, and complete the circulation; but as physicians you will be called upon to examine the manner of the heart's action; and the phenomena presented in the arteries, capillaries, and veins. The *pulse* will deeply engage your attention. It is the sensation imparted to the fingers when laid upon an artery, and in some cases a vein, during life, and it depends essentially upon the yielding of the vessels to the injecting force of the heart; hence it follows that weakened walls will *cæteris paribus* cause a bounding pulse, strong walls a more equable one. Disease always weakens, consequently, to talk of increased arterial action in an inflamed part is wrong; more blood is rushing through the arteries leading to the part because their contractile power is weakened, and in the capillaries destroyed: they throb more violently because they yield more readily to the injecting force of the heart. The sac of an aneurism is nothing but an evidence of this yielding, this loss of power disease. The same is seen in delicate, nervous females. The heart may be acting quietly, and yet the carotids and all their branches may be throbbing violently so as to distress the patient greatly. That this is a local affection of the vessels, and that its cause must be sought in some alteration of the controlling influence of the nerves upon the vessels, is rendered certain by Professor Claude Bernard's researches. He exposed the submaxillary gland and chorda tympani nerve. The nerve he divided, and galvanized its peripheral extremity, when immediately the vessels of the gland became dilated, the blood passing so rapidly through it that, upon pricking the vein, the blood escaped in jets. The same effect follows the division of the sympathetic in the neck, the corresponding side of the head and face becoming suffused with blood. But Claude Bernard's beautiful experiment teaches us something more, and I have purposely introduced it in this part of the course; excepting the heart, you have here a complete circulation, and a complete

* "First Principles of Medicine," 5th edition, p. 9.

proof that a bounding vein is the result of a weakened yielding artery, and that it is to the contractile pressure of arteries that the equable stream in the veins is due.

The coats of the arteries, as I have shown, are not simply elastic. They have vital as well as physical properties; consequently it is impossible to find their equivalents, but it will be both interesting and instructive to consider the results of Dr. Marey's experiments on fluids in elastic tubes, as detailed in Brown-Séquard's Journal de la Physiologie.

By means of an instrument called a sphygmograph, consisting of delicate levers, he was enabled to indicate the height and duration of pulsation at any part of the tube, and by adapting to its distal extremity outlets of various diameters, could regulate the amount of tension of the tube likewise, a forcing-pump having been connected with the orifice of inlet of the tube. This is in imitation of our occasionally throwing one leg across the other, the knee of one resting in the popliteal space of the other, when, with every pulsation of the artery beneath, the foot will be raised. The foot corresponds to the extremities of his levers, which are furnished with writing points, and indicate upon a revolving cylinder the movements of the tube.

Now, as the conclusions at which he arrives have an important bearing upon the cardiac mechanism which will form the subject of the next lecture, I hope you will give them your best attention, for if for tube you substitute the arterial trunks, and for narrow and wide outlet, capillary tension and relaxation, you will get a close approximation to what must pass in the living body. He finds that *all the pulsations commence*, only they are not completed, *at the same instant*. There is, therefore, no retardation of the pulse, but only a retardation for the maximum of pulsation; in other words, that the pulse occurs at the same instant in the carotid as in the posterior tibial, but that the distension of the former vessel is completed before that of the latter; for he finds that near the orifice of entry of tube, the levers mark a sudden ascent and a slow descent; far from this orifice, on the contrary, the ascent has a duration increasing with the distance from the pump, and when the rise and fall of the tube occupy alternately equal times, the mean dynamic, as he calls it, is attained, the lever not ascending beyond half the distance of that near the orifice of entry, which marks the maximum pulsation.

Now it is evident that of two persons, one slightly touching the carotid, the other the posterior tibial, the first would feel the sudden distension of the former before the other the slower distension of the latter, although a more delicate instrument than the finger might show that the commencement of pulsation was the same in both.

Again, using tracings on the cylinder to mark the distension of the tube under varying conditions, he comes to the following conclusions:—

1st. That whatever the swiftness of the current, the line of levels falls on the side of the orifice of discharge; but the decrease of tension is so much greater as the escape is more rapid.

2nd. The augmentation of the afflux, by reason of more frequent impulsions or from more voluminous waves, raises the mean tension, more especially on the side of entry.

3rd. The increase of impediment to the flow produced by narrow adaptations, raises the line of levels, especially on the side of the aperture of escape.

Further on he observes that an elastic dilatation of one side of the tube will as completely change the character of the movement as a considerable length of tube, and if it be sufficiently large all pulsation beyond it will be destroyed. So is it with an aneurism in the course of an artery: the pulse is weakened or obliterated in the artery beyond the dilatation, and frequently from the same cause, and not from any obstruction to the flow of blood through the tumour.

And here I must express my regret that I cannot give you a detailed account of some experiments I made in conjunction with Drs. Richardson, Hyde Salter, and Leared, upon Mr. Groux, a gentleman in whom there existed a large sternal fissure, the skin alone covering the heart and origin of the large vessels. We had been deputed by the Medical Society of London examine the case, and my colleagues requested me to draw up the report, which I subsequently read to the society. Since then the paper is nowhere to be found, but I will again write to England to endeavour to recover a copy. Fortunately I have preserved a diagram which I made at the time, and to which I will now direct your attention. The blue lines represent the margins of the fissure, the red patches pulsating points in the fissure, of which the largest is below, and corresponded to the base of the right ventricle; above this is the right auricular appendage, and highest up the aorta. Some very interesting experiments were made upon this gentleman as to the synchronism of the pulse. The instruments used were a sphygmosphone, an electro-magnetic machine furnishedwith hammers, a drawing of which I send round. Taking the radial artery for comparison, it was found that a slight interval was recorded between the pulsation of the ventricle and the artery; that a greater existed between the pulsations of the auricle and artery, while those of the ventricle and aorta were almost if not quite synchronous. These results appear not to tally with those obtained by Dr. Marey, and yet I am not sure that the sphygmosphone records more than the maximum of pulsation; if so, the two sets of experiments would establish the same facts.

The conclusion at which I would arrive is, that in relaxed states of the arterial system the pulse may be due to an undulation in the contained blood; but in the healthy contractile state it will retain little of that character, but as a continuous stream is urged on by the forces behind, its motion being accelerated and, if I may use the expression, modulated, by the continuous pressure of the arteries.

I will now pass round six lithographs taken from photographs of

M. Groux in the act of opening and closing this fissure at will. You will see in them, in addition, the expanded lung, the pulsating aorta, and contracting auricle and ventricle; but this you must remember, that the sides are changed, that which is seen as the right side of the chest is the left, and *vice versâ.*

We will now examine the movements of the living machine which sets the wonderful currents of blood in motion. And first of the pericardium.

You have most probably examined microscopically the ovum of the water-snail. You there see the embryo first a little dot, and then ultimately filling the egg, and during its imprisonment it may be seen moving and rolling, changing its form. From first to last the ovum contains the same amount of matter, and preserves its original form. So is it with the pericardium and its contents; for although the chambers of the heart are ceaselessly filling and discharging, the aorta and pulmonary artery are as ceaselessly expanded and springing back; yet the amount of its contents must ever during health be the same. What the auricles lose the ventricles receive, what the ventricles lose the commencement of the large vessels admits, whilst, at the same time, the auricles are filling; all these interchanges being facilitated by the small amount of fluid the pericardium contains: but in disease, where there is any obstruction to the cardiac movements, the quantity of fluid is usually found increased; and this is also constantly the case in the reptile, the movements of whose heart is, when compared with that of man, laborious and irregular.

I insist, then, upon the unvarying size of the pericardium, and the unsoundness of most of the conclusions which have been drawn from observations made on the hearts action after the removal of this sac.

In order to comprehend thoroughly the heart's action, recourse must certainly be had to vivisection. Not one alone will suffice; but I shall not have recourse to this proceeding on the present occasion, but refer you to diagrams for an outline of the chief phenomena. It is easy to perform these vivisections, but the necessary delicate observations cannot be made by a large number of spectators. No pain need be inflicted, for I have never but in one instance operated without the use of chloroform; and when the animal has been under its influence I have removed the chest walls, keeping up artificial respiration with a pair of bellows, dropping occasionally into the valve-opening some of the anæsthetic. In this manner I last winter demonstrated to my class the heart's action, which was forcibly and rhythmically maintained beyond an hour, the animal never being permitted to recover consciousness. The instance in which I did not use chloroform was in the case of a turtle. I had previously made myself acquainted with the anatomy of the reptile, and was enabled to remove the whole plastron without scarcely losing any blood; but I shall never repeat it, it is the "damned spot" on my physiological fingers, and will not out. Moreover, there is a horror connected with the proceeding I had never anticipated; it is this, the creature looks, but cannot utter the tortures it endures: the frog can scream, the serpent hiss, but, as far as I am aware, the turtle is dumb.

The action of the auricles in all cases immediately precedes that of the ventricles; and passing a string across the pericardium on a level with the auriculo-ventricular sulcus, so as to represent a fixed horizontal line, their contraction is from below upwards, at the same time that the base of the ventricles ascends beyond the line, the sulcus no longer corresponding with the fixed line across the pericardium; in other words, the being-distended ventricle takes up part of the space within the pericardium previously occupied by the retreating auricle.

In the turtle, as I have before mentioned, the auricular action is at times irregular.

In the snake it is rapid and strong, raising the upper and left angle of the ventricle quite to the highest part of the arch of the aorta.

In the bird it is extremely sudden, seldom permitting the auricles to become distended, but preserving their form of little addenda to the ventricles.

In the mammal, including man, the rapidity of action is intermediate between that of the reptile and bird.

The Ventricle.—The pulsations in the turtle not being more than 12 per minute, a good opportunity is afforded of watching and following carefully the movements of the ventricles. While the ventricle is contracting the base descends, the blood that it is ejecting elongating and distending the vessels which arise from its base, the distending auricles following the contracting ventricles. At this time the apex of the ventricle is not drawn up, but glides backwards, downwards, and slightly to the left. Now, that is to say when the whole ventricle is small, an impulse produced by the contracted hardened state of the muscular fibres can readily be felt by the finger and thumb. To this condition succeeds the distension of the ventricle, its base being raised, its bulk increased, it occupies more room in the pericardium, it has encroached upon the auricles, to the eye it is tense, but to the finger it is flabby and relaxed.

In the snake there is the same impulse felt all over the ventricle during its descent in the pericardium, but none during its ascent. A distinct pause occurs between the end of the ventricular and the next auricular contraction. A month or two past I was out shooting, or rather carrying a gun and firing it off occasionally, when I was on the point of treading upon a very large brown snake. I stepped back, and my friend blew his head off. In return for his kindness I opened the snake, and demonstrated to him the movements of the reptilian heart, which continued beating rhythmically as long as we observed it, say half an hour. To record our observations would be to repeat what has been said above.

In the salmon parr, one two days, the other five days old, which were recently hatched in Melbourne, I observed the same mobility of that part of the ventricle continuous with the bulbus arteriosus. The movements I watched for many days, using a 2-inch objectglass, which discovered the little beauties in their gravelly bed most readily.

In the bird the contraction of the ventricle is both rapid and powerful, giving a smart impulse during its descent; for here again the apex is the most fixed point, the base most moveable.

In the ass and the dog, and, from my examination on M. Groux, in man, I must repeat the observations I made as a student twelve years ago, and which I have since so many times verified :—

During the systole, or contraction of the ventricles, the base of the heart approaches the apex; the latter at the same time is pressed downwards, backwards, and from right to left, describing part of a circle; the ventricles, assuming a contracted globular form, descend, describing also part of a circle, but passing forwards and from right to left. There is also a forward movement of the left ventricle above the apex from left to right. These minor movements must be seen, they cannot well be described; but the facts of importance to be remembered are, that, when the ventricles contract, their bases descend towards the apex, and the latter is not tilted forward so as to give any blow to the thoracic walls, but is pressed downwards, its extremity being directed backwards and from right to left.

The ventricles contracting, the auricles simultaneously receive blood and then occupy part of the space within the pericardium previously taken up by the ventricles in their relaxed distended state. The finger and thumb spanning the diameter of the ventricles are perceptibly further separated during the contraction of the ventricles, and approximated during their relaxation.

The same *apparent* blow is felt over every part of the ventricles during their contraction, but more forcibly over the centre. The impulse at the ribs is most probably given by the fibres just above the apex.

The apex is the most fixed part of the heart. Great pains were taken to ascertain whether the eye was deceived or not. A piece of string was stretched tightly across the thorax, and a pin thrust through it into the substance of the heart. The string acting as the fixed point, the oscillations of the pin corresponded to the movements of the part into which it was inserted. Thus, when inserted about the centre of the sulcus separating the ventricles anteriorly, the head of the pin moved upwards during the contraction of the ventricles, and downwards during contraction of the auricles, that is, in a reverse direction to that of the heart and the pin's point inserted into it. In this situation the pin moved longitudinally along a line equal to | , whereas when inserted into the apex the distance did not exceed | . The same was tried over other parts of the heart, and always with the same result, viz., that the apex was more fixed than any other part.

If now, in such an animal, you compress the venæ cavæ with bull-dog forceps, and the pulmonary veins, the heart will continue its motions; its contractions being frequently more forcible than when blood is flowing through it. From this I would have you gather two facts : first, that the blood is not the cause of the stimulus to the heart's action, for it will beat a long time when removed from the body, and, as in this experiment, when it is empty ; secondly, that relaxation of the muscular fibres of the ventricles is distinct from dilatation of the heart's cavities ; for how—when the flow of blood through the heart is stopped, and hence all force *from within* removed—how can the ventricular walls expand, how can the ventricular cavities be dilated ? It is a physical impossibility ; and yet the globular form of contraction, and the lengthened form of relaxation, are distinctly seen, but no dilatation can take place. Therefore, in considering the order of occurrences in the heart's rhythm, we must say that relaxation of the ventricles occurs previously to their dilatation, and that the two conditions must not be confounded : in other words—

Contraction—as applied to the action of the *muscular walls* of the heart, is correct.
Contraction—as applied to the heart's *cavities* consequent on the contraction of its walls is also correct.
Dilatation—as opposed to contraction, and expressing the state of the heart's *cavities* when distended with blood, is also correct ; but
Dilatation—as opposed to contraction of the *muscular walls* of the heart, is incorrect—it should be *Relaxation.*

And further, relaxation of the muscular fibres of the ventricles has no more to do with the dilatation of their cavities, or with the passage of blood into them, than relaxation of the sphincter ani has to do with the expulsion of fæces from the bowel ; yet in both cases the same passive yielding state of the relaxed muscular fibre is necessary to complete the act. As the abdominal muscles, through the medium of the fæces, dilate the sphincter, so do the auricles, through the medium of the blood, dilate the ventricles.

Of the pericardial portions of the great vessels.—In the mammal, with the contraction of the ventricles and descent of their bases, these portions of the aorta and pulmonary artery become suddenly elongated and distended, and as suddenly react upon their contents, visibly distending the sinuses of Valsalva.

In the reptile it is the same, but the distension and contraction of the vessels are more slowly executed.

The Venæ Cavæ.—In the turtle, snake, and frog, during the auricular contraction, blood is thrown back into these vessels. This is so undoubtedly the case that, if a thread be passed round the inferior vena cava of the snake, say one inch from its entrance into the right auricle, and tied whilst the auricle is filling, it will become immediately emptied, but upon contraction of the auricle it will again become distended, and remain so, receiving impulse from each contraction of the auricle.

This simple experiment shows us enough why the auricular contraction is so sudden ; its effect being to stop the current in the veins, hence its rapidity, that the arrest may be as transient. And this stoppage to the circulation would be very serious were there no compensating force, viz., the contractile power of the arteries, which you will remember I showed you was most considerable in the reptile, where, indeed, we now see it to be most wanting. In the bird this rapidity attains its maximum, so that, while each form of heart is of course the best that could be given to each of the animals we have been considering, that of the bird must be considered the most simple, the most perfect; this perfection being indicated by the more perfect cone-shaped ventricle and small auricle.

Secondly, it goes far to prove what I stated at the commencement of this lecture, viz., that frequently during the filling of the auricles in the reptile, blood flows freely into the ventricle; otherwise, upon tightening the ligature during this state of the auricle, the vein would not become emptied had there not existed a free communication at the moment between auricle and ventricle.

Thirdly, it disproves entirely the suction or exhausting function of the heart; for if such a power existed it is clear that this one inch of the vena cana would be soon emptied, but it never is after the first regurgitation from the auricle, as when, by applying the ligature, the vis a tergo is shut off.

The same occurs in the mammal, but to a less extent.

Lecture II.

Of the auriculo-ventricular valves.—These form, immediately upon the filling of the ventricles, and before contraction of the latter, a perfect septum between them and the auricles; and their strength you will find always in proportion to that of the ventricles which they close. Thus, on the right or pulmonic side, they are weak; on the left or systemic, they are strong; they have to resist at the instant the whole force of the ventricular contraction, a force which was estimated by Hales in the case of the horse at 113lbs. By the end of the ventricular contraction, their opposite flaps lie side by side with the walls of the ventricle: they therefore offer no opposition to the flow of blood from the auricles.

I take this circular piece of paper. It is clear it would form a perfect septum between any two cavities; but I wish to do more than that; it is necessary for something to pass through it, but not return. Well, that is easily accomplished. I take a pair of scissors, insert the point of one blade through the centre, and cut in four or five directions nearly to the circumference, and we have a septum consisting of teeth or cusps with a circumferential ring. If to one surface of these cusps limiting strings (chordæ tendineæ) be attached, you have before you a rough imitation of what nature, does so perfectly. Again, if now the opening guarded by this valve should, when requiring the most perfect closure, become contracted, t is evident that such a valve would well fulfil the purposes for which it was required.

Such, indeed, are the auriculo-ventricular valves, completely closing the ventricles during their most distended state, as also during the whole of their systole : the musculi papillares contracting at the same time that the base of the ventricle descends.

The semilunar or ventriculo-arterial valves readily permit the passage of blood from the ventricle, and as securely prevent its return ; for the more the aorta and pulmonary artery become distended, the more forcibly are they closed, the blood accumulating on their arterial surfaces by reason of the pouches termed sinuses of Valsalva.

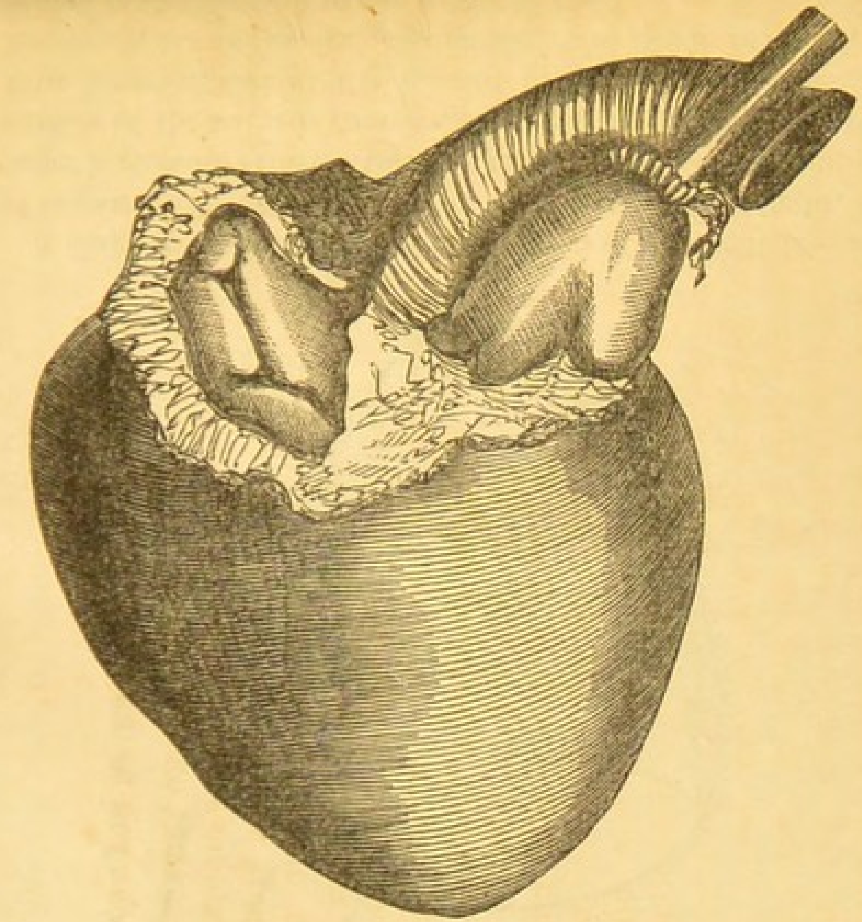
Of the Time and Manner of Closure of the Auriculo-Ventricular Valves.—There are two things necessary to the closure of these valves ; viz., the shutting down of the semilunar valves and auricular contraction.

When the auricle is about to inject the ventricle, the latter is empty and contracted, with its distal or ventriculo-arterial valves firmly shut down by the pressure of the blood upon their upper surfaces. Immediately the auricle contracts, its contained blood passes into (distending and lengthening) the ventricle ; the force which it transmits not being sufficient to overcome the arterial pressure and weight of blood upon the upper or arterial surface of the semilunar valves, is expended in distending the ventricle and closing the auriculo-ventricular valve, which then forms one of the walls of the ventricle. To this succeeds the ventricular contraction ; the auriculo-ventricular valve, being already closed, now becomes tense, the pressure in the ventricle overcomes that in the artery, and the semilunar valves are raised.

That the above is correct is proved as follows :—If we cut away the auricle and clear out the coagulum from the ventricle, on placing the heart in fluid we find that the flaps of the auriculo-ventricular valve are borne up to a certain extent towards the auriculo-ventricular opening ; but the latter does not become closed without employing force, as with a stream of water thrown with a syringe from the direction of the auricle, and this closure is not perfect nor sustained without first shutting down the semilunar valves, which is best done thus :—For a human heart, an elastic self-supplying syringe, with a tube of like diameter with the aorta or pulmonary artery, is adapted to either vessel, and its semilunar valves shut down, gentle pressure being maintained by the fingers upon the bottle in imitation of the elastic pressure of the aorta or pulmonary artery. If the ventricle be now injected, the closure of the valve is instantaneous, its upper surface becoming convex (not funnel-shaped), and its under surface deeply concave. For a bullock's heart a plumber's forcing pump must be used, and for a bird's a smaller apparatus, and the same result will ensue.

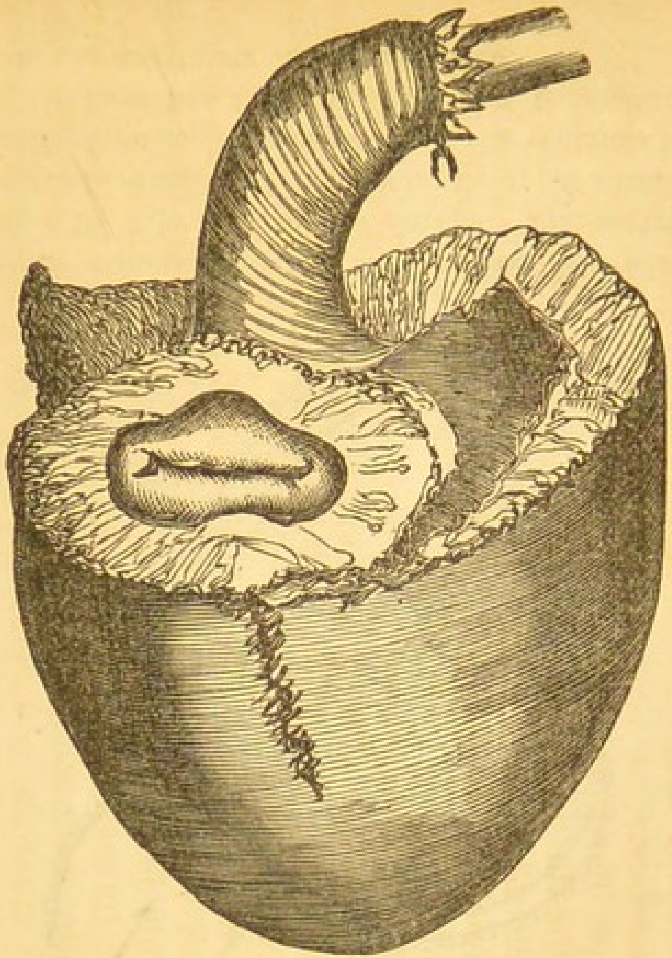
I now refer you to diagrams 1, 2, 3, 4.

FIG. 2.



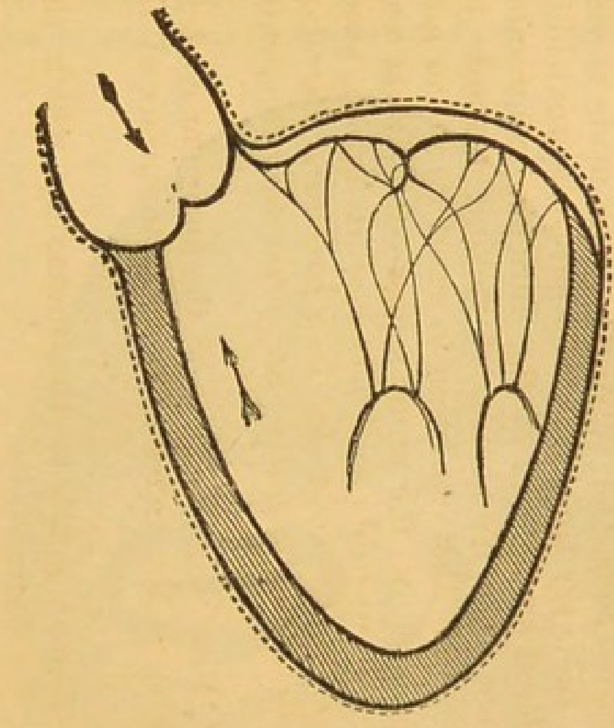
Front view of the heart; auricles removed. The pulmonic valves shut down and the artery distended. The right ventricle has been treated as the left in fig. 1, and the tricuspid valve closed.

FIG. 1.



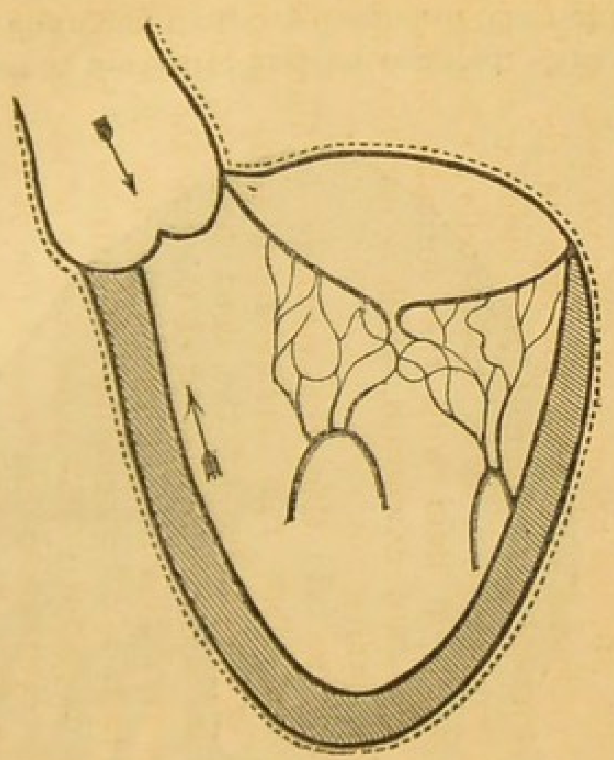
Back view of the heart; auricles cut away. The semilunar valves having been shut down and the aorta distended with fluid, the left ventricle was filled with water with a syringe from above, and the mitral valve closed.

Fig. 3.



A diagram representing the state of the ventricle immediately after its injection by the auricle. The auriculo-ventricular valve is raised and convex on its upper surface, as in the preceding figures. The capacity of the ventricle has been increased, its base has been raised, and at the instant of its contraction the semilunar valves *must* open.

Fig. 4.



A diagram representing the condition of the ventricle and of the auriculo-ventricular valve, if, as is generally taught, the latter is closed by the contraction of the ventricle. The upper surface of the valve is concave, the capacity of the ventricle is thus lessened, and at the instant of its contraction *not the semilunar, but the auriculo-ventricular valve would be raised*, by which both time and power would be lost.

The dotted line represents the pericardium, and the arrows the direction of the pressure.

From this I hope you will see that the auriculo-ventricular valve must be closed previously to the systole of the ventricle, as in figs. 1, 2, 3, otherwise the ventricle could not thoroughly be filled, nor could the valve itself perform its office properly; for as the ventricle contracts and its base descends, the valve would be made to yield towards the auricle at the very time it is required to be unyielding. But with the valve closed by the end of the auricular contraction, as in fig. 3, there is not only no chance of yielding towards the auricle, but the ventricle is in that condition to exert its power most instantaneously and effectively, as the prime mover—the *fons et origo*—of the circulation. *The rapidity and power of its action would be impaired were any of its force expended in a backward direction, had it indeed to close the auriculo-ventricular, previously to opening the semilunar valves.*

But it may be asked, How can the force of the auricular contraction be brought to bear upon the under or ventricular surface of the valve?

The following preparations point to the means by which this process is effected, you observe—

1st. That if we open a ventricle and cut away the flaps of the auriculo-ventricular valve from their attachments, both to the zona tendinea and to the chordæ tendineæ, on placing the preparation in fluid, the chordæ tendineæ rise up like stems of aquatic plants from the musculi papillares, and from the side of the ventricle.

2nd. That when the chordæ tendineæ are cut off close to the under surface of the flaps of the valve, the latter are still supported at a certain level in the fluid, and their delicate margins curl upwards towards the auricle. This latter fact is more evident in the right than in the left ventricle, and was first remarked by Dr. Markham. Again, when a whole valve with the upper part of the ventricle is cut out so as to form a muscular ring with the flaps of the valve hanging loosely, and is placed in fluid with the auricular surface *upward*, their delicate margins turn up as little scrolls; when the same preparation is placed in fluid with the auricular surface *downward*, their edges now turn downward, which is not the case with any other part of the valve.

Now, if to the above we add that the ventricle in filling is an enlarging cavity, and that this enlargement takes place below the attachment of the valve to the zona tendinea, and that in the elongation and upward movement of the base the valve participates; and if we remember that, even to the last drop of blood from the auricle, there is a force causing the particles of blood within the ventricle to press upon the under surface of the valve, even after the auricular contraction has ceased (for it cannot be supposed that ever, even for an instant, the blood is at rest), then are we led to the following conclusions, viz.:—

The chordæ tendineæ by position serve to open out and prop up (as stems of water-plants do their leaves) the flaps of these valves; their firm connection at the circumference with the zona tendinea tends also to their support; moreover, the elasticity producing the upward curl assists in the approximation of their edges; finally, the pressure exerted by the blood from the auricle brings all into play, and their closure is effected.

Who, I ask, can refrain from admiring this instance of economy of time and power, by which the ventricle is assigned its one function of expulsion, the very force which fills and distends the ventricle closing these valves? That force is auricular contraction.

But let us stop to see how necessary such a state of the ventricle, as represented in diagram 3, is to the purposes of the circulation, to the tension of the arteries which we have seen so requisite, which is proved by Magendie's and my own experiments, is seen in the rapid spirt from a wounded artery, and is so insisted upon by Dr. Marey as the result of his observations upon the effects of fluids in elastic tubes. From such a ventricle tense at the instant as at the termination of its action merrily speeds the blood to every part of the body. But with a condition as represented in fig. 4, we have before us a ventricle not filled, and, as a consequence, a small pulse, slow capillary current, and serous exudations, first in the feet then higher up—such, in fact, is mitral disease, when from thickening, &c., the valves require more than auricular force to close them, and when, in addition to rigidity, patency arises, another set of more serious symptoms commences, first in the lungs, thence affecting the whole vascular system.

The Sounds of the Heart.—Two sounds accompany one rhythm of the heart's action in the mammalia: the first long, the second short. The long immediately precedes the short, hence they are termed the 1st and 2nd sounds of the heart, and may be tolerably well imitated by stretching slips of paper of different lengths.

This was the simple illustration used by Dr. Billing to his class at the London Hospital, and in his second publication on the subject, the first having taken place in February, 1832, he says: "The first sound takes place exactly synchronous with the impulsion and action of the ventricle; hence it might be supposed that the action of the muscle (as averred by some) produces the first sound. But the second sound takes place at a time when there is no action of the heart going forward; and this is peculiarly evident when there is an intermitting pulse, as there is then a marked pause after the second sound; so that, in fact, there is nothing but the semilunar valves in action to produce sound at the instant." Further on he says: "I have thus proved that the second sound can be produced by nothing but the valves; and I have therefore shown the tension of the valves to be a sufficient cause of the first sound; and as "*nil frustra natura facit*," according to the laws of reasoning in physics, more causes than are true or sufficient are not to be assigned (Newt. Princip. lib. iii. Reg. Phil. 1), so I discard muscular action as the cause of the first sound."

With this Dr. Billing has ever rested satisfied, not caring for experimental demonstration for or against. I, who have been honoured with the close acquaintance and warm friendship of this truly gifted and excellent man, can pardon if not enjoy the hard blows he deals about him in his little work on "Diseases of the Chest." Thus he tells us that at least twenty-nine theories have been proposed in explanation of the heart's sound from the time of Laennec to 1852, but adds, "what a libel on the brains of the profession!" It was in 1852 that I became a member of the profession, since which time I have been "*terris jactatus et alto*," a little rest here, a good deal of unquiet there, still I have never ceased to reach if possible the one cause of the heart's sounds. Had my opportunities been greater, I verily believe these lectures would have been worthier of your audience; as it is, with all their imperfections, this I can confidently assert, that every observation and experiment has been repeated not once, but probably fifty, certainly twenty, times.

The second sound of the heart is generally, but not universally, attributed to tension of the semilunar valves.

Of the cause of the first sound there is less unanimity of opinion.

I will only mention four as being worthy of consideration.

1. Impulse of heart's apex against ribs.
2. Bruit musculaire.
3. Rush of blood.
4. Valvular tension.

1st. The impulse of the heart against the ribs.—Many prominent men, as Magendie, Carpenter, Skoda, Williams, Walshe, Kirkes, have assigned this as a cause for the heart's sounds, and we cannot wonder when, in this completed edition of "Arnott's Elements of Physic," the eminent author thus writes: "The heart alone is the rugged anomaly which, from before birth unto the dying moment, throbs unceasingly, and sends the bounding pulse of life to every part; and which, moreover, instead of being secured and tied down to its place is attached to the extremity of the aorta, like a weight at the end of an elastic branch of a tree, and every time that it fills the aorta, is thrown with violence, by the consequent sudden tendency of that vessel to become straightened, against the ribs, in the place where the hand applied, feels it so distinctly beating."

But are they right? I think not, for the heart never swings about as this description by Dr. Arnott would lead the reader to suppose. How can the heart leave the chest-walls unless something take its place? and what is to take its place except the lungs? Now, as the heart moves four times while the lung is moving once, it cannot be they—*ergo*, it can be nothing. But, say these authorities, and perhaps you yourselves, the heart is felt beating. It does give a blow. Gentlemen, let me use another of Billing's simple explanations of this apparent blow. Place the fingers on the masseter muscle and retain them there, then put the muscle forcibly in action, and although the fingers never leave the muscle nor the muscle the fingers, still the sensation of a blow will be perceived; but, as you see, it is simply the muscle assuming the shortened thicker form of contraction. So indeed it is with the heart, it never leaves the chest walls (excepting when, as in forced inspiration, the lung intervenes), the shortened form of contraction, as we saw in the exposed heart, giving rise to the apparent blow. Is it to be supposed also, according to these physiologists, physicians, and philosophers, that the heart is at the same time lifted up from and "thrown with violence" down upon the diaphragm? I can assure them that its impulse is felt more readily if the hand be placed beneath the diaphragm than outside the ribs. As to the first sound being produced by a blow of the heart against the ribs, this is again contradicted by the fact of the sound being heard more plainly after the ribs have been removed.

Valvular tension as the origin of the first sound. The evidence that exists to support this view rests, I believe, upon the experiments of Brackyn of Dublin and my own. But the amount of support that pathology lends to this view is very great. In fact, I doubt if any physician listening to the heart ever dreams of bruit musculaîre, but is certain that whatever sounds he hears are produced in the neighbourhood of or by these valves.

Brackyn's experiment is very ingenious, an account of which I quote from *The Lancet*, Nov. 24th, 1849: "The apparatus used consists of an ox's heart carefully dissected from the animal, so as to avoid injury to any of the appendages. To this I attached an apparatus consisting of a flanged tube, attached to the middle of the left ventricle, and piercing its wall, introduced through the auriculo-ventricular opening, to which was screwed externally another tube, with a flange also, so as to grasp the wall of the ventricle all round the tube, and render the junction air-tight; to the outer tube a bladder is tied. A free communication is thus established between the bladder externally and the cavity of the ventricle within. To the left auricle, a similar apparatus, but without flanges, was then attached by one trunk of the pulmonary veins, the rest being tied. Then, having tied all the offsets of the aorta, I tied a tube and bladder to its abdominal extremity; to the distal end of this a small stopcock was then tied, into which a brass pipe, fastened to the end of an india-rubber one, can be wedged; the other extemity of the caoutchouc pipe is finally attached to the distal extremity of the auricular bladder. There is thus completed an apparatus, permitting a mimic circulation through the left heart (it being sufficient for illustration), which may be conducted with perfect ease in the following mode.

Let the system be inflated with air through the orifice of the elastic tube next the stop-cock, when, having wedged back the stop-cock into the pipe and opened the cock, a rythmical circulation may be carried on by alternating manual pressure applied to each of the three bladders in succession (without removing any of the three hands applied), thus representing the successive contractions of auricle, ventricle, and aorta, with the natural attempts at regurgitation, which close both sets of valves in succession. Hereby a complete imitation of the normal sounds may be produced on either a very magnified or diminished scale, according to the force used in propelling the air.

These sounds, being produced without any muscular contraction or rush of blood, &c. must evidently be valvular, which can be further demonstrated by removing part of the apparatus (the auricular) so as to show the mitral valves in action synchronously with the first sound, or by introducing a wire cage prevent them closing on regurgitation when no sound follows ; above all, the first sound is as perfect as the second, the valvular origin of which is I believe undisputed. In fine, the illustration, though conducted with air, ought to be conclusive, inasmuch as a suddenly strained membrane, which gives a tympanic sound in air, will do the same in water also, as I have tried, but not so loudly."

At that time two of my fellow students, the present Dr. Waters of Liverpool, Fothergillian Medallist, for his important work on "The Anatomy of the Lungs," and Mr. Seacombe, Lecturer on Dental Surgery, at St. Mary's Hospital, London, went heart and soul into this heart business, and with me repeated Brackyn's experiments. Poor Mr. Brackyn, I have never heard of him since ; but how for a fortnight or so we worshipped him! for he had left his apparatus with us, and after we had verified all you have heard stated, we produced, to the great delight of our fellow students, all sorts of noises. We did not let the matter rest there. My friend Waters read a paper on the subject, which produced a great sensation amongst the students of St. George's. I supported him, and promised, if the debate were adjourned, to produce further experimental proof of the truth of the valvular theory. I instituted other experiments which I will presently detail. The great objection urged against Brackyn's experiment was that although such sounds might be produced in air, there was no proof that they would arise in water.

Although the experiments I made on the ass and dog in 1851 were regarded by most as more valuable than those of Brackyn, still I would not myself have them dissociated ; and in the winter of 1860 I instituted many experiments with an apparatus like Brackyn's, but many times more powerful, using a big forcing pump to represent the left ventricle.

Having filled a large tank with water, the whole system was submerged, and all the air expelled from the tubes, dilatations, and heart. By turning on and off the stopcocks I found that all was going on well. Only two or three times, however, on applying a stethoscope to the heart could I detect anything like the first sound, and then only when the pump was rapidly and forcibly used. I then cut away the auricle, and saw the valve perfectly closing the ventricle. At the instant of the pump's down stroke, a perceptible bulging of the valve towards the auricle took place, no fluid passing from the ventricle into the auricle.

A little reflection will show you how impossible indeed it is to imitate the manner in which the valves are made tense by the pressure of the blood. In life the walls of the ventricle are not yielding as in this experiment, neither is the valve: the former are powerfully compressing the fluid and through the musculi papillares keeping the valve stretched upon the fluid. We must then have recourse to vivisection.

Large dogs were obtained, and, as in my preceding experiments, the heart was exposed, and the circulation kept up with artificial respiration. A stethoscope being applied to the organ, the sounds were distinctly heard. The superior and inferior venæ cavæ were now compressed with bull-dog forceps, and the pulmonary veins by the finger and thumb; the heart continuing its action, a stethoscope was again applied, and neither first nor second sound was heard. After a short space of time the veins were allowed to pour their contents into both sides of the heart, and both sounds were instantly reproduced. The veins being again compressed, all sound was extinguished, notwithstanding that the heart contracted vigorously. Blood was again let in, and both sounds were restored. The sounds I have thus kept destroying and reproducing as long as I pleased, and in one or two instances the same heart has contracted vigorously upwards of an hour.

When first, in 1851, undertaking these inquiries in Mr. Lane's Anatomical Theatre, I was most willingly and effectually assisted by Mr. Blenkins, then one of our Lecturers on Anatomy; and by Dr. Waters, now Lecturer on Anatomy at the Liverpool Royal Infirmary School of Medicine. They were so satisfied with the theory and result of the experiment, that Mr. Lane, as the head of the school, requested me to repeat the experiment, in order that he might himself witness what I was about. Perhaps a more impartial and capable judge in such matters could not be found. The experiment was commenced, Mr. Blenkins compressing the pulmonary veins and vena cava superior, and I, by means of Liston's bull-dog forceps, the inferior cava: the contractions continuing well, Mr. Lane applied the stethoscope, and, to my great surprise, said he heard the first sound indistinctly, not so clearly as before the compression. I listened, and certainly there was the sound as he described it. Attention was then directed to our compression, Mr. Blenkins feeling certain he had secured the vena cava and pulmonary veins, and I re-applying the forceps, completely securing the vena cava inferior. Mr. Lane again listened, and said, "I still hear the sound with the contraction of the ventricles." We then left off the compression, allowing the blood to flow freely through the heart: Mr. Blenkins suggesting some anatomical irregularity as the cause of this singular contradiction to our former experiments. The result was that the vena azygos was found entering the right auricle by an independent opening; this vessel was then included with the inferior cava in the forceps, and the other vessels compressed as before. Mr. Lane then listened, and during the contraction of the ventricles heard no sound—the heart contracted vigorously, and yet he heard no sound. The veins were presently allowed to pour their contents into both sides of the heart, and both sounds became distinctly audible. After thus destroying and reproducing the sounds for the space of half an hour, Mr. Lane was perfectly satisfied.

The last experiment differs in kind and result from all those of Hope, Williams, and the Committee of the British Association. In this there is no rude interference with the mechanism of the heart's action; the cavities of the heart are untouched, there is no finger thrust into the auricle or ventricle, no hooking back of valves; in truth, not one source of sound substituted for another.

From my experiment, I think we have good reason for believing that both sounds depend upon the same cause, which is simply the backward pressure of the blood producing *tension*, first of the auriculo-ventricular (first sound), and secondly of the ventriculo-arterial valves (second sound).

In order to make it more certain, I have instituted a careful examination of the sounds elicited from hearts having different valvular apparatus, for it must follow that as the organ is muscular and receives and ejects blood equally, though with varying force, in reptile, bird, and mammal, if the sounds depend upon "bruit musculaire," or upon the passage of blood into or out of the heart, there will be little difference between them; but if, as my experiment tended to show, then the sounds should vary with the size and structure of the valves and lengths of the cordæ tendineæ. The results I will place before you in my next lecture.

Lecture III.

Examination of the Valves and Auscultation of the Heart of Reptiles.—In the *Puff-adder* the auriculo-ventricular valves are attached to the under surface of the septum auricularum, and are free laterally, with the exception that delicate processes like cordæ tendineæ pass from their borders to the sides of the ventricle. Water injected from the auricles closes these valves, which are then convex on their upper, concave on their under surface.

The vessels arising from the ventricles are guarded each by two semilunar valves.

It may well be supposed that I have not listened to the heart of the puff-adder, but I have had my ear for a long time over the beating heart of a very large species of python, and Guinea rock snake, in their dormant condition, and when held down by men in a most lively and *noli me tangere* state, twisting, hissing, and micturating, but all to no purpose, so firmly had my assistants secured them. Here I will take the opportunity of thanking the Council of the Zoological Society of London for having given me all the privileges of a Fellow, Dr. Sclater, for offering me every facility for enquiry, and Mr. Bartlett, for having so frequently assisted me in my experiments.

On the 31st October, 1860, after many failures, I heard the heart's sound in a very large python, under great excitement. It is impossible to describe sounds, but taking those of man as standards of comparison, I will say, that except during the most perfect stillness, they were inaudible, but when heard, the first sound was distant, dull, and short, and that the second did not differ much from it. The number of pulsations was from twenty-six to thirty per minute.

The Alligator.—The right and left aorta and pulmonary artery are guarded each by two semilunar valves—the auriculo-ventricular openings are each furnished with large semilunar valves, one of them to the right of the ventricle being as in the right ventricle of the bird, muscular.

Not a trace of sound could I discover although I many times listened but in vain.

The Snapping Turtle.—The auriculo-ventricular valve is very thick, being attached anteriorly and posteriorly to the inner surface of the ventricle, and above to the under surface of the septum auricularum. It opens laterally from each auricle into the common ventricle, and is slightly larger than the openings it has to close.

Not the slightest sound to be heard.

The Tortoise.—Nothing audible.

Edible Turtle.—The auriculo-ventricular valve differs from that in the snapping turtle, in having tendinous cords attaching it to the ventricle, chiefly on the right side. In other respects the heart is the same.

Number of pulsations ten to twelve per minute.

In this case I had removed the plastoon so as to apply a small stethoscope directly to the heart; but although I listened for some hour and a-half, and the force of the ventricular contractions were frequently very strong, I could hear no sound whatever. I then removed the heart from the body, and it continuing to contract as forcibly as before, I again listened and heard with every contraction of the ventricle a distinct blowing sound. Here I was puzzled; it was the "bruit musculaire" of the committee of the British Association? not at all, it was the air passing into and out of the ventricle with each contraction and falling open of its walls, for upon ligaturing the right and left aorta and pulmonary artery it ceased entirely, although the heart continued to contract for hours after.

Examination of the Valves and Auscultation of the Heart in Birds.—The right auriculo-ventricular opening is guarded by two partly fibrous but chiefly muscular valves. The left auriculo-ventricular valve is fibrous as in mammalia, but the cordæ tendineæ are short and pass from three principal papillary muscles, which, however do not stand out separately from the walls of the ventricle. Aorta and pulmonary artery guarded by three semilunar valves. I pass round the heart of the common goose, in order that you may better see than I can describe. I am sorry I cannot show you the hearts of all the animals I allude to; I had collected together and dissected a large number, when just on the point of leaving England they were sold by mistake with other things, pickle and blacking bottles, by the cook to the ragman, who must have made a good bargain from the spirit they contained. Here are, however, a few water-colour drawings executed from my dissections by a younger brother; they show very well the left valves.

The pulsations in the *Eagle* are when the animal is quiet a little over 100, but on the least excitement, even of an instant's duration, they become very frequent. The bird I so often examined was a very fine specimen of *aquila audax* an Australian bird. With the keeper he was quiet, and he soon began to know me, so that by the keeper taking him in his arms and holding his head slightly on one side, I have had my head at his chest for twenty minutes at a time.

I could never detect any difference between the first and second sound; that is to say, that if in man the sounds can be tolerably well imitated by pronouncing the words lub, duc—in the eagle they would be duc, duc.

The Ostrich.—The right auriculo-ventricular opening is guarded by two valves, one large the other small, composed internally of muscular fibres, externally of fibrous tissue, which seems to give shape to the valve.

The left auriculo-ventricular valve is exceedingly strong, the cordæ tendineæ being an inch in length, and resisting all my efforts to break them. The left ventricle is eight-tenths of an inch in thickness.

Aorta and pulmonary artery guarded each by three semilunar valves.

After many interviews I became tolerably intimate with four young ostriches. The pulsations are from between seventy and eighty per minute. The sounds differ little from those heard in man, with the exception that the first is more muffled.

The Apteryx.—Professor Owen, in the second volume of "The Zoological Transactions," in describing the anatomy of the apteryx, says: "The principal deviation from the ornithic type of the structure of the heart is presented in the valve at the entry into the right ventricle. This is characterised in birds by its muscularity and its free semilunar margin. In the apteryx it is relatively thinner, and in some parts semi-transparent and nearly membranous; a process, moreover, extends from the middle of its free margin, which process is attached by two or three short cordæ tendineæ to the angle between the free and fixed parietes of the ventricle. We perceive in this mode of connection an approach in the present bird to the mammalian type of structure analogous to that which the ornithorhynchus, among mammalia, offers, in the structure of the same part, to the class of birds: for the right auriculo-ventricular valve in the ornithorhynchus is partly fleshy and partly membranous." By "membranous" Professor Owen means what we human anatomists commonly call tendinous, as will be seen from his following remarks: "There was nothing worthy of note in the left ventricle, or in the valves interposed between it and the left auricle; the two membranous flaps presented the usual inequality of size characteristic of the mitral valve in birds." In addition to what has been quoted from Professor Owen's paper, I will add, that from the wall of the right ventricle proceed two distinct carneæ columnæ, from which the chordæ tendineæ pass to the tendinous flaps of the valve. The left ventricle contains carneæ columnæ of the mammalian type, and disposition. The left auricular appendage is nearly, if not quite as large as that of a mammal. In fact here is a bird with a heart nearly identical in structure with that of a child or of a dog.

As stealthily as thieves to their business, or as Tarquin to Lucrece, did the keeper and I approach the apteryx by night. He leading the way. Having secured her in his arms she became easily pacified, and unseen by her I placed my stethoscope to her chest, broad, without a keel, and listened for some time. Never was there a prettier result. The sounds were not like those of the eagle, for the first sound had resumed its mammalian length, and lub, duc was once more heard. The pulsation averaged 110.

On my next visit to the apteryx I made use of a dark lantern, but she became aware of my presence and I failed to approach; I remarked, however, her mammal-like gate when removing from me, and seen from the side she had the appearance of a quadruped wanting the forelimbs.

On my third visit, for I wished still to verify my first observations on this marvellous being, whose deficiency of sternum renders it so easy for auscultating the heart's sounds, we succeeded in finding her asleep; quietly the keeper threw a handkerchief over her head, and raised her in his arms. She evidently awoke, but remained perfectly still. I listened for some time, the sounds being exactly as I have before described them. I had my stethoscope on one and another part of her chest for upwards of a quarter of an hour.

Examination of the Valves and Auscultation of the Heart in Mammalia.—Nearly all have valves (I pass round drawings of many), and heart sounds alike agreeing with those of man, but the first is modified by the thickness and strength, or thinness, of the auriculo-ventricular valves and cordæ tendineæ. One example will suffice.

The Kangaroo.—The right ventricle is peculiar in that the pulmonary artery does not spring from it till it has ascended above and got to the left of the aorta. But the left auriculo-ventricular opening is guarded by a valve connected with which are many long cordæ tendineæ. The ventricle is very thick (pass round drawing.) The first sound is of a ringing character.

Deductions to be drawn from these Experiments and Observations.—1st. Brakyn's experiment proves the sufficiency of valvular tension to produce sound.

2nd. My own experiment is thus spoken of by the writer of an article entitled "Cardiac Physiology," in *The British and Foreign Medico-Chirurgical Review*, April 1860, associating my little pamphlet with the writings of Milne Edwards, Barth and Roger, Beau, Carpenter, and Paget, he has the following remarks:—"Of the truth of the facts stated by Dr. Halford, we have the testimony of many on whom we can rely, and from repeated examinations we can add our own. . . . . We have performed the experiment ourselves under conditions of absolute silence in a room with few attendants, and in the quiet of the night; we feel, therefore, that we are in a position to speak confidently of our own observations."

You will find also in this recent work on Diseases of the Chest, by Dr. Fuller, that the author "bears testimony from personal observation" to the accuracy of my statements.

I feel now justified in arguing from my experiments as from facts; but before doing so, I will endeavour in as short a time as possible, to get rid of two other causes which have been assigned for the production of the first sound of the heart, viz., "bruit musculaire," and "rush of blood into and out of the heart."

Bruit Musculaire.—You are aware that a low rumbling sound is heard when the ear is applied to the contracting muscles of the thumb, and the same may be heard at night on putting the masseter and temporal muscles into action. Again, in some cases of disease of the brain, when the muscles of the limbs are thrown into violent action, this sound is undoubtedly heard. Its cause has been attributed to vibrations produced in the muscle itself, but you must remember that an exactly similar sound can be produced by pressing a handkerchief or the corner of the pillow against the ear, or by slightly pressing the tragus into the meatus, another sharp sound being developed by its sudden disengagement on the removal of the finger. That it does not seem due to muscular contraction appears certain from this one fact, which I have frequently verified, and which was I think first mentioned by the late Dr. Bellingham of Dublin, viz., that this same sound, heard during the contraction of the masseter and temporal muscles, is only heard by the ear resting against the pillow. And again, you may satisfy yourselves that compression of the air within the external meatus is necessary; for, if you sit up in bed, and simply contract the masseters, no sound is heard; but applying the palms of the hands so as to close the orifices of the ears, it is immediately heard. By some it is considered as an acoustic delusion, probably, I suppose, in the same way that pressure upon the retina produces the sensation of light; so also may these impressions on the acoustic nerve give rise in the brain to the perception of sound. I confess to you, it is a very difficult subject to explain. But that it does not give rise to the first sound of the heart, in fact is not associated with the heart's movements, I think I can prove.

In the first place I must tell you, that the opinion is based upon the most wretched experiments ever conceived, and supported by arguments of the homœopathic kind. The experiment was that of cutting out the heart, putting a finger into the ventricle after the valves were destroyed, and then hearing a sound. So, you will remember, I heard the same after removing the turtle's heart, but that, upon ligaturing the vessels leading from it, all sound ceased, although the heart contracted forcibly for hours after. Their arguments were, that more muscle produces less muscular sound, and *vice versâ* lessen the cause increase the effect, which my old schoolmaster would have said was absurd, and thereon have whipped me soundly. That it is not the cause of the first sound seems proved by my experiment of shutting off the blood, when, although the heart's contractions were forcible enough to raise the listener's head, no sound whatever was heard. Dr. Fuller, in his most recent volume, confirms this. He says :—" The first sound wholly ceased, although the contractions were forcible enough to jolt the head placed on a stethoscope applied to the heart, and the eye could detect little difference between the force of their contraction when the blood was admitted into the heart, and when it was excluded." I am glad of this gentleman's testimony as that of a most painstaking and truth-seeking physician.

When auscultating the heart of the turtle, you will recollect that, after carefully searching for hours, I heard not the slightest sound, although my stethoscope was upon the heart itself. It may be objected to this, that the contractions were too slow to produce sound; but they were incomparably more rapid than is the contraction of the muscles of the ball of the thumb or the masseter, to produce the so-called bruit musculaire. Again, why should there be such a difference in the character of the first sound in the animals I have mentioned, all their ventricles being muscular? Especially, why should the first sound of the heart of the eagle differ from that of the apteryx? and why should the latter be like the same sound in the dog and child?

Again, I have frequently heard the sounds of the fifth month fœtal heart, the liquor amnii being an excellent conductor of sound; but as Dr. Fuller remarks, " If the contractions of the small muscles are productive of sound, it is difficult to understand why the contractions of much larger muscles, such as exist in the auricles of an adult, and still more so in the auricle of a horse or an ox, should not be attended by sound, and yet experience proves conclusively that they are not so."

Lastly, in hypertrophy of the walls of the ventricles, the sound is weakened, but when the walls are thin it is louder and clearer, which is diametrically opposed to the notion of *bruit musculaire* being the cause of the first sound.

Rush of blood out of the heart.—If this be the cause of the first sound, why could I not hear it in the turtle, with the heart so long exposed? I listened expressly for this cause, but heard none. Why is it not heard in every reptile? why so much difference in the same sound in birds and quadrupeds? why such a similarity to the sounds of the latter to those in man? Blood is rushing out in all in the same manner through orifices much alike, and guarded by valves of nearly the same form and number; but in all, as I believe, the rush is as noiseless as in the turtle. In the experiment with the bullock's heart, to which was attached quite three feet of the aorta, and this continued on by an elastic tube of a like diameter, I failed, upon using the greatest force the pump would give, to produce any sound, either at the aortic orifice, along the aorta, or in the elastic tube. I tied the aorta with thick string so as nearly to obliterate its canal, but the passage of water could not be heard. I modified this in many ways, but could produce no bruit, neither did pressure cause any sound.

The friction, then, sufficient to produce this sound does not exist. I have shown you also that in health at the instant the ventricle commences its contraction the semilunar valves open; they are moved onward as silently as the leaves of a water-plant by the stream; the column of blood on their arterial surfaces moving along simultaneously with the attempted compression of the blood in the ventricles.

The facts upon which I would lay the greatest stress, as pointing to *valvular tension* alone as being the causes of both sounds of the heart, and which have all been placed before you, are the following :—

1. That the vibrations of the valves are audible, as in Brakyn's experiment.

2. That, when the valves are prevented from being acted upon, as in my own experiment of shutting off the blood all sound what ever ceases.

3. That, when the chordæ tendineæ are long and of unequal lengths, and the cusps of the valves of uneven size, the vibrations are uneven, the first sound long, the second short, as in the mammalian heart, and in that of the ostrich and apteryx among birds.

4. That when the chordæ tendineæ are short and of uniform length, and the flaps of the valve of more even size, and moreover limited to one ventricle, as in birds, the first sound, like the second, is short and clear.

5. That in reptiles, unless greatly excited, as in a writhing python, no sound is heard, and that then, owing to the absence of chordæ tendineæ and to the limited vibration of the auriculo-ventricular valve, there is little, if any, difference between the first and second sound.

6. That in all cases, the nearer you get to the valves, the more audible is the sound, as in removing the chest-walls of an animal, and in disease, when the thinner the walls of the ventricles, the louder and clearer does it reach the ear.

7. That, immediately the valves become altered, alterations of the sounds ensue. This is well shown in this water-colour representation of the first stage of endocarditis, taken from my friend's and former colleague's Dr. Richardson's work, "On the Coagulation of the Blood." You will observe the auriculo-ventricular valves are œdematous, the first sound was nearly lost, the vibratory power of the valve being affected. Greater alteration, as in some of the specimens before you, is attended with greater alterations of sounds.

In conclusion, the sum of these lectures is soon expressed.

The auricles produce such a state of tension in the ventricles as that the force of the latter is expended in urging on the circulation alone.

The ventricle has no power of filling itself, neither has the auricle, and that to the force of the latter is due the distension of the ventricle, and the closure of the auriculo-ventricular valves. Were it not so, no such tension of the arterial system could exist as we have seen to be the case in health.

Whenever the ventricle has first to close the auriculo-ventricular, previously to opening the ventriculo-arterial valves, as in mitral disease, this arterial tension is destroyed, the capillary stream is sluggish, the venous current languid, and at the heart, indeed, thrown back.

And we have great reason to believe that the first sound is caused by the vibrations produced by the sudden tension of the auriculo-ventricular valves and of their tendinous strings, and the second by a similarly sudden tension of the ventriculo-arterial valves, minus strings.

The following table will, I hope, assist you in these studies.

ANALYSIS OF ONE COMPLETE ACTION OF THE HEART.

Time occupied, say, one second.

Rhythm.	Time.	Order of Occurrences.	Muscular action taking place.
LAST PART OF PAUSE.	$\frac{1}{8}$	Auricles contracting. Ventricles distended with blood by the force of the Auricles. Auriculo-ventricular valves closed.	CONTRACTION OF AURICLES.
FIRST SOUND AND IMPULSE.	$\frac{1}{2}$	Ventricles contracting on their contents; tension of the auriculo-ventricular valves and chordæ tendineæ; blood passing into and increasing the calibre of the Aorta and Pulmonary Artery. Auricles relaxed, permitting the flow of blood into them from the venæ cavæ and pulmonary veins.	CONTRACTION OF VENTRICLES.
SECOND SOUND.	$\frac{1}{4}$	Ventricles relaxing; auriculo-ventricular valves and chordæ tendineæ no longer tense; small quantity of blood passing into Ventricles. Auricles filling with blood; calibre of the Aorta and Pulmonary Artery diminished by the elastic reaction of their coats on the contained blood, producing forcible closure and tension of the semilunar valves.	NONE.
FIRST PART OF PAUSE.	$\frac{1}{8}$	Ventricular fibres, auriculo-ventricular valves, and chordæ tendineæ fully relaxed. Auricles distended with blood. *Here the requisite condition of both Auricles and Ventricles is arrived at for a new set of actions.*	NONE.

FINIS.

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