The movements, structure, and sounds of the heart / by Francis Sibson.

Contributors

Sibson, F. 1814-1876.
Royal College of Surgeons of England

Publication/Creation

London : Pardon & Son, printers, 1869.

Persistent URL

https://wellcomecollection.org/works/tbtdjyxz

Provider

Royal College of Surgeons

License and attribution

This material has been provided by This material has been provided by The Royal College of Surgeons of England. The original may be consulted at The Royal College of Surgeons of England. where the originals may be consulted. This work has been identified as being free of known restrictions under copyright law, including all related and neighbouring rights and is being made available under the Creative Commons, Public Domain Mark.

You can copy, modify, distribute and perform the work, even for commercial purposes, without asking permission.

wellcome collection

Wellcome Collection
183 Euston Road
London NW1 2BE UK
T +44 (0)20 7611 8722
E library@wellcomecollection.org
https://wellcomecollection.org

THE

MOVEMENTS, STRUCTURE, AND SOUNDS

16.

OF

THE HEART.

REPRINTED FROM THE LAST FASCICULUS OF "MEDICAL ANATOMY."

With the Dedication and Preface of the whole Work.

ROYAL COLLEGE OF SURGEONS OF ENGLAND
-3 JUN 19

BY

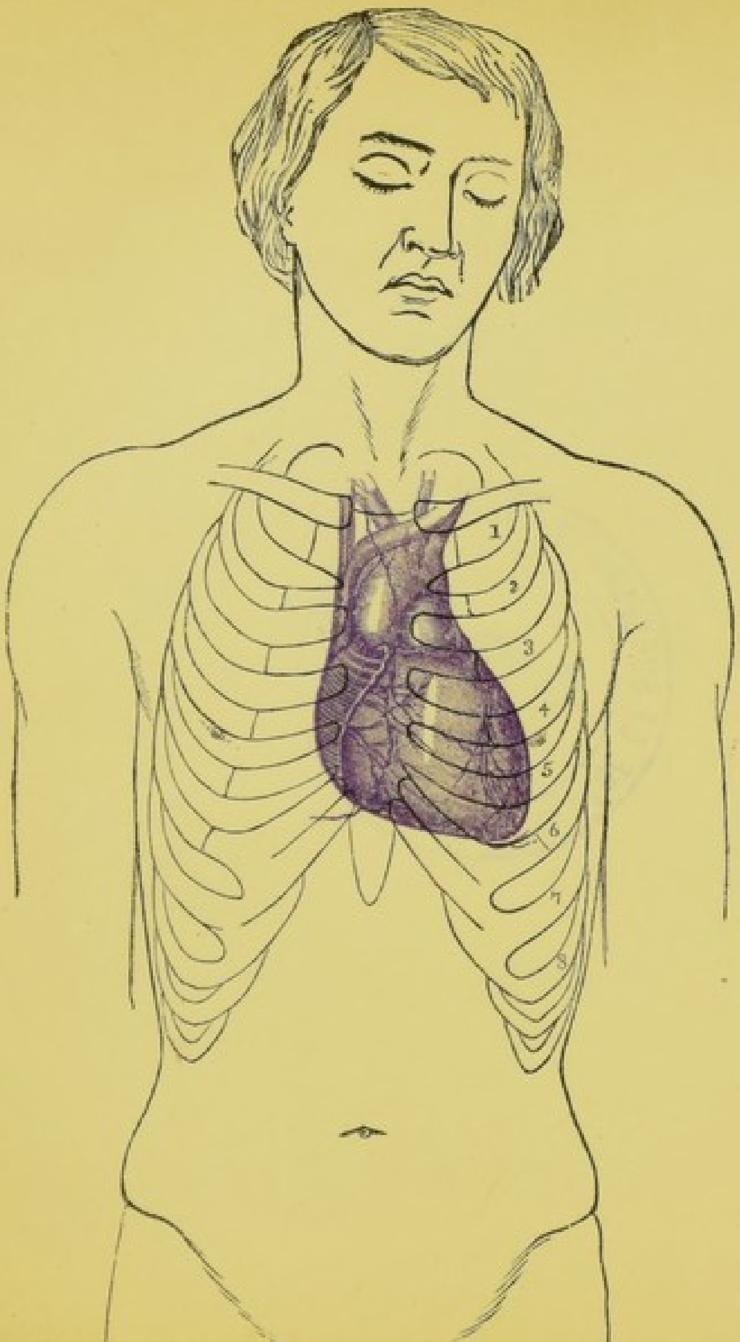
FRANCIS SIBSON, M.D. LONDON AND DUBLIN, F.R.S.,

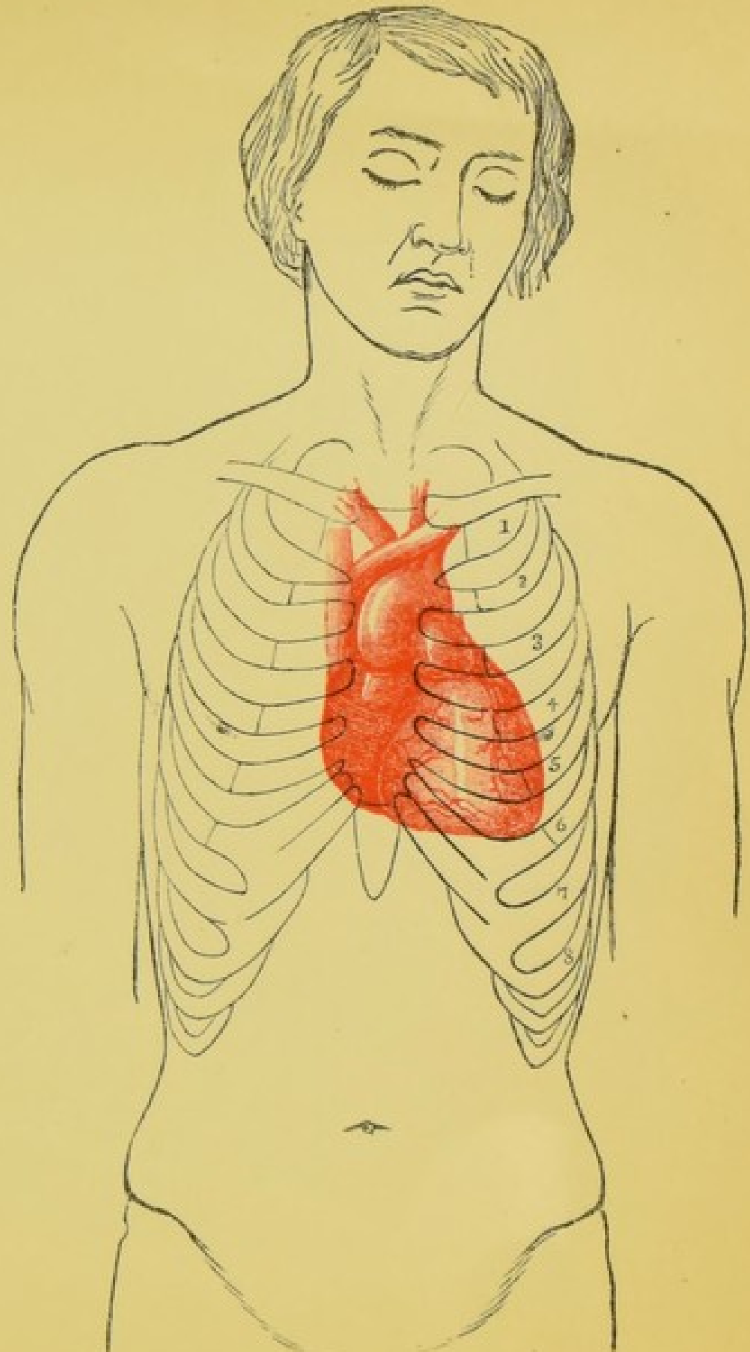
Fellow of the Royal College of Physicians; Senior Physician to, and Lecturer on Clinical Medicine at, St. Mary's Hospital; Member of the Senate, and late Examiner in Medicine, of the University of London.

LONDON:
PARDON & SON, PRINTERS, PATERNOSTER ROW.

1869.

COLLEGE OF SURGEONS OF ENGLAND
3 JUN 99





THE

MOVEMENTS, STRUCTURE, AND SOUNDS

OF

THE HEART.

REPRINTED FROM THE LAST FASCICULUS OF "MEDICAL ANATOMY."

With the Dedication and Preface of the whole Work.

ROYAL COLLEGE OF SURGEONS OF ENGLAND
-3 JUN 19
LIBRARY

BY

FRANCIS SIBSON, M.D. LONDON AND DUBLIN, F.R.S.,

Fellow of the Royal College of Physicians; Senior Physician to, and Lecturer on Clinical Medicine at, St. Mary's Hospital; Member of the Senate, and late Examiner in Medicine, of the University of London.

LONDON:
PARDON & SON, PRINTERS, PATERNOSTER ROW.
1869.

TO

WILLIAM STOKES, M.D., D.C.L., LL.D., M.R.I.A.,

PHYSICIAN-IN-ORDINARY TO THE QUEEN IN IRELAND; REGIUS PROFESSOR OF PHYSIC IN THE UNIVERSITY OF DUBLIN;

THIS WORK IS

DEDICATED BY

THE AUTHOR.

Digitized by the Internet Archive
in 2016

https://archive.org/details/b22459364

PREFACE.

Descriptive and Surgical Anatomy are well taught in our medical schools, but the practical teaching of Medical Anatomy, or the knowledge of the relative position of the internal organs, is neglected. Indeed, on the present plan and with the existing means, it is impossible to teach that subject, which is as important for the physician as Surgical Anatomy is for the surgeon.

When a body is prepared for the dissecting-room, the arteries are injected from the arch of the aorta, to the injury of the great vessels. The superficial dissection of the body precedes that of the internal organs; and by the time those parts are reached, they have lost that freshness which is so necessary for their successful study. Generally, indeed, they are then in a state of decay, and their relative position has been altered.

It is impossible, therefore, that the relative anatomy of the internal organs can be taught in the dissecting-room: but the dead-house affords all the materials for their study.

It falls to the teacher of pathology to make the *post-mortem* examinations; and it would be easy for him to give practical demonstrations of the contents of the chest and abdomen in health as well as in disease. It ought, therefore, to be one important duty of that officer to teach the topographical anatomy of the healthy viscera on the dead body. Afterwards he might take the pupils into the wards or the out-patient room, and indicate to them, on the living body, the varying position of the organs during the healthy exercise of their functions. He would at the same time train them to a knowledge of the physical signs furnished by the healthy viscera. Under his tuition, the student ought to be as familiar with the position and movements of the organs as if he saw them stripped of their parietes and exposed to view.

Until this be done, it is self-evident that the teaching of clinical medicine must be imperfect.

The student naturally rivets his attention upon the subjects of his coming examination to the exclusion of everything else. He knows that his acquaintance with the anatomy of the limbs and the head and neck will be carefully tested, and that anatomy he studies. He also knows that he will not, as a rule, be examined on the bearings of, say, the great vessels, the heart or lungs in relation to the walls of the chest, or on the movements of those parts during life, or on the signs of their healthy functions. The result is, that the student does not seek to acquire, and has not the opportunity of acquiring, that kind of knowledge of which I have just spoken.

If the examiner were to require the candidate to point out accurately, on the exterior of the living body, the corresponding position and the movements of the internal organs, and the signs by which they are distinguished in health, the teacher would speedily discover the method whereby he could convey the desired information, and the pupil would eagerly avail himself of it.

This work, which consists of a series of illustrations of Medical Anatomy, is founded upon the Author's paper in the *Provincial Medical Transactions* for 1844 on the situation of the internal organs. That paper, in the preparation of which he received important aid from his friend, the late Dr. Hodgkin, was the result of numerous observations made by himself in the wards, and, more especially, on the dead body.

In 1848, Conradi published a valuable memoir on the position and size of the thoracic and abdominal organs. In that work, which has been translated into English by Dr. Cockle, with a view to publication, Conradi gives the topography of the internal organs as laid down by the Author in the paper just referred to. He then describes his own numerous researches by means of percussion on the living body, and compares them *seriatim* with the Author's observations on the dead.

Those researches substantiate in the main the anatomical conditions defined by the Author.

The Illustrations in the earlier and larger portion of this work represent the parts exactly as they were found after death. The front, the sides, and the back of the frame, from the surface to the deepest parts, are depicted in succession.

In making these drawings, the Author employed mechanical aids, described in pages 1 and 24, by means of which he has been able to represent with precision every organ, with its external and internal relations, at each stage of the dissection.

The exact topography of the parts contained in the body, from its circumference to its centre, is thus presented.

Accurate representations of the exterior and interior of the dead body give, however, no adequate idea of the movements and varying position of those parts during life. At the time of, and after death, indeed, the heart and great vessels and the lungs shrink upwards, the diaphragm ascends, and the stomach and liver and the subjacent organs are partially raised.

In looking, therefore, at all drawings that are literal transcripts from the parts contained in the body after death, due allowance must be made for those changes which take place during and after the departure of life.

To supply, as far as possible, this deficiency, and to represent and describe the organs in motion as they are during life, the later portion of the work is devoted to the movements of respiration, and to the movements, structure, and sounds of the heart.

The part relating to the movements of respiration developes and illustrates the papers by the Author on the "Mechanism of Respiration" in the *Philosophical Transactions* for 1846, and on the "Movements of Respiration in Health and Disease" in the *Medico-Chirurgical Transactions* for 1848.

The description of the movements, structure, and sounds of the heart is derived from numerous original experiments, observations, and dissections made by the Author during the last seven or eight years. The peculiar methods employed by him in pursuing those inquiries are described in pages 1-9, 21, 23, and 30.

These researches have been a work of great labour and deep interest to the Author. He believes that they represent important physiological truths, and he trusts that they may be useful to those who are engaged in the study of the vital phenomena of respiration and circulation.

59, BROOK STREET,
January, 1869.

CONTENTS.

ON THE MOVEMENTS, STRUCTURE, AND SOUNDS OF THE HEART.

THE observation of the heart in the dead body gives a very inadequate idea of its intrinsic movements and varying position during life. The organ after death almost always shrinks upwards, and as the last effort is one of expiration, the diaphragm and the heart and great vessels are unduly raised.

My last commentary contained a description of the movements of respiration, and included an account of the effect of inspiration in lowering the heart and great vessels, and of expiration in raising them.

In this concluding part, I shall endeavour to describe and illustrate the heart in motion, and give an account of the structure of the organ, especially as regards the muscular and valvular apparatus by which its movements are accomplished.

THE MOVEMENTS OF THE HEART.

My first experiments on the movements of the heart were made upon the ass, in the year 1843, in Nottingham, when I was assisted by Mr. Shepperley. The animal was rendered apparently lifeless by means of the Wourali poison, with which I was kindly supplied by my friend, the late Mr. Waterton; and the beating of the heart, and the circulation of the blood were maintained in full force, by the aid of artificial respiration, for a period of four hours.

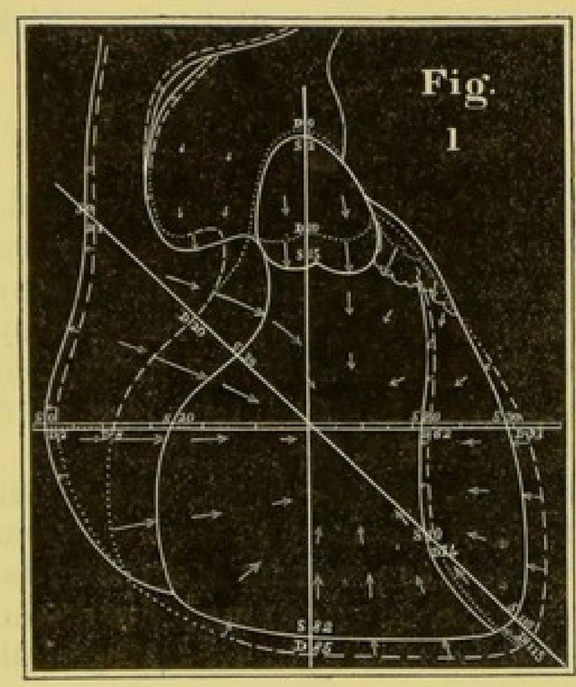
My recent experiments, in which I was assisted by that excellent observer, Dr. Broadbent, were performed on the dog and the ass, when rendered unconscious by chloroform, which was given by Mr. Edwards. Following the plan of Dr. Halford, we watched the movements of the heart through the pericardium, which was rendered almost transparent by stripping off its fatty covering.

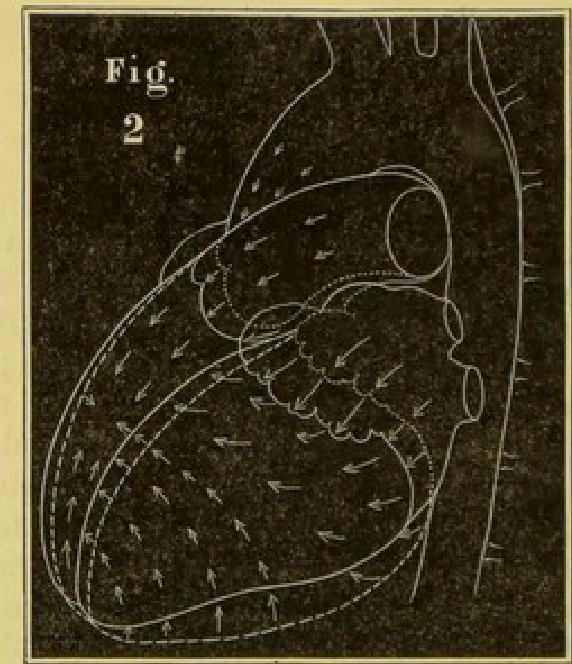
In order that the successive movements of the heart might be observed with accuracy, a millimetre measure was stretched across the gan, as in Fig. 1, and its precise position in relation to the measure was noticed, first at the end of the diastole, and then of the systole.*

* The systole and the diastole of the heart are represented in Plate XXI., and in Figs. 1 and 2. In those figures the outlines of the cavities of the heart and the great vessels are indicated—at the end of the systole of the heart, by continuous lines, at the end of the diastole, by interrupted or dotted lines. The dotted are less accurate than the interrupted lines. The systolic movements are everywhere shown by arrows, the extent of the movements being marked by the length of the arrows. It is more difficult to watch and measure the movements of the heart at the side than at the front. The side view, Fig. 2, is therefore not so accurate as the front view, Fig. 1. I believe, however, that both figures very fairly represent the movements of the heart.

The heart, when in full action, presents to the eye the most remarkable contrasts in the size, position, colour, and form of its various cavities and great vessels. When the ventricles contract, they do so with a twisting movement, their walls become rigid and corrugated, their apex and base approximate, the descent of the base being greater than the ascent of the apex, and the arteries and veins on their surface become prominent and tortuous. The auricles become swollen with blood, and seem to push before them the retreating ventricles at the base. The great arteries are distended and lengthened, being apparently drawn downwards at their origin, by the contracting ventricles.

When, however, the ventricles expand, the aspect of all the parts is reversed. The ventricles enlarge in every direction, but especially towards the base. Their walls are flaccid, swollen, and smooth; and the arteries and veins on their surface become straight and small. The auricles shrink, becoming pale and wrinkled, and are in great part replaced by the ventricles, into which they empty their blood. The great arteries lessen in size and shorten, and ascend at their origin, being apparently raised by the upward enlargement of the ventricles.





Owing to the reciprocal contraction and distention of the ventricles on the one hand, and the auricles and great vessels on the other, the whole fluid contents of the heart and great vessels are obviously nearly the same in amount during the systole as during the diastole. The distribution of the blood, however, is different, its quantity being greater in the ventricles at the end of the systole, in the auricles and great vessels, at the end of the diastole.

The Systole of the Heart.—The contraction of the right ventricle, owing to its position at the front of the heart, and its consequent complete exposure, is marked and vigorous. Its whole right margin (Fig. 1), at the junction of the ventricle to the auricle, moves extensively from right to left; while its left margin, at the septum, moves to a comparatively slight degree from left to right. At the same time, the top of the ventricle, at the origin of the pulmonary artery, descends, while its whole lower border, where it rests on the diaphragm, ascends. These various movements converge upon a space or point of rest, situated about the middle of the ventricle, but comparatively near the septum. This point of rest corresponds with the attachment of the anterior papillary muscle.

The right auricle and vena cava are distended, and the pulmonary artery is enlarged and lengthened simultaneously with the contraction of the ventricle. The auricle, which just before was pale and wrinkled, becomes plump, glistening and purple; and its auricular portion and left edge move rapidly inwards, and to the left, so as to replace the ventricle. The movement of the auricular portion is remarkable. It suddenly enlarges and becomes purple, its tip moving from the right to the left edge of the sternum, at the level of the third costal cartilages.

The contraction of the left ventricle is only visible along its left border, including the apex, where it moves forwards and to the right, the apex having, in addition, a revolving movement upwards. The appendix of the left auricle, which is scarcely visible during the diastole, distends during the systole, and moves rapidly forwards and downwards, so as to replace the retreating ventricles, and fill up the angle between them and the pulmonary artery.

When we remove the left ribs, and look at the heart from the left, so as to obtain a view of it in profile (Fig. 2), the animal lying upon its back, we see that the whole ventricle moves forwards during the systole; the posterior wall advancing much more than the anterior; and that the base of the ventricle descends while the apex ascends, so that apex and base approximate. It is difficult to fix upon the precise point or zone of rest of the ventricular walls towards which the apex, on the one hand, ascends, and the base, on the other, descends; but it is somewhere about the middle of the ventricle—nearer, perhaps, to the apex than the base. This region of stable equilibrium corresponds to a similar point of rest in the papillary muscles. Owing to this arrangement, the ventricles and the valves adjust themselves to each other throughout the whole period of the ventricular contraction.

The left auricle, like the right, becomes swollen during the systole; when it descends and advances, so as apparently to displace the base of the left ventricle. That I might discover whether the displacement of the base of the ventricle was really caused by the distension of the auricle, I cut off the supply of blood to the auricles by tying the venæ cavæ. Both auricles soon became empty, their walls shrinking inwards. Both ventricles became smaller; but they still contracted forcibly during the systole, the base approximating to the apex, though to a less extent than when the blood circulated freely through the heart. It is, therefore, evident that the descent of the base of the ventricle during the systole is intrinsic, and not due to the displacing effect of the distending auricle, though it may be influenced by that agency.

When the left ventricle propels its contents into the aorta, its arch is distended and lengthened, and its origin, like that of the pulmonary artery, descends. The arch of the aorta enlarges both in length and breadth, and becomes tense and rigid. Its lateral enlargement is small, but its elongation is considerable, as Skoda remarks in his work "On Auscultation and Percussion," translated by Dr. Markham, page 159. There are two agencies at work in common, each of which would necessarily cause the descent of the origin of the aorta. The ventricle, by its contraction towrds its own centre, pulls down the artery at its point of attachment; and the blood acting from within, distends and lengthens the vessel, and pushes downwards the origin of the artery.

Since the auricles and great vessels enlarge in all directions during the systole, they not only descend into the place just left by the retreating ventricles, but they also enlarge outwards. The result is, that there is a greater amount of blood at the base of the heart, including the great vessels, at the end of the systole than at the end of the diastole. Since, however, during the systole, the ventricles empty themselves, the increase of the blood at the base is probably balanced by its diminution towards the apex. During the period of rest which follows the dilatation of the ventricles, the blood flows from the veins into the auricles. At its conclusion, therefore, when the auricle contracts, just before the ventricular systole, the amount of blood in the heart and great vessels is greater than at any other time.

The Lever Movement of the Ventricles during the Systole.—In all our early experiments, which were performed when the animal lay upon its back, the apex and the anterior walls of both ventricles invariably advanced during the systole. On one occasion the creature was turned upon its side, when I noticed that the anterior walls of the ventricles, instead of advancing, actually receded during the systole. I subsequently repeated this experiment again and again, in the same and in different animals, and invariably with the same result. When the dog lay upon its back, the anterior walls of the ventricles always moved forwards; when it was turned on the side, they either fell backwards or were stationary. It occurred to me, that if this advance of the apex and front of the ventricles, when the animal was lying upon the back, were due to the fulcrum afforded to the base of the left ventricle, the walls advancing, as it were, by a lever movement, that the same effect would be produced if it were lying upon its side, by inserting a fixed prop or fulcrum behind the base of the left ventricle. And it was so. When I introduced a flat ruler, or my finger, behind the ventricle, so as to give it a fixed support, when the dog lay on its side, the anterior walls, which just before were stationary or receded during the systole, now advanced, just as when it lay upon its back, though scarcely to the same extent. On the frequent repetition of this experiment, which always excited my admiration, the same result followed. In order to ascertain how far this effect was due to the fluid contents of the ventricles, and how far to the rigidity of their muscular walls, I cut off the supply of blood by tying the venæ cavæ. The effect not only remained but was intensified. When, in this state, the animal lay on the back, or the prop was inserted when it lay on the side, the anterior walls advanced more than when the blood circulated freely. It was evident, therefore, that this lever movement forwards was due to the intrinsic muscular contraction and rigidity of the walls themselves, and in no respect to the blood contained in the cavities. That I might discover, if possible, the precise part of the muscular structure on which this lever movement forwards depended, I removed in succession the anterior wall of the right ventricle, the septum, and the papillary muscles of the left ventricle; and I found, contrary to my anticipation, that after each successive removal, the ventricles continued to advance when the dog lay upon its back, or when a fulcrum was introduced behind the heart, when it lay upon its side.

Before leaving this subject we must ask, upon what fulcrum does the base of the left ventricle rest when the animal lies upon the back, and the apex and anterior walls of the ventricles advance during the systole by a lever movement? That this fulcrum cannot be the spinal column is evident, for the aorta and œsophagus are interposed between the heart and the bodies of the vertebræ. Neither can it be those vitally important tubes, for they could not with impunity be subjected to forcible and ever-recurring pressure. We must look for this fulcrum to the fibrous structure of the pericardium, which is of great strength. In my paper " On the Mechanism of Respiration," in the *Philosophical Transactions* for 1846, p. 538, I stated that, "From the floor of the pericardial sac" (the central tendon of the diaphragm) " is given off a strong tendinous web that sheathes the whole pericardium, and is inserted into the investments of the great vessels at the upper part of the chest." The base of the left ventricle rests securely upon the strong fibrous pericardium, upon which it is slung as it were upon a hammock, and which is attached to the central tendon of the diaphragm below, and to the great vessels above.

The Effects of the Pressure of the Blood upon the Walls of the Ventricles in producing the Impulse.—I observed, in repeated experiments, that when the finger was pressed upon the front of the ventricles, it was lifted forwards with force, during the systole, to the extent of nearly half an inch ($\frac{45}{100}$ths.) This propulsion forwards of the finger was much greater than the forward movement of the walls when not pressed upon, as indicated to the eye, or by means of a delicate lever. When the finger was applied to the apex, and pressed gently upwards, it was pushed forcibly downwards during the systole to the extent of a quarter of an inch. This downward propulsion of the finger was the reverse of the ordinary movement of the apex during the systole, when it ascended towards the base if not thus subjected to pressure. Again, when the heart was grasped by the hand, the fingers and thumb sank into the flaccid walls of the ventricles during their dilatation, but were driven asunder with great power when the walls contracted.

What is the cause of this protrusion of the finger when pressed on the walls of the ventricle during the systole? Is it muscular rigidity? That this cause may operate is probable; but when we find that a finger pressed upon the muscles of the thigh is propelled forwards only to a slight extent when those muscles contract, we must answer, that there is some other agent at work besides muscular rigidity.

A little consideration will show that this additional agent is the counter pressure exerted by the blood on the walls of the ventricles, when the contraction of those walls drives it into the great arteries. The pressure exerted by the blood, when propelled outwards, is equal in every direction; it therefore evidently presses not only on the outlets through which it escapes, but also on the walls by which it is expelled. To use the words of Skoda, as rendered by Dr. Markham, "During the ventricular systole, the blood presses upon every part of the heart's surface with a force equal to that by which it is itself compressed." The pressure of the blood thus reacts on those walls that by their contraction propel the blood outwards. In order to test this explanation, the blood was shut off from the heart, when it was found that the finger applied to its front walls or apex was forced forwards or downwards during the systole to a much less extent than when the blood circulated freely through the heart.

The Causes of the Impulse.—It is evident, from what has just been said, that the impulse of the heart is due to more causes than one.

The rigidity of the muscular walls is one of those causes.

The lever movement, described above, and illustrated elsewhere by Ludwig, which is itself due to muscular rigidity, is another.

An additional, and probably the most important, cause of the impulse is the outward pressure of the blood in the ventricles on the walls by which it is expelled, and through those walls, on the ribs and intercostal spaces; just as the pressure of the blood produces the pulse at the wrist and the pulsation of an aneurismal tumour. The pressure of the blood is a cause of the impulse which tells invariably, whatever may be the position of the body, which, as we have already seen, is not the case with the lever movement.

According to Gutbrod and Skoda, "the pressure which the blood exerts," owing to the contraction of the ventricles, "upon the walls of the heart opposite to the opening whence the stream escapes, causes a movement of the heart in a direction contrary to that of the stream of blood; and by this movement the impulse of the heart against the walls of the thorax is produced. The heart is driven in a direction contrary to that of the arteries, with a force proportioned to the quantity and velocity of the current of the blood." A precisely similar explanation of the impulse was given by Dr. Alderson, in the *Quarterly Journal of Science, Literature, and Arts* for 1825.

Skoda gives also the following additional cause of the heart's impulse:—"The aorta and pulmonary artery, being free and unattached to some distance from their origin in the heart, allow of a lengthening of the blood column downwards; and the heart will consequently be forced in that direction."

The two causes thus advanced by Skoda produce the impulse by the common effect of forcing the heart in a direction downwards; and they are grounded upon his view that the heart descends, "in some cases as much as one or two inches lower during the systole than during the diastole"! Now, these two agencies exist, and they tend to produce the effect described, of forcing the heart downwards. They are, however, overbalanced by the more powerful agency of the muscular contraction upwards of the lower half of the ventricle. The result is, that while the upper portion of the ventricles is lowered, their lower portion, including the apex, is raised during the systole, when the ventricles contract from all sides towards their own centres; and that practically the heart's impulse is not influenced by either of those causes.

It is to be noticed before leaving this important question, that the impulse is not a downward movement of the heart, but a propulsive movement forwards and outwards. The ventricles, in short, over their whole surface, make a direct thrust against any object upon which they impinge, and wherever, therefore, they come in contact with the walls of the chest. The impulse is concentrated at the apex, in the fourth or fifth intercostal space, or diffused over the whole front of the ventricles, in the spaces between the costal cartilages, according to the extent to which the heart is covered by the lung. When the heart is lowered by the descent of the diaphragm, and the lung interposes everywhere between that organ and the walls of the chest, the impulse is no longer perceptible over those walls, but may be felt in the epigastric space close to the xiphoid cartilage. The muscular rigidity and the lever movement of the ventricles, and above all the pressure of the blood in those cavities during the systole produce the impulse wherever the heart is in immediate contact with the parietes. When the heart is displaced to the right side of the chest, the same causes produce the same effect, and the impulse is then felt, with a propulsion not downwards, but forwards, over the right intercostal spaces.

The Movements of the Papillary Muscles.—That I might observe the action of the papillary muscles, I removed the anterior wall of the right ventricle when the heart was beating *in situ;* and I found that the tip of the anterior papillary muscle of the right ventricle contracted towards the septum during the systole.

I then removed the septum, so as to expose the two papillary muscles of the left ventricle, and I noticed that the muscles, which during the diastole were wide asunder, approached and came close together during the systole. At the same time, the tips or free ends of the muscles, with their tendinous cords, descended; while their attached ends ascended. The fixed point towards which the two ends approximated corresponded apparently to the zone of rest, or stable equilibrium, in the walls of the ventricle towards which the base and the apex of the ventricle approximate during the systole.

The Action of the Mitral and Tricuspid Valves.—In order that I might see the movements of the mitral and tricuspid valves, I cut out the heart when beating vigorously, and immersed it in water. The ventricles contracted with force, and expelled the water from the great vessels during each systole. The jet from the aorta was six inches in length. The segments of the mitral and tricuspid valves came together at their beaded margins, so as to close the valves, and prevent the efflux of any liquid. It was difficult to observe whether the valves at their outer rim, where they are attached to the muscular walls, altered in shape or size towards the end of the systole; but it appeared to me that they retained their form and dimensions, and they were certainly completely closed, throughout the contraction of the ventricles.

At the beginning of each diastole, the margins of the valves separated quickly from each other, so as to admit the flow of water into the cavities. It was evident that the valves were thus opened by the intrinsic action of the heart, and not by the pressure of the fluid from behind, since in this experiment no such pressure was exerted.

THE STRUCTURE AND MOVEMENTS OF THE VENTRICLES AND THEIR VALVES.

After death, the left ventricle is generally empty, and firmly contracted, so that it represents the completion of the systole. Sometimes, however, it is distended with blood, and in a state therefore of complete diastole. Different hearts present every stage between the complete contraction and complete dilatation of the left ventricle.

The right ventricle, on the other hand, frequently represents after death the state of diastole, rarely that of complete systole.

That I might fix the heart in the exact form that it presented in the dead body, I hardened it by immersion in spirit, the vessels having been tied so as to retain the blood. I then exposed the interior of the cavities by removing the walls or making sections. In this way I obtained a series of hearts for examination, in some of which the ventricles were in a state of complete systole (Figs. 7, 8, 22); in others, in that of complete diastole (Figs. 4, 5, 20); while in others they were in an intermediate state (Figs. 9, 10, 21). These figures were accurately drawn by Mr. Harvey Smith, from the preparations and photographs. I intend to offer the preparations from which the figures were taken that illustrate this part to the Royal College of Physicians, in the hope that they may be placed in the Museum of the College, and so be open to inspection.

THE LEFT VENTRICLE.

When we make a cross section through the middle of the ventricles, whether they are in the state of dilatation (Figs. 4, 5) or contraction (Figs. 6, 7), we see that the left ventricle is cylindrical, while the right is crescentic in form. The septum forms the anterior concave wall of the left ventricle, and the posterior convex wall of the right.

The base of the left ventricle (Figs. 3, 4, 6) is occupied, behind, by the mitral orifice, and in front, by the aortic orifice,

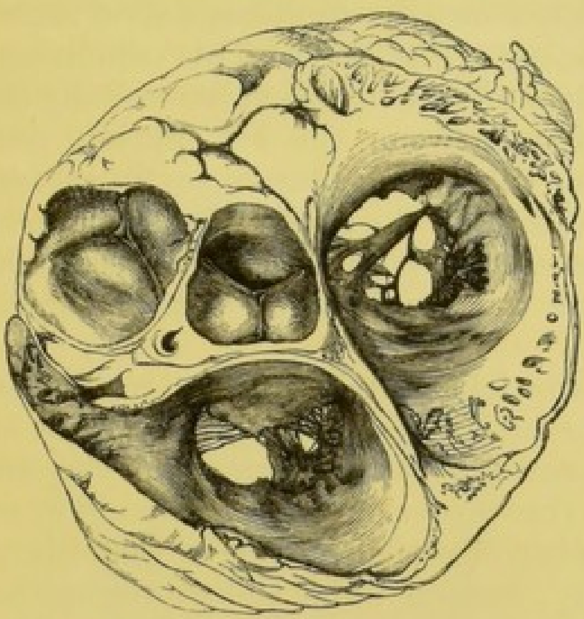


Fig. 3.

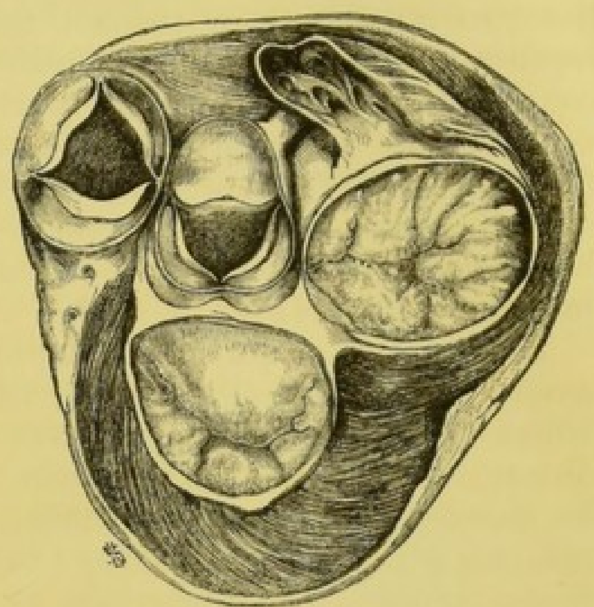


Fig. 6.

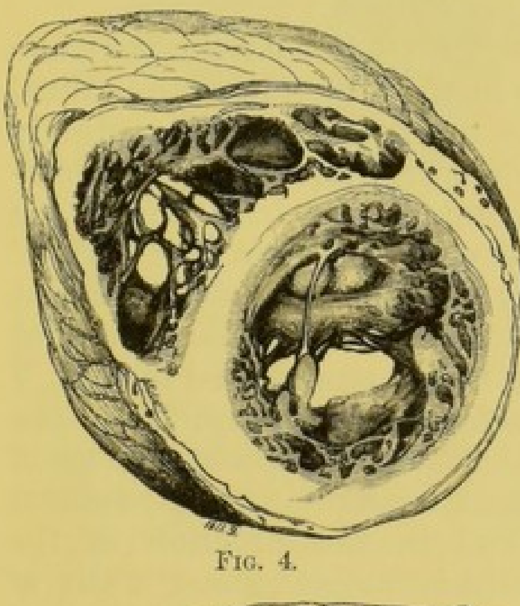


Fig. 4.

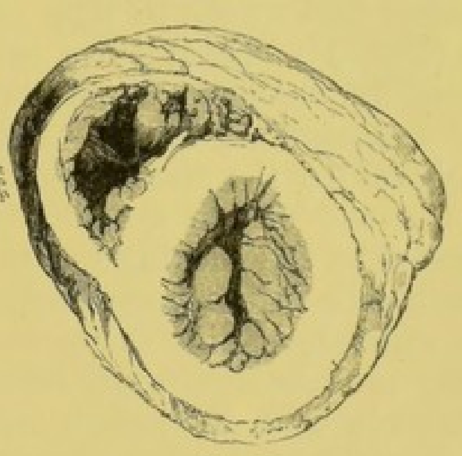


Fig. 7.

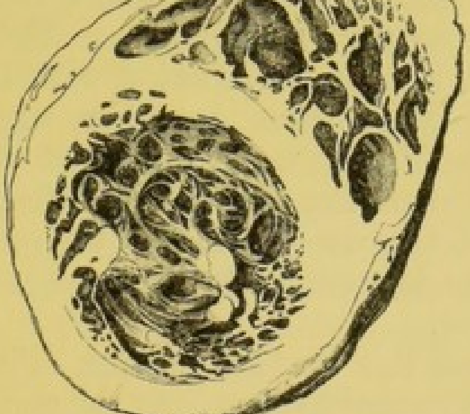


Fig. 5.

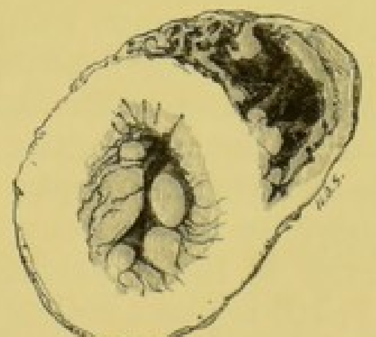


Fig. 8.

The muscular circuit of the aortic and mitral openings is in each case incomplete, those apertures being completed by a common tendinous septum (Figs. 3, 6). In consequence of this, if the heart be boiled for many hours, so as to soften out the tendinous structures, the two openings are thrown into one (Fig. 23). This tendinous septum is formed by the anterior flap of the mitral valve and by its continuation, which forms a partition between the left auricle and ventricle, on the front of which rests the two posterior aortic valves. (Figs. 3, 4, 6.) This septum, likewise, divides the cavity of the ventricle near its base, into two portions—a mitral portion behind receiving blood from the auricle, and an aortic portion in front sending blood into the aorta. (Figs. 3, 4, 6.)

The anterior or aortic portion of the left ventricle forms, when the cavity is expanded (Figs. 4, 5), an arched space, the anterior walls of which are almost smooth, and are formed by the septum and the left anterior free wall of the ventricle. The posterior or mitral portion of he ventricle is irregular in shape, being occupied by the two papillary muscles which project into the cavity, one on either side, and by the fleshy columns which interlace, so as to form a loose network of cells. This network, as it approaches the apex, surrounds the whole interior of the cavity, and assumes a spiral direction (Fig. 5.)

During the diastole, the mitral or posterior portion of the ventricle is enlarged backwards, its long axis lying in the direction of the mitral orifice (Fig. 4). During the systole, the mitral portion is gradually narrowed by the advance of its posterior walls, and the approximation of the papillary muscles and fleshy columns, the long axis of the ventricle taking the direction of the aortic orifice. (Figs. 7, 8, 12).

At the end of the systole, the cavity of the ventricle is almost obliterated by the packing together of the thickened papillary muscles, as is well seen in the cross section of the heart, represented in Figs. 7 and 8, which looks like the section of a solid muscle. (Fig. 22.) The papillary muscles and fleshy columns thus fill up the whole interior of the ventricle, with the exception of a small triangular spiral channel (Figs. 7, 8), just behind the septum, and in the direction of the aortic opening. The spiral fibres, of which the muscular walls of the ventricle are formed, grasp, like the coils of a serpent, the vertical papillary muscles and fleshy columns during their contraction. Those muscles, consequently, fill up the cavity, and in conjunction with the contraction of the outer walls which forces them together, expel the blood in the manner described by Borelli. In consequence of this packing together and thickening of the papillary muscles and fleshy columns during the systole, the extent of the contraction of the muscular walls required to empty the cavity is materially lessened, and their expulsive force is thereby economised.

The interior of the ventricle, when seen in a vertical section (Plate VI., Figs. 9, 10) is like a hollow cone with concave sides. At the end of the diastole, when the ventricle is of full size, it is somewhat egg-shaped. Its walls are hollow, its apex is blunt, and its cavity widens from apex to base; the widest part corresponding with the tips of the papillary muscles (Fig. 4). Just above this point, at the base, close to the mitral orifice, it again contracts, leaving, however, an ample space between the posterior segment of the valve and the posterior muscular walls. The cavity contracts rapidly, and curves forward as it approaches the aortic valves, where it forms the remarkable intervalvular space

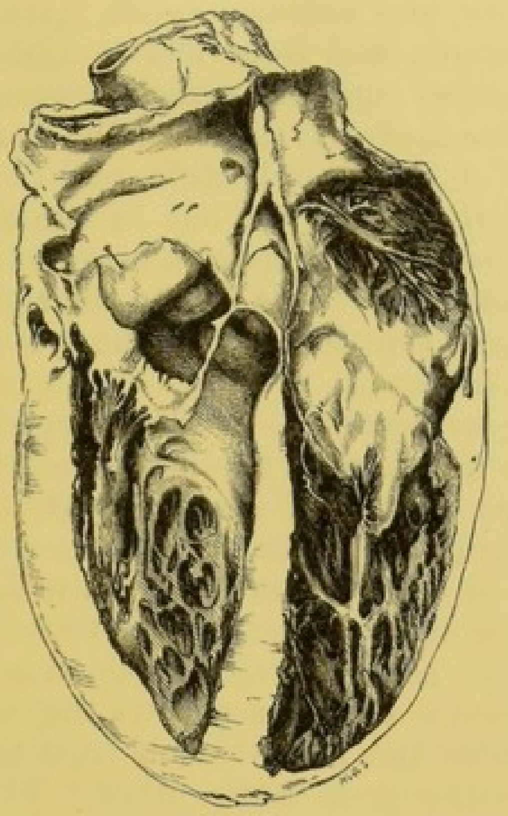


Fig. 9.

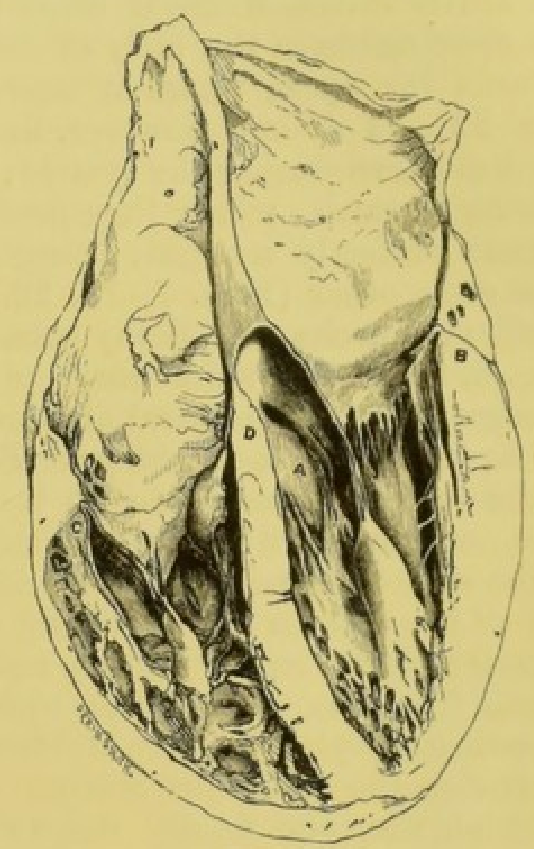


Fig. 10.

(Figs. 4, 9), which I shall hereafter describe. The two papillary muscles are as wide apart as possible. Towards the apex they join and intercommunicate with each other and the fleshy columns, so as to form the remarkable spiral network of cells just described (Fig. 5). The two papillary muscles separate from each other during the diastole in the form of a horse-shoe, the space between them being greater low down, where in one heart it was ·85 in. than higher up between the tips, where in the same heart it was ·65 in.

During the progress of the systole (Figs. 9, 10), the circumference of the whole cavity, from base to apex, gradually narrows; the walls become less concave; and a remarkable change takes place in the relations of the walls to the mitral valve at the base. While the circumference of the valve at the tendinous ring undergoes little or no diminution, the muscular walls at the base, just below the valve, contract steadily inwards, so as to present a shoulder projecting into the cavity immediately below the mitral valve (Fig. 10, B, A). This shoulder never touches the under surface of the valve, but leaves a small space in which the pressure of the blood closes the valve up to the end of the systole. The result is, that the contracted cavity of the ventricle widens outwards at the base, which is the reverse of what takes place in that region at the end of the diastole.

The cavity of the ventricle, which at the end of the diastole is somewhat egg-shaped, is totally changed in form at the end of the systole. It is then narrow and triangular, except towards the apex, where it is obliterated; and it presents a spiral twist in a direction from the aortic orifice to the apex. This spiral curve commences at the aortic valves, where it bears backwards and from right to left, is just appreciable in the body of the cavity, and becomes again marked towards the apex, where it bears forwards and from left to right* (Fig. 22). I do not, however, find that the papillary muscles assume a spiral curve during the systole; on the contrary, they lose the bend looking inwards, which they presented during the diastole, and they become perfectly straight, being parallel to, and all but in contact with each other (Figs. 7, 12, 22.) Towards the apex, however, the papillary muscles and fleshy columns curve forwards and to the right (Fig. 8, 22). The spiral curve of the left ventricle during the systole corresponds with the spiral direction of the aorta.

The Central Fibro-Cartilage or Tendinous Septum.—The fleshy septum of the ventricles terminates at the base in a strong tendinous aponeurosis, or fibro-cartilage, which performs a part of great importance in the structure and mechanism of the heart. This tendinous termination of the septum is beautifully seen in the preparation from which Figs. 9 and 10, representing a vertical section of the heart, have been taken. The muscular septum (D) is, in fact, converted at this region into a tendinous septum; but while the muscular septum separates the two ventricles, the tendinous septum separates the left ventricle from the right auricle, and finally the two auricles from each other. This fibro-cartilaginous septum corresponds with the central fibro-cartilage and bone of the heart of the ox, and I possess one human heart in which it is converted into bone. It may be seen in Fig. 6, that this fibro-cartilage is intimately attached to the right posterior sinus of the aorta, to the tendinous ring of the mitral orifice, to the tendinous ring of the tricuspid orifice, to the central angle of the mitral valve, especially its anterior segment, and to the central angle of the tricuspid valve. It also gives insertion to numerous muscular fibres from the right ventricle, the left ventricle and the septum, and origin to muscular fibres which go to the right and left auricles, and the inter-auricular septum. The connections, in fact, of this great central tendon are universal. It binds all these important parts together, and gives to them unity, mutual inter-dependence, and correlation of action.

The Intervalvular Space.—The left ventricle, as I have already said, curves forwards and to the right, as it approaches the aortic

* In my paper on the Situation of the Internal Organ ("Prov. Med. Trans.," 1844, p. 518), I thus describe the systolic movements of the left ventricle. During the systole, "the cavity changes its place, being more to the right, and with its axis, which was formerly in the direction of the auricle, now pointing to the aorta. The contraction proceeds in a twisting manner; the blood is, as it were, wrung out of the cavity, and with a current that takes naturally the twisted direction of the spring and arch of the aorta."

aperture. There it forms a chamber or space of remarkable interest which I have called the intervalvular space, situated between the aortic valves in front, and the anterior cusp of the mitral valve behind. This space is beautifully shown in the preparation from which Fig. 9 is taken, and in which the aortic valves are seen through an opening, cut in the anterior flap of the mitral valve, and the continuous wall of the left auricle. Its immediate walls are everywhere rigid and aponeurotic, and it cannot therefore be compressed by the contraction of the muscular walls during the systole. The aortic valves, during the diastole, play directly into this space, and owing to its existence the mitral valve is closed up to the end of the systole by the pressure of the blood on its anterior flap. The inner or right boundary of this space is formed by the central fibro-cartilage, or tendinous septum, just described; the anterior and left, or external boundary, by the muscular walls of the ventricle, which are there lined by a rigid aponeurosis; and the posterior boundary, by the anterior flap of the mitral valve and the continuous wall of the left auricle, upon which the two posterior sinuses of the aorta are implanted.

The Mitral Valve.—When the closed mitral valve is looked at from the auricle (Figs. 6, 11), its outline resembles that of a horse-shoe or Saracenic arch. The valve is set in the muscular structure of the left ventricle, and its base, which is tendinous, is situated immediately behind the two posterior aortic sinuses, and stretches from the left or external to the right or central fibro-cartilage (Fig. 6). This tendinous base, which is continuous with the mitral valve, forms a portion of the walls of the left auricle. The mitral valve presents two segments or flaps, an anterior and a posterior. The posterior segment, which is crescentic in form, is set in the muscular walls, and fills up the two posterior thirds of the mitral orifice. To enable it to do so with perfect adaptation, it is divided into three sub-segments. The anterior segment, which is shaped like a half-moon, is attached to the membranous structure at the base of the valve, and it fits like a lid into the posterior or crescentic segment, which forms a frame for its reception, so as to close the valve. When the valve is shut, the central, the left, and the right sub-segments of the posterior or concave flap are opposed, respectively, to the middle, the left, and the right portions of the anterior flap (Fig. 6). The three sub-segments, where they meet, form two angles, which are filled up by the corresponding angles of the anterior flap.

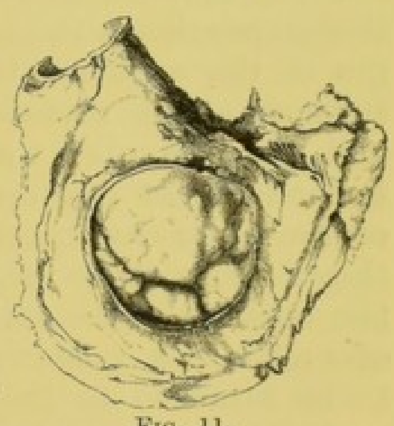


Fig. 11.

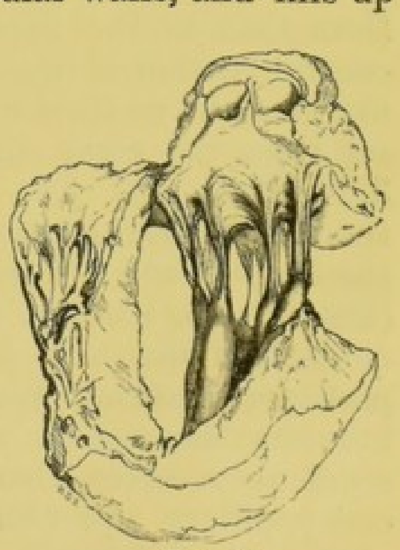


Fig. 12.

The lips of the closed valve at the meeting of the two segments are beaded (Figs. 6, 11), and its upper surface presents small rounded prominences. These prominences, as Skoda pointed out, are caused by small pouches, or sacculi, on the under surface of the valve. These sacculi are formed by the meeting together of the fan-shaped expansions by means of which the tendinous cords are inserted into the margins and under surface of the valve. This structure is beautifully seen on the anterior segment. The tendinous cords are distributed to that segment in four rows (Fig. 12), the two outer rows being attached to its margins, the two inner ones to its under surface. These rows are arranged so as to form three arched spaces, the central space being the widest. This arrangement is well seen in the preparation from which Fig. 12 is taken, in which it presents the appearance, as it were, of the nave and aisles of a Gothic cathedral.

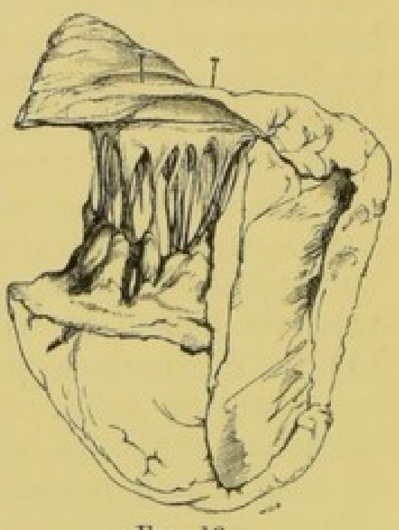


Fig. 13.

The tendinous cords are distributed to the crescentic or posterior segment of the mitral valve in two rows, an outer and an inner (Figs. 13, 16, 17). These rows are inserted by fan-like expansions; the inner row into the margin of the segment, the outer into its under surface, about mid-way between its margin and the muscular walls, to which the posterior segment is attached. Where the cords of the outer row meet each other at the top, they form a range of pointed arches, around the outside of the valve (Figs. 13, 16, 17). Just above this range of arches the posterior segment of the valve turns over at its rim, to be attached to the tendinous ring; and it thus forms a vaulted space between the base of the valve and the muscular walls (Figs. 16, 17).

The distribution of the tendinous cords to the angles is different from that to the flaps of the valve. The anterior segment, and the central portion of the posterior segment of the valve, receive at their margins and on their under surfaces two converging sets of cords, one set from the right, the other from the left papillary muscle (Figs. 3, 4, Plate VI). The cords, on the other hand, that are attached to the inner or right, and the outer or left angles of the valve, spring, from the longest and outermost tip of the corresponding papillary muscle (Figs. 12, 13, 16, 17); and are inserted by a divergence or radiation of cords into the angle formed by the meeting of the anterior and posterior segments (Figs. 3, 4, Plate VI). Each of the angles formed between the central and two lateral subdivisions of the posterior segment receives also a set of diverging cords, that radiate from one papillary tip. (Fig. 17). This arrangement of the convergence of the cords towards the centre of each cusp, and their divergence towards the angles where the segments meet, is needful for the perfect adjustment of the lips and angles of the valve.

All round the base of the valve, between it and the muscular walls, there is, as I have just described, a vaulted space, which becomes gradually narrower during the progress of the systole; but which is never, even at its very end, obliterated. During the contraction of the ventricle, as I have already stated, a shoulder of the muscular walls projects inwards all round the base. Between this shoulder and the under surface of the valve, a distinct space exists, so that the shoulder never touches the under surface of the valve itself (Figs. 10, 11 A, B). A thin layer of blood intervenes to the very last between these opposing surfaces, so as to secure the pressure of blood upon the whole under surface of the valve, and its consequent closure throughout.

This distribution of the cords to the flaps of the valve holds them down, when, like sails bellied by the wind, they are pressed upon by the blood during the contraction of the ventricle, in the manner first pointed out by Lower.

If the cords were distributed to the margins only of the valve, as in Fig. 14, the bellying of the under surface of the flaps, caused by the pressure of the blood, would lead to the separation of their edges, and the regurgitation of the blood.

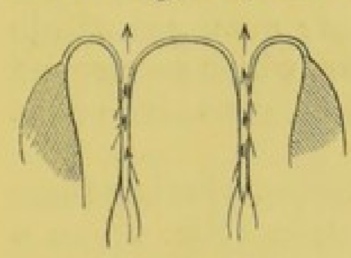


Fig. 14.

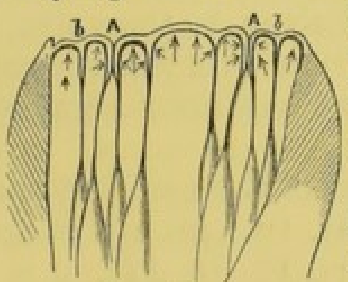


Fig. 15.

Owing, however, to the distribution of the cords to the under surface, as well as the margins of the valve, so as to hold them equally downwards, and the formation thereon of many small pouches or sacculi, as in Fig. 15, the blood, during the contraction of the ventricle, is forced into these pouches, so that they are each filled to distention. The adjoining pouches being all of them distended, and held down by the cords, necessarily displace each other outwards, so as to widen the whole area, and enlarge the circumference of the valve, in the manner represented in Fig. 15. The lips of the two segments of the closed valve are sacculated on their inner surface, and present, therefore, beaded margins, when looked at from the auricle (Figs. 6, 15 A A). When the bead-like sacculi of the lips are distended during systole, they dovetail into each other, so that the opposite margins fit together with the greatest accuracy. The sides of the lips are pressed together by the distention of their sacculi during the systole, the firmness with which the valve is closed being proportioned to the force with which the ventricle contracts so as to distend the sacculi. At the same time the whole surface of the valve is held down and flattened by the tightening of the cords (*b*). These beaded margins are thus pressed against each other, so as to shut the valve by the contact, not of their mere edges, but of their vertical sides, in the same way that the semilunar valves are closed, or that the mouth is shut by the contact of the lips (Figs. 6, 11, 15A).

When I observed the heart acting vigorously under water, after being cut out, it seemed to me that the circumference of the shut valve did not lessen with the diminution of the ventricle towards the end of the systole. It would appear, in fact, that the pressure of the blood by filling the sacculi on its under surface unfurls, flattens out, and enlarges the valve so as to maintain it almost of the full size up to the end of the systole. Indeed, any material diminution of the valve would necessarily cause it to fly open, and so lead to the regurgitation of the blood from the auricle into the ventricle, through the mitral orifice.

The Papillary Muscles.——Sometimes the papillary muscles are concentrated into two single muscles, an external or left, and an internal or right (Fig. 16), each of which presents a row of papillæ. More often they are distributed into two great groups of papillary muscles, a left and a right group, which are distributed to the corresponding portions of the valve (Fig. 4). In many hearts the two groups are united posteriorly, by a series of intermediate muscles; the posterior ones being comparatively short (Figs. 12, 13, 17). In such instances they are placed round the two posterior thirds of the ventricle, just within the muscular walls. The muscles, and the tendinous cords which connect them to the valve, are arranged within the muscular walls of the ventricle in crescentic rows, which correspond with the crescentic form of the posterior segment of the valve (Figs. 6, 11, 12, 13, 17).

Whatever be the distribution of the papillary muscles, whether there be two single muscles (Fig. 16), two groups of muscles (Fig. 4), or a crescentic row of muscles (Figs. 12, 13, 17), it is convenient to speak of them as two, the left or external, and the right or internal.

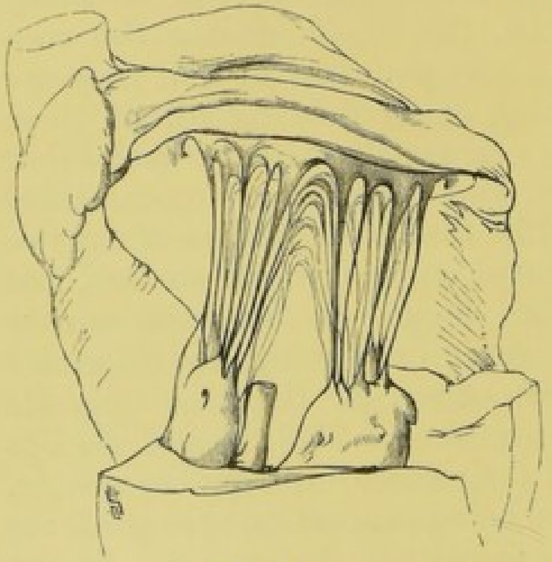


Fig. 16.

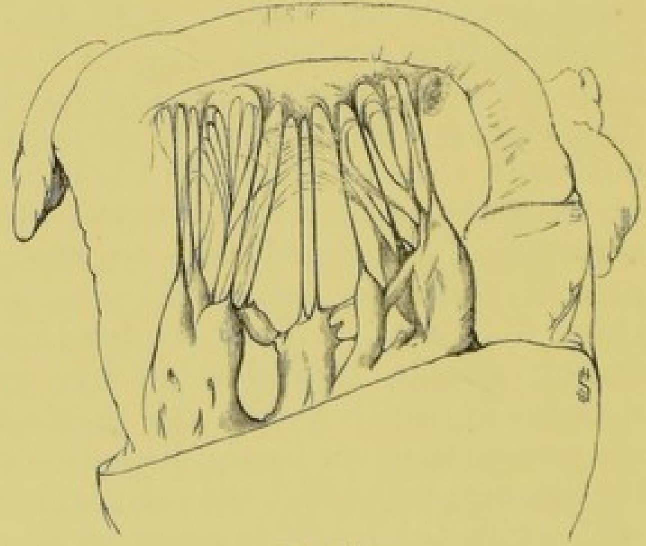


Fig. 17.

Whether the muscles are simple or compound, the principle of their arrangement and distribution is alike in different hearts. Each muscle presents, at its extreme point, a lengthened peak or papilla, with radiating cords to the corresponding angle of the valve, which are short, so as to restrain its movement. The intermediate papillary muscles, or papillæ, become gradually shorter, and towards the centre of the valve, where its segments enjoy the greatest play, the shortness of the muscles is compensated for by the greater length of the cords; while at each angle, where the movements of the valve are restrained, the length of the muscle makes up for the shortness of the cords (Fig. 17). As a rule, the external or left papillary muscle is more massive than the right or internal.

I have already described the mode in which the two papillary muscles communicate with each other, and become subdivided into and intermingle with the fleshy columns as they approach the apex (Fig. 5), where they combine to form a beautiful spiral network of cells.

During the systole, when, as we have seen, the papillary muscles and fleshy columns are packed together so as to fill the cavity of the ventricle, the right and left papillary muscles double upon each other, so as to present in a cross section, not a crescent, as during the diastole (Figs. 4, 17), but two oblique parallel rows, which fit into each other (Figs. 7, 8), as may be readily seen by making a section of the calf's heart.

The Influence of the Papillary Muscles in Opening the Valve during the Diastole.——As soon as the muscular walls relax after the end of the systole, the two papillary muscles move as far from each other as possible. In doing so they open the valve, by stretching and so drawing forward its anterior flap. When the diastole is complete, the anterior flap is held taut between the two papillary muscles (Figs. 3, 4); so that at this period the mitral orifice is fully open. I watched the opening of the valve, when the heart was beating with full force under water, and observed that the flaps separated at the beginning of the diastole, not by the pressure of the water, for no such pressure was exerted, but by the intrinsic movement of the valve itself. I believe that the stretching forwards of the anterior segment of the valve, by means of the moving asunder of the relaxed papillary muscles in the manner that I have just described, is an adequate explanation of the automatic opening of the valve.

THE RIGHT VENTRICLE.

Comparison between the Right Ventricle and the Left.—The right ventricle differs in many important features from the left. The septum, which is the party wall of the two ventricles, properly belongs to the left. How completely the septum is appropriated by the left ventricle at the base is well seen in the preparations from which Figs. 6, 9, and 10 are taken. The right ventricle is shorter from base to apex than the left, the shortening being chiefly at the base. The tricuspid valve and the base of the right ventricle are about half an inch lower, or nearer to the apex, than the mitral valve and the base of the left ventricle. The base of the left ventricle, therefore, appropriates to itself exclusively the upper or aponeurotic portion of the septum, which completes the circuit of the mitral orifice on its inner or right side. The result is, that the septum at the base is not interventricular, but is situated between the left ventricle and the right auricle (Figs. 6, 9, 10 D).

The right ventricle is then, so to speak, an abutment of the left ventricle. It is built upon the septum, which forms its borrowed posterior wall, and projects forwards into its cavity. The antero-inferior free wall is the only proper wall of the right ventricle. The anterior portion of this proper or free wall is situated immediately behind the lower costal cartilages and sternum, while its inferior portion rests upon the diaphragm. While this proper wall is convex without, concave within, the borrowed or party wall is convex within.

The right ventricle is compelled to adapt itself to the form and movements of the left, and it is therefore more complicated than the left. Various peculiarities in structure are implanted, therefore, on the right ventricle, when compared with the left, which all turn upon this, that the left is the principal, the right, the supplementary cavity.

The left ventricle, in a state of expansion, is cylindrical in form, in a cross section, while the right is crescentic. The left ventricle is egg-shaped, while the right is pyramidal, the top of the pyramid being formed by the pulmonary artery, while its base, prolonged to the left (Figs. 19, 20, 21, 22), rests upon the central tendon of the diaphragm.

In the left ventricle, the aperture of entrance through the mitral orifice is contiguous to the aperture of exit at the aorta, the two orifices being separated by a membranous septum. In the right ventricle the aperture of entrance, through the tricuspid orifice, is at a distance from the aperture of exit at the pulmonary artery, the two orifices being separated by the muscular channel of the *conus arteriosus*. In the left ventricle, the current of blood inwards, which descends during diastole behind the anterior segment of the mitral valve, is parallel in direction to the current of blood outwards, which ascends during the systole in front of that segment (Fig. 18). In the right ventricle, the current of blood inwards is at right angles to the current of blood outwards, since the blood enters the cavity

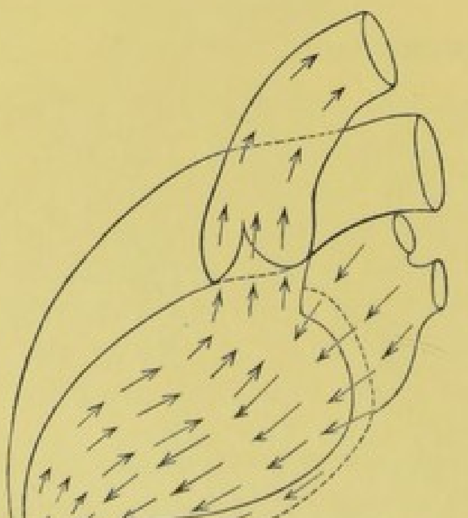


Fig. 18.

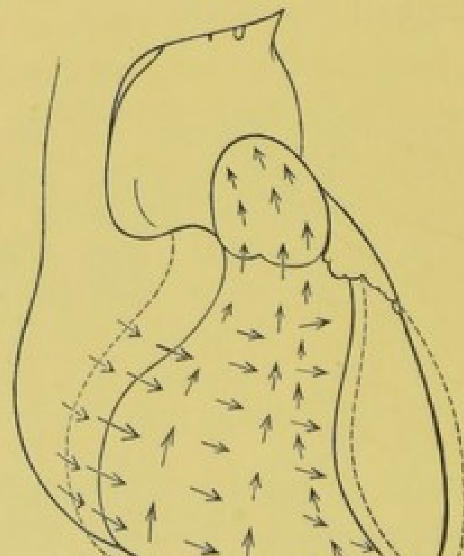


Fig. 19.

from right to left, and leaves it from below upwards (Fig. 19). During the systole, the stream of blood in the left ventricle takes a spiral direction towards the aortic orifice, in accordance with the spiral direction of the aorta itself (Fig. 18). The stream of blood in the right ventricle, as it ascends, mounts over the bulging septum, being restrained by the concave free walls. This upward stream, which narrows as it proceeds, thus takes the curved direction upwards, backwards, and inwards of the *conus arteriosus* and the pulmonary artery. In the left ventricle, the anterior segment of the mitral valve, and the right and left papillary muscles, form a hollow channel for the stream of blood, which, as it ascends to the aorta, presses upon the under surface of the valve. In the right ventricle, the stream of blood, as it ascends, sweeps onwards at right angles to the under surface of the tricuspid valve, and rushes between and across the papillary muscles, and through the tendinous cordage that connects those muscles to the valve (Figs. 19, 21).

The Tricuspid Valve.—The structure and action of the tricuspid valve and its papillary muscles are, in principle, the same as those of the mitral valve and its papillary muscles. Owing, however, to the difference in the form of the two cavities, in the relative position of their two orifices, and in the direction, inwards and outwards, of the stream of blood in the two ventricles, many important differences are implanted upon the tricuspid valve, when compared with the mitral.

The closed tricuspid valve, looked at from the auricle (Fig. 6), is irregularly oval; being large and rounded in front and below, slightly concave towards the septum, and angular behind and above, where it is attached to the central fibro-cartilage, close to the right posterior aortic sinus. The valve itself is subdivided into three great cusps: the anterior, the posterior, and the inferior. The inferior cusp, which is the largest, is deeply subdivided into several segments. Two of these sub-segments are very long and narrow; their length being twice their width. Each of them has a series of tendinous cords, which are inserted into the centre of the sub-segment from the tip to the base, in addition to a series of cords to each edge (Fig. 20, *d*). The length of these sub-segments, which meet with each other, and with the anterior and posterior cusps at a common point, about the centre of the valve (Fig. 6), is due to the great breadth of the tricuspid orifice at that region, which corresponds with the angle formed by the meeting of the anterior and inferior aspects of the free wall. For the same reason, the tips of the middle or anterior papillary muscle (Figs. 20, 21, 22, F), project into the centre of the cavity; and those of the lower papillary muscle do the same, though not to the same extent. To afford an advanced basis of support for these papillary muscles, as well as to thicken the walls, without materially diminishing the cavity and solidifying the walls themselves, a remarkable many-celled structure, made up of the net-formed meeting of numerous fleshy columns, fills up the angle between the anterior and inferior surfaces of the free wall of the ventricle (Figs. 4, 5, 20). This many-celled structure completely occupies the cavity of the ventricle in the neighbourhood of the apex. Thence the structure extends in two directions; towards and up to the tricuspid orifice on the one hand, and on the other, towards the pulmonary artery, so as to occupy the angle formed between the septum and the anterior walls.

The series of central cords which are attached to the tips of the prolonged sub-segments of the lower cusp (Fig. 20, *d*), as well as to the middle of the posterior cusp (B), while they permit those tips to meet at the centre of the valve, retain them there in exact adaptation, when the valve is closed during the systole (Figs. 6, 21).

The superior deep angle of the valve, which is implanted, so to speak, upon the aponeurotic structure of the septum, close to the right posterior aortic sinus, is guarded by two small sub-segments (Figs. 3, 6, 20 *n*), which are situated between the anterior and posterior cusps, and which present a complete contrast to the elongated sub-segments of the lower cusp. These sub-segments are short, and have very little play, being tied closely down by short tendinous cords, which spring immediately from the adjoining wall, or from very short papillæ. They are thus fitted to the very restricted angle between the anterior and posterior cusps, which they fill up and close during the systole (Fig. 6).

The upper border of each of the two superior cusps, the anterior and the posterior (A, B), which taken together are about equal in size to the inferior cusp (Fig. 6), are supplied with a series of cords, which spring directly from the posterior wall of the ventricle, or from short papillæ. These papillæ and cords combine to form the superior papillary muscle (G) which is in great part latent, being incorporated with the muscular structure of the septum.

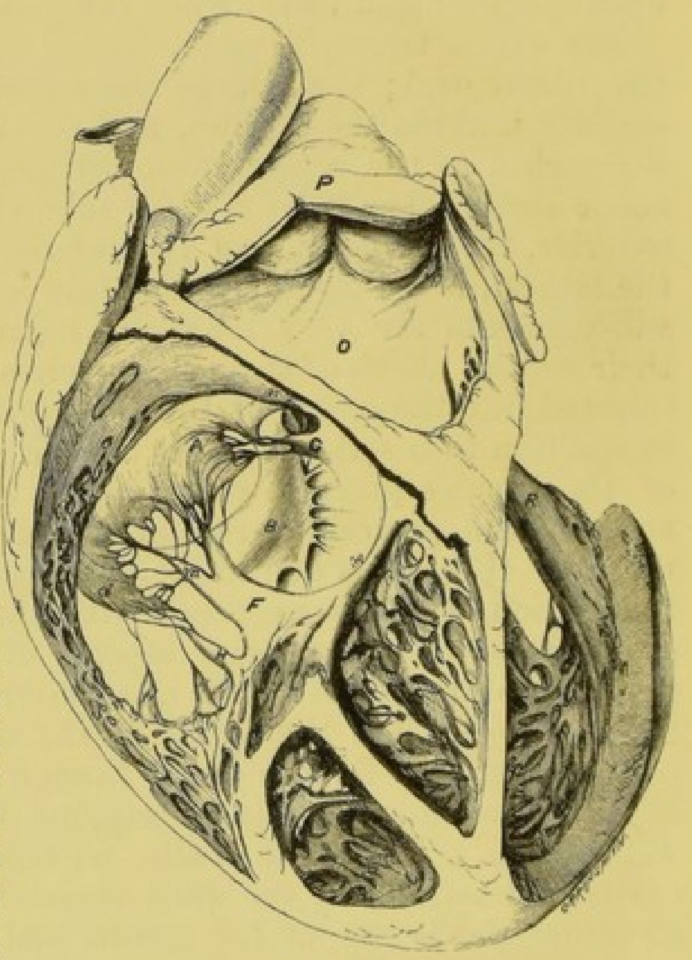


Fig. 20.

The three papillary muscles, of which I have just spoken, the superior (G), the middle or anterior (F), and the inferior (H), are so arranged as to be placed each of them between two adjoining cusps. The superior muscle is distributed, as I have just said, to the upper edges of the anterior and posterior segments; the middle muscle, to the lower edge of the anterior cusp, and the upper edge of the inferior or compound cusp; and the inferior papillary muscle, to the lower edge of the posterior cusp, and to the upper edge, and various sub-segments of the inferior cusp (See also Figs. 3, 4).

In the tricuspid valve, the distribution of the cords to the segments, though so different in detail, is the same in principle as in the mitral valve. The angles between the segments are supplied by the diverging cords radiating from one elongated papilla (*m*), while the flap of each segment is supplied by cords which converge from two distinct papillary muscles or papillæ, upon its upper and lower, or its anterior and posterior edges respectively (Fig. 20, F, A, G).

The Movements of the Right Ventricle.—The difference between the cavity of the right ventricle in a state of complete dilatation (Fig. 20), and in that of complete contraction (Fig. 22), is striking. It is difficult to recognise that it is the same cavity in the two opposite states of dilatation and contraction. The cavity during the middle of the systole (Fig. 21),* presents an intermediate approximation to the two opposite states of expansion and contraction (Figs. 20, 22).

I have already described the external movements of the right ventricle. I may, however, repeat them here in a few words. The ventricle contracts during the systole from side to side, to the extent of three-eighths of its diameter, towards a common point of rest,

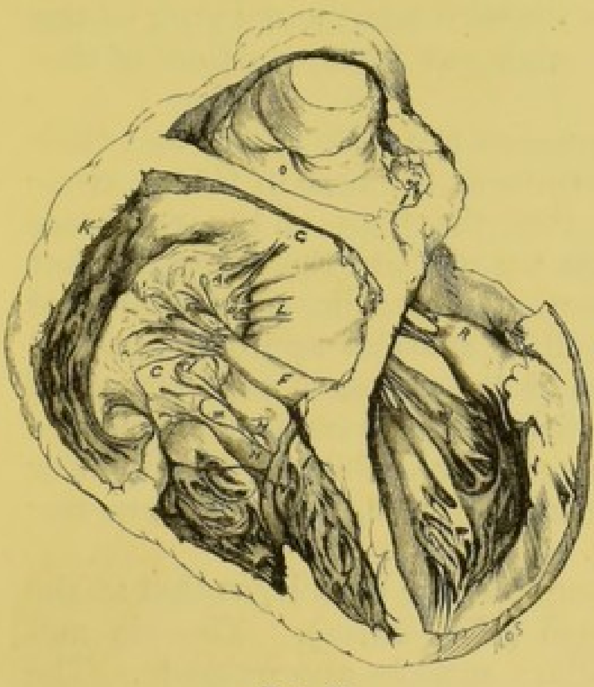


Fig. 21.

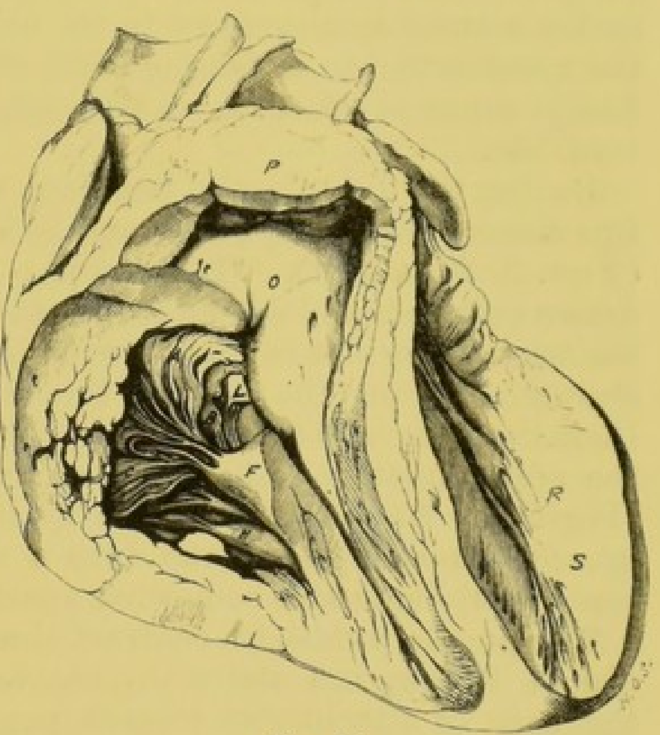


Fig. 22.

which is near the septum. The movement of the auricular border to the left, is six times as great as that of the septum to the right. The

* The preparation from which Fig. 21 was taken represents the mitral and tricuspid valves in a state of perfect closure; in this preparation, the cavities were injected with size, so as to close the valves. The heart was then hardened by being steeped in methylated spirit, and the cavities were cut open in the manner represented in the figure. Dr. Pettigrew injected plaster of Paris, so as to close the valves, into the hearts from which the drawings were made that illustrate his paper on the valves of the heart. By substituting size, the cavities can be cut open after their walls are hardened, so as to display the internal mechanism of the valves.

upper and lower boundaries of the ventricle approximate, the descent of the upper boundary and the pulmonary artery being greater and more constant than the ascent of the lower boundary, which rests on the central tendon of the diaphragm (Fig. 1). In short, the ventricle contracts from all sides towards a common centre, which is situated at the attachment of the anterior papillary muscle (F).

During the systole, the fleshy columns which form so extensive and remarkable a network at the end of the diastole (Fig. 20) shorten, approximate, and at length come into close contact. The many-celled structure (Fig. 20) contracts, driving the blood out of its meshes, and finally disappears, being replaced by solidified and thickened walls (Fig. 22). The septum or posterior wall bulges forwards into the cavity, while the antero-inferior free wall contracts in every direction. The arterial cone is greatly narrowed, flattened, and shortened. The walls close in from all sides upon the tricuspid valve. As they do so, a shoulder projects into the cavity at the base which never touches the valve, but leaves a space in which the blood continues to press upon its under surface, so as to close the valve up to the end of the systole (Fig. 10, C). It may be seen, by studying Fig. 22, that the right ventricle makes a twisting movement in the neighbourhood of the apex, owing to the great extent to which the papillary muscles and the network of the fleshy columns close in upon each other at that portion of the ventricle.

During the diastole, the papillary muscles are wide apart, and their tips diverge from each other, and look towards the base of the ventricle (Figs. 3, 20 F, G, H). The result is, that the flaps of the valve are drawn outwards and downwards towards the walls of the cavity, so that the tricuspid orifice is thrown wide open, its valve being incapable of closure. During the systole, the papillary muscles approximate, and their tips converge towards the middle of the valve, so as to permit of the approximation and contact of its flaps, and its consequent closure (Fig 21). At the end of the systole, the middle and the inferior muscles shorten and group into a mass (Fig. 22, F, H), the superior muscle (G) being still somewhat apart.

The papillary muscles contract throughout the systole, so that at the end of it they are materially shortened (Fig. 22, F). The tip and the base of attachment of each papillary muscle approximate. The tricuspid valve and the tips of the papillary muscles move with equal steps towards the apex and the septum, at the same time that the apex, the septum, and the attachments of the papillary muscles move towards the base. All the parts of the cavity and the tricuspid valve are thus maintained in a state of perfect adjustment through the whole period of the systole, the closure of the valve corresponding with the contraction of the cavity.

THE MUSCULAR AND TENDINOUS STRUCTURES OF THE HEART OF THE COW.

From the days of Lower, Senac, and Wollff, to the present time, the muscular structure of the heart has been examined in successive layers, from without inwards, each layer being stripped from the subjacent one. These observers all agree that the outer layers of fibres take an oblique direction from right to left, that the inner layers take a cross direction from left to right, and that the intermediate fibres run transversely. The varying direction of the fibres is admirably described by Weber, in his classical edition of Hildebrandt's "Anatomie;" and is beautifully shown in the valuable paper of Dr. Pettigrew.

This cross direction of the inner, in relation to the outer fibres, which exists throughout the whole heart, is found also in each portion of the heart's walls. Thus Ludwig has shown, in his important memoir on the ventricles of the heart (Henle's "Zeitschrift," vii, 193), that in every piece of the walls of either chamber, the fibres on the inner surface take a cross direction to those on the outer surface, the intermediate fibres taking, in regular order, a corresponding change of direction.

While inquiring into the muscular and tendinous structures of the heart, I employed three methods, in addition to that just alluded to.

By the first of these plans, either ventricle was laid directly open by a section through its anterior wall, and its papillary muscles and walls were examined from within outwards. (Figs. 24, 25, 26.)

In the second method, the fibres were unravelled in successive layers from without inwards, the layers overlapping each other in the manner shown in Figs. 27, 28. Each layer was traced from its right to its left extremity, and from the outer towards the inner surface of the heart.

The third plan was that followed by Mr. Savory, of making a series of sections through the walls and tendinous structures of the heart.

The Tendinous Structures of the Heart.—The tendinous structures at the base of the heart, as Lower, John Reid, and Ludwig have shown, give attachment or insertion to the numerous muscular fibres of the walls of the ventricles. These tendinous structures, which I shall briefly describe in successive order, are all firmly connected together, and they rest upon, surround, and support the various great orifices of the ventricles.

1. The great central fibro-cartilage (Fig. 22, A A) is situated upon the septum, with which it is incorporated, between the mitral and tricuspid orifices, and behind the right posterior sinus of the aorta. It gives insertion to very numerous muscular fibres from both ventricles, and origin to many fibres to both auricles.

2. The left fibro-cartilage (B), which is much smaller than the central fibro-cartilage, is seated to the left of the mitral orifice, and behind the left posterior sinus, with which it is closely attached. It gives insertion to numerous fibres from the left ventricle.

3. A strong fibrous half-ring or loop (C C) is situated in front, and to the left of the root of the aorta, and stretches from the left to the central fibro-cartilage, with both of which it is intimately incorporated. This tendinous half-ring is divided into two layers. The posterior or inner layer is united to the anterior and left posterior sinuses of the aorta, and gives insertion to muscular fibres from the left ventricle. The anterior and outer layer gives attachment to numerous fibres from the *conus arteriosus*, and from the left ventricle. The left and central fibro-cartilages (A B), and this connecting fibrous loop, form an united and powerful fibrous structure.

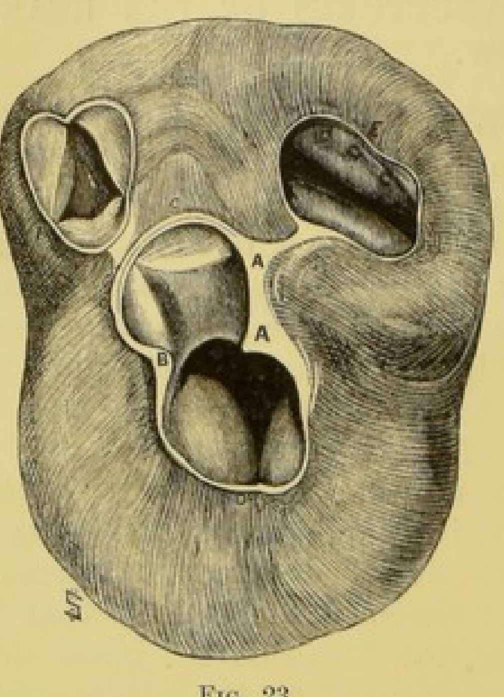


Fig. 23.

4. The tendinous ring of the mitral orifice (D) is united at one extremity to the left, and at the other to the central fibro-cartilage. It gives insertion to fibres from the left ventricle.

5. The tendinous ring of the tricuspid orifice (E) is attached at both ends to the central fibro-cartilage. It gives insertion to numerous fibres from the right ventricle

6. A fibrous ring surrounds the origin of the pulmonary artery (F), which is slightly connected to the fibrous half-ring of the aorta.

Fibrous pads rest upon the muscular floor of each of the sinuses of the pulmonary artery, and upon the muscular structure which gives support to the anterior and left posterior sinuses of the aorta. Numerous muscular fibres are inserted into these tendinous pads, which form the floors of their respective sinuses.

These various fibrous structures of the base are all associated together. They form, in fact, if we keep out of view the fibrous ring of the pulmonary artery, one common fibrous structure, which surrounds the aortic, the mitral, and the tricuspid orifices, which rests upon the bases of the left and right ventricles and their septum, and which gives a general insertion to the muscular fibres of both of those cavities, and a general origin to the muscular fibres of both auricles.

The Muscular Structure of the Left Ventricle, examined from within (Fig. 24).—When a section is made anteriorly through the right ventricle (A) and the septum (B) into the left ventricle, the posterior aspect of that cavity is fully exposed, and the two papillary muscles are brought into view, resting upon and incorporated with its walls.*

* I made the drawings of the muscular structure of the ventricles by tracing the outlines of the intimate structure on a piece of glass placed over the preparation. This method, which has recently been employed in Germany, is the same, substituting glass for lace or muslin, as that by which I made the drawings for this work, and for my paper on the Position of the Internal Organs, and the figures, many of which are

The two papillary muscles lie side by side on the posterior wall of the ventricle, the whole of which they occupy (Fig. 24, 25, C D). The left muscle (D) is solid, massive, and perpendicular. Its truncated extremity and body are connected with the whole base of the ventricle, including the origin of the aorta (E), by strong diverging fibres (F), which are inserted into the tendinous ring and the two fibro-cartilages (E I). It interchanges fibres freely along its whole left border with the fleshy columns of the septum (G), and along its whole right border (H H,) with the right papillary muscle, the two muscles being thus incorporated where they adjoin.

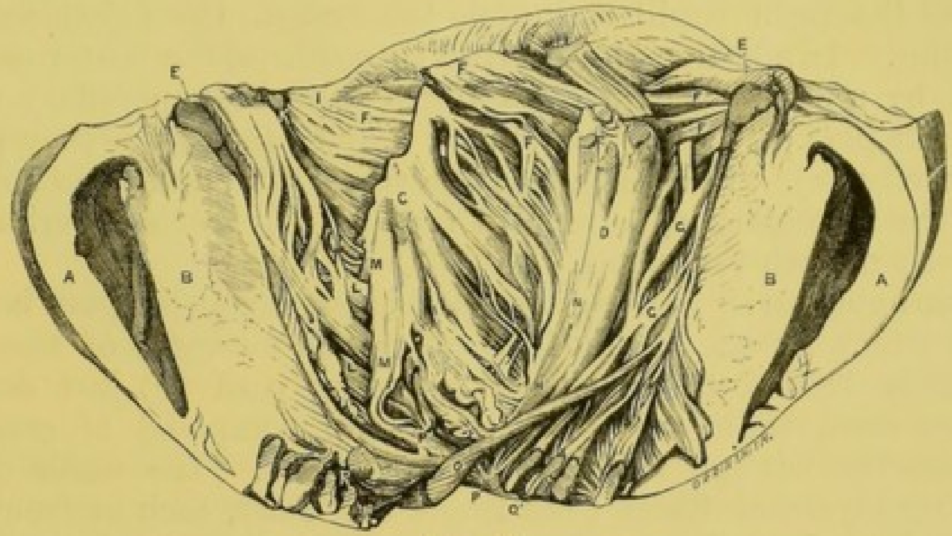


FIG. 24.

The right papillary muscle (C) is straggling, oblique from right to left, and pointed. It is reinforced by bands of fibres along its whole right margin from the right portion of the tendinous ring, the right fibro-cartilage, and (L L) the right portion of the septum, and it gives off many fibres (M M) which pass into the septum, intermingling with those that go from the septum to the muscle (L).

Thus both papillary muscles blend with each other where they adjoin; send diverging fibres to the tendinous ring and two fibro-cartilages; and interchange fibres with the septum and body of the ventricles. It will be seen, therefore, that a complete unity is established between the two papillary muscles, and the base, walls, and apex of the ventricle. The papillary muscles are therefore truly a portion of the walls of the ventricles, and their contraction and that of the walls are not so much simultaneous as one common contraction.

The superficial fibres of the left papillary muscle, the adjoining fibres of the right papillary muscle, and the fibres of the left side of the septum, converge to form a twisted band or cord of fibres (O), which passes out of the ventricle at the apex, where it becomes superficial,

minute, that illustrate my paper on the Mechanism of Respiration, in the "Philosophical Transactions" for 1846. Dr. Hodgkin, who advised me to adopt this plan, saw Benjamin West make use of it in his studio, and to him it had come down, according to tradition, from its inventor, Leonardo da Vinci. I cannot, however, find any account of it in that great master's work on painting.

which takes a direction from left to right, and winds round as it disappears with a bearing upwards and backwards. This superficial band of fibres takes a course over the back of the heart from apex to base, in a fan-shaped manner, diverging so as to cover the posterior longitudinal furrow, and the adjoining fibres right and left.

This cord of fibres (O) as it leaves the ventricle to the right, crosses in front of another cord or band of fibres (P P), which passes from the interior to the exterior of the ventricle, in a direction to the left, in the manner pointed out by Dr. Pettigrew.

The fibres which form this posterior cord (P) come from the right portion of the right papillary muscle (C), and (L) the adjoining part of the septum. In addition, however, to these fibres, the posterior cord is supplied by a fan-shaped layer of fibres from both papillary muscles and the left part of the septum, which bear to the left as they pass out of the cavity (P). They then become superficial, and wind round the front of the left ventricle, being distributed partly to the exterior, partly to the body of both ventricles.

A remarkable series of five or six fan-shaped layers (Q) may be seen in Fig. 24, which lie one behind the other, the foremost of them being immediately behind the posterior emerging cord (P) just described. Like that cord, these successive layers are composed of converging fibres from the left and right papillary muscles. The whole of these converging layers of fibres wind round the heart, each in front of the other, and as they do so, they diverge (R), ascending towards the base, and disappear in the body of the ventricle.

FIG. 25.

The Muscular Structure of the Right Ventricle, examined from within (Fig. 26).—In order to examine this structure, the ventricle was laid open by dividing, first the free wall, close to the septum, from base to apex (A A), and then the *conus arteriosus* (B B), and pulmonary artery (C), close to the base of the left ventricle.

The muscular structure of the right ventricle does not present the remarkable symmetry of that of the left ventricle, whichis adapted to the cylindrical cone-like form of the cavity. The papillary muscles, the intricate fleshy columns which interlace so as to form numerous cells, and the muscular fibres of the right ventricle, are adapted to the remarkable muscular cone leading to the pulmonary artery and to the form of the cavity, the posterior wall of which is convex, being formed of the septum, while its anterior or free wall is concave. The anterior papillary muscle is attached to the anterior wall, while the superior and inferior papillary muscles are incorporated with the posterior wall of the ventricle.

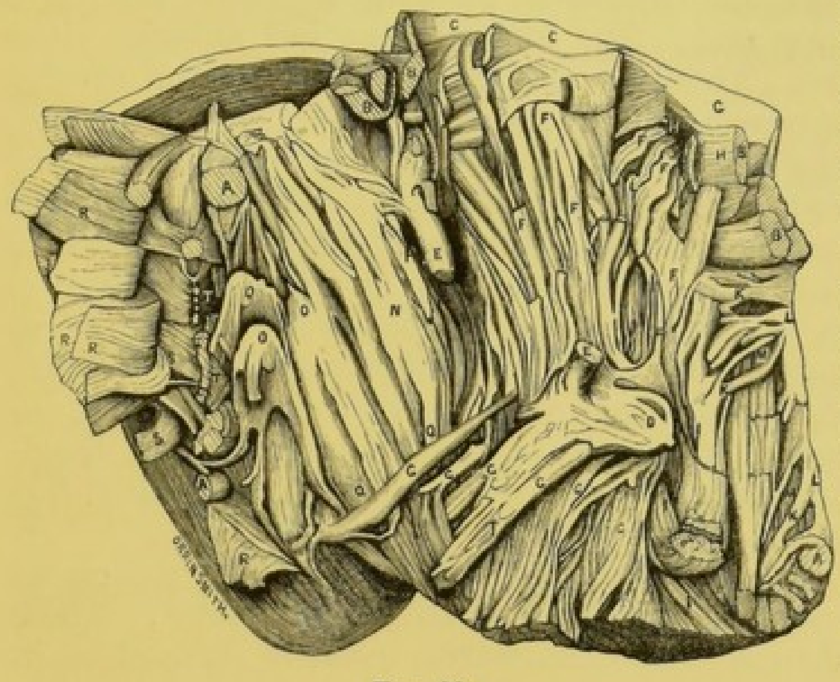


Fig. 26.

The anterior papillary muscle (D) projects into the cavity from the middle of the anterior wall. During the systole, as I have already stated, the anterior wall of the right ventricle contracts from all sides towards the anterior papillary muscle, which is itself in a state of rest. The base, therefore, of the ventricle, the apex, the pulmonary artery, and the septum all move towards that muscle, when the cavity contracts.

A large and remarkable fleshy column (E) extends from the base of the anterior papillary muscle across the cavity of the ventricle to the septum, where it forms a portion of the superior papillary muscle. The fibres that are connected with the base of the anterior papillary muscle are connected also with the root of this column, which forms a bridge of connection between the anterior and the superior papillary muscles, and between the anterior wall of the ventricle and the septum.

The fibres (F), from the anterior papillary muscle to the pulmonary artery, ascend in a direction almost perpendicular; while those (G) to the apex descend in a direction from right to left. These ascending and descending fibres form, therefore, with each other a rather obtuse angle; and as the papilla (D) projects inwards, the papillary muscle, taken in conjunction with those fibres, assumes a pyramidal form.*

The fibres (FF) from the anterior papillary muscle to the *conus arteriosus* and pulmonary artery are very numerous, and are attached to the muscle from its base to its papilla. At first those fibres run

* When looking at Fig. 26, it must be borne in mind that the whole anterior or free wall of the right ventricle is reflected backwards or to the left, in the form of a large square flap (CBLA). Consequently all those parts that look outwards or to the left, in the reflected flap in the drawing, look inwards or to the right, when the anterior wall of the ventricle is *in situ*.

parallel to each other; but as they ascend they diverge, so as to surround the whole cone as it approaches the pulmonary artery. Finally they are inserted into the tendinous ring of the pulmonary artery, and, chiefly, into the tendinous pads upon which the three sinuses (CCC) of the artery rest. The fibres to the left anterior sinus go directly upwards (F). Those to the right anterior sinus diverge in an angular manner forwards and to the right, and those to the posterior sinus diverge backwards and to the right, some of them passing as they ascend into the septum. These fibres are in several layers, one outside the other, and as they approach the pulmonary artery, each of the longitudinal layers (F) is associated with a transverse layer of fibres (HH) which runs in the direction of the circuit of the *conus arteriosus*. These transverse fibres extend some way into the cone, from its mouth at the pulmonary artery. The arterial cone, or infundibulum, is consequently there composed of circular and longitudinal bands of fibres, which are woven in and in with each other, like a circular piece of basket or wicker-work.

Numerous fibres (G) descend from the anterior papillary muscle to the apex and the septum at the posterior longitudinal furrow. These fibres, when unravelled from within outwards, present themselves in radiating layers (GI). The inner or deep fibres (GG) descend towards the apex, while the outer or superficial fibres ascend towards the base, the intermediate fibres taking an intermediate direction.

Towards the base of the ventricle, at the tricuspid aperture (L), the inner fibres of the anterior wall are arranged like a net, with large irregular meshes (KK). These net-formed fibres descend obliquely, and are merged in a group of transverse spiralising fibres, situated just above the anterior papillary muscle, with which it is connected.

By the combined action of these various fibres, during the systole of the heart, the anterior or free wall of the right ventricle contracts from all directions upon the anterior papillary muscle as a centre, in the manner already described.

The posterior wall of the right ventricle is formed by the convex anterior surface of the septum. This surface is comparatively smooth. The superior papillary muscle (PE) is, so to speak, latent, being mainly embedded in the posterior wall of the ventricle. The only prominent portion of that muscle is the strong column (E), which stretches across the ventricle from the anterior to the superior papillary muscle. The inferior papillary muscle (OO) is comparatively prominent, and although it is seated upon the posterior wall, close to the longitudinal furrow, it has also connections with the free wall of the ventricle. A considerable portion of this muscle is, however, embedded in the posterior wall (OQ).

Ascending fibres from the superior and inferior papillary muscles, are inserted into the great central fibro-cartilage. The descending fibres from the same structures, and from the intervening portion of the posterior wall of the ventricle (QQ), when they reach the anterior longitudinal furrow, double upon themselves, and so pass from the posterior wall or septum to the anterior wall. These fibres from the posterior wall, as they pass to the anterior wall, and those from the anterior papillary muscle cross each other where they meet, and are interwoven so as to form an imperfect wicker-work structure (QG).

By far the greater number of the fibres of the free wall of the ventricle, when they reach the posterior furrow, pass directly over the septum, and are incorporated with the fibres of the left ventricle. The majority of these fibres are shallow (R); but some of them are deep (S), so that they may be traced into one of the papillary muscles and the inner walls of the left ventricle.

A certain number, however, of the fibres of the free wall, when they reach the longitudinal furrow, bend upon themselves (TT), and pass behind or into the inferior papillary muscles, and that portion of the septum which forms the posterior wall of the right ventricle.

Examination of the Muscular Structure of the Ventricles from without.—After the thin superficial layer of the muscular fibres of the heart is stripped off, it is easy to separate the subjacent fibres from each other in a succession of layers, which imbricate one over the other. If we examine these fibres on the posterior aspect of the heart (Fig. 27), be-

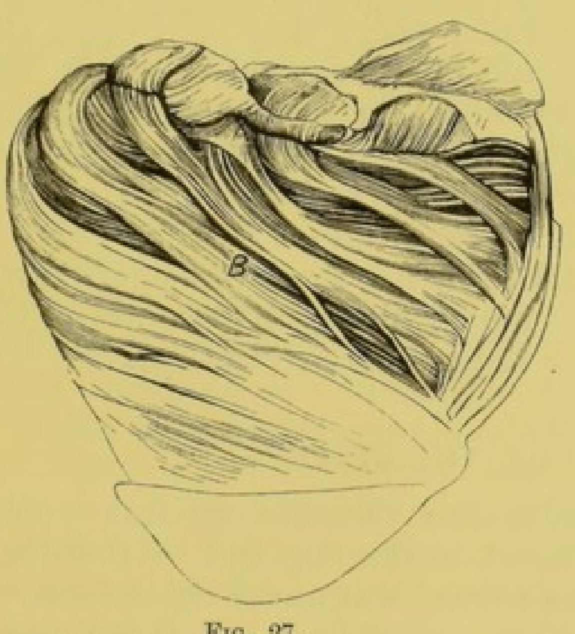


FIG. 27.

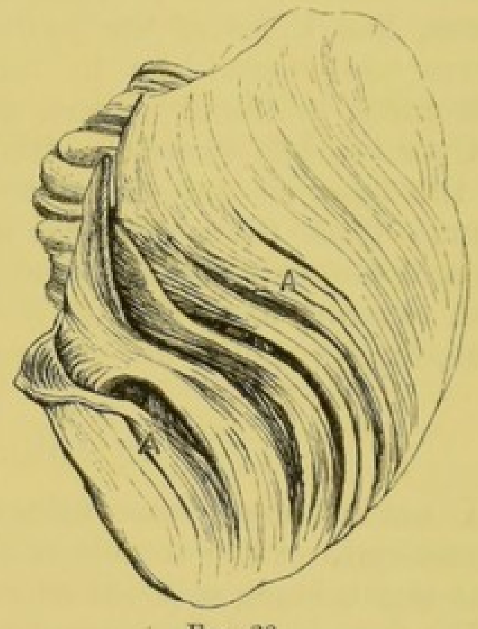


FIG. 28.

ginning at the base, and unravelling them from right to left, we find that over the right ventricle and the longitudinal furrow (AB), they overlap each other in a succession of layers, somewhat like the capes of a coachman's great coat. The right portion of each of these layers is superficial to the one below it. As, however, the layer proceeds from right to left, it twists upon itself, and at length dips underneath that layer, to which it was superficial at the beginning of its course. Each band of fibres, where it turns upon itself, is riband-like in form, and it expands towards either extremity, right and left, owing to the radiating divergence of the fibres, so as to present a fan-like structure.

These layers of fibres are easily separated from each other at the base, along the posterior longitudinal furrow where they are inserted, one below another, into the central fibro-cartilage (A). Some of the layers end in the fibro-cartilage; but others, that pass over the furrow close to the base, send an off-shoot of fibres to the cartilage, so that those layers present the shape of the letter T or Y (A). When this angular off-shoot is traced, it is found to be formed by fibres which come both from the right and the left.

The fibres along the furrow (B), at about an inch from the base, are no longer readily split into layers; for there the fibres of one layer communicate with those of another layer, both upwards and downwards (Fig. 27). This intercommunication is particularly marked where the branches of the artery dip into the walls, and is probably connected with an arrangement to guard the vessels from the pressure of the contracting fibres during the systole.

The distribution of the muscular fibres of the anterior walls of the heart, and of the anterior longitudinal furrow (Fig. 28), when unravelled from without inwards, is, in principle, the same as the distribution of the fibres of the posterior walls. The anterior fibres, traced from left to right, present themselves in layers or bands, which turn upon themselves at the anterior longitudinal furrow A. These bands of fibres, like those of the posterior walls, where they turn upon themselves are riband-like in form, and they expand towards either extremity, by the divergence of their fibres, in a radiating direction.

Over the left ventricle, the higher layers of fibres, or those nearer to the base, are superficial to the lower layers, or those nearer to the apex. These fibres converge upon the longitudinal furrow, where they become band-shaped and horizontal. Thence the layers again diverge, and, twisting upon themselves, the higher fibres, or those nearer to the base, dip under the lower fibres, or those nearer to the apex.

THE SOUNDS OF THE HEART.

I made many observations, with the valuable assistance of Dr. Broadbent, on the sounds of the heart in the dog and in the donkey, that organ being exposed when the animal was under chloroform.

We found that the second sound was most loud and sharp over the arch of the aorta, where the first sound was also heard, the second being three times as intense as the first. The second sound was only half as loud over the pulmonary artery as the aorta, the first sound being equal over the two vessels.

Over the whole right ventricle the first sound was louder than the second. The first sound was, at the beginning and during its course, rather rumbling in character; but it ended in an accent or sharp sound. It was of uniform character, and equally loud, over the *conus arteriosus* close to the pulmonary artery, over the base near the tricuspid orifice, and over the lower border of the ventricle, where it was occasionally of a ringing character. This equal diffusion of the sound over every part of the ventricle demonstrates that the cause of the sound is not concentrated upon any one valve or outlet, but is spread over the whole cavity. The second sound was generally audible, though feeble, over the right ventricle.

Over the left ventricle, also, from base to apex, the first sound began and continued with a rumble, and ended with an accent or sharp sound. It was carefully noticed that this accent corresponded with the precise end or stop of the contraction of the ventricles, when a marked, but not strong shock of reaction was felt over their walls.

The second sound was always coincident with a second impulse or sharp shock felt over the arch of the aorta and pulmonary artery, and not over either ventricle. The loudness of the second sound corresponded with and varied exactly in the ratio of the strength of the second impulse, the sound being loud where the impulse was strong, faint where it was feeble, and almost or quite inaudible where it was imperceptible. The second impulse could be felt strongly at the top of the arch, feebly along its descending portion, not at all over the lower thoracic aorta, and scarcely or feebly over the innominate artery.

The blow made by the return flow of blood from the arteries back upon the arch and valves of the aorta was the common cause of the second shock and second sound. The cause of the second sound is not therefore limited to the semilunar valves, but is common to them and the walls of the arch of the aorta.

Again, the second sound is not due to the closure of the semilunar valves, but to the shock of the return flow of blood upon those valves when already closed. A little consideration will make it evident that the sigmoid valves must come together at the very end of the systole, otherwise blood would at once flow back into the ventricle, during a period that, as M. Marey has shown in his important work on the Circulation of the Blood, precedes the second sound by one-tenth of a second, and coincides with the short pause. During this short pause between the first and second sounds, the walls of the arteries, just charged to the full by the systole, return upon themselves and drive the blood forwards into the smaller vessels, and backwards upon the arch and aortic valves; those valves being already approximated by the elasticity of their under surface, in the manner demonstrated by Dr. Markham, and by the pressure of the blood upon their upper surfaces.

In estimating the cause of the first sound, we must bear in mind that it is equally loud over the whole of the ventricle, that it begins and continues with a rumble, and that it ends with an accent or sharp sound, which is coincident with the extreme contraction of the cavity and with a faint shock felt just then over the ventricle. If the blood be shut off from the heart by tying the venæ cavæ, the second sound is generally extinguished, and the first sound is rendered so feeble as for a time apparently to disappear. There are, however, distinct remains of the first sound. The accent appears to be quite lost, and the rumble is materially weakened, but a feeble rumble is still distinctly heard during each contraction of the ventricle.

It is clear, therefore, that the systolic accent and the louder shear of the rumble are due to the action of the blood on the walls as well as the valves of the ventricle. The accent, which any one may hear by listening over the healthy heart, is undoubtedly synchronous with the end of the systole. At that time the semilunar valves necessarily come together and are pressed against each other by the blood contained in the arch. As the expulsion of the blood must then stop, the fluid remaining in the ventricle probably causes a faint shock or accent at the end of the systole, which shock would not be concentrated upon the valves, but, like the accent, be diffused over the whole cavity, the pressure of the blood being equal in every direction.

The part of the rumble that is still audible when the blood is shut off, is doubtless due to the muscular rumble of the contracting walls of the ventricle.

LONDON: B. PARDON AND SON, PRINTERS, PATERNOSTER ROW.