This paper evidences a structuration of the cardial muscle unsuspected to date. This myocardial organization sets new bases for cardial mechanics and Physiology, pillars on which the great cardiology building rests.

Francisco Torrent Guasp (Gandia, 1931) went to Medical school in Madrid and Salamanca. In 1956 he worked in the Department of Anatomy of the University of Saint Andrews (Scotland). In 1959 he received a Schoolarship from American Heart Association and the Public Health Service of U. S. and did a course on experimental Physiology at the Eugene Talmadge Hospital, Augusta (Georgia). Internist in Denia (Alicante) since 1962. Among his most recent works it is worth mentioning: **La dinámica valvular (1970). The electrical circulation (1970). Estructuración macroscópica del ventrículo Izquierdo (1972).**

francisco torrent guasp

THE CARDIAC MUSCLE

...S OF

juan march foundation

THE CARDIAC MUSCLE

COLECTION OF MONOGRAPHS

SECTION 5.—BIOLOGY, MEDICINE, PHARMACY, VETERINARY AND AGRARIAN SCIENCES

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THE CARDIAC MUSCLE

PUBLICATIONS OF
«JUAN MARCH FOUNDATION»

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The secretary of
the Departament of Medicine,
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reported for ite approval.

* * *

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To Donald Ross

AUTONOMOUS UNIVERSITY
OF BARCELONA

After seeing the proposal made by the Dean of the School of Medicine and in recognition of his scientific worthiness,

THIS RECTORATE *of the Autonomous University of Barcelona, by agreement dated 28 September 1971 appoints*

DR. FRANCISCO TORRENT GUASP
ASSOCIATE PROFESSOR OF PHYSIOLOGY

for the School Year 1971-1972, with annual extendable character by mutual agreement.

Barcelona, October 1sr 1971.

THE RECTOR
VICENTE VILLAR PALASÍ

(There is a facsimile of a rubber stamp on which can be read the words «AUTONOMOUS UNIVERSITY OF BARCELONA - SCHOOL OF MEDICINE)

The author of this work has received a special Grant of the "Juan March Foundation" during 1972.

This work was carried out with the material and moral assistance of the Juan March Foundation. The former has enabled me to carry out these routine acts unfortunately unavoidable, in all human activity. The latter more transcendent, has imbued me with the vigor and agressiveness that the approach to any scientific problem requires. Thus, I have been able to overcome the worst obstacle that over many years of work, has always come between my objectives and I. Solitude.

Therefore I wish to express my gratitude to the Juan March Foundation and all those who have given me their company.

Denia, April 1972.

THE AUTHOR

PROLOGUE

I met Dr. Francisco Torrent Guasp in the National Heart Hospital of London in 1970, where Donald Ross had invited him to deliver a lecture.

«Do you know Dr. Guasp?», Donald Ross asked me. «He is a Spanish physician, from Denia. He has done some works on the anatomy of the heart, which I do not understand, but seem very interesting and I have brought him to the Institute so that the pathologists listen to him». I was full of curiosity with a group of Spaniards because to be exact I had been spending my summers in Denia for the last five years and I had not met Dr. Torrent Guasp.

And Torrent Guasp went to the dais with typically latin candour and grace, took us in his hands from the first instant with his theory of the papillary muscles and did not leave us during a whole hour. It was a mastery lecture full of theories and facts and suggestions; memorable, the Britishers would say. And all of us left with that indefinable emotion of supreme instants. For the first time we were understanding the anatomy of the heart which time and again had eluded our comprehension. Jane Somerville told me a little later, full of enthusiasm, that Torrent said things that were so original, and drew so masterly, that he seemed to be Leonardo da Vinci.

Naturally, since then I am a great friend of Francisco Torrent, but I recognize that I have no merits in our friendship. As Laín would say «my friends are the best because the best are my friends». And Torrent was a countryman enriched with all charisms: coming from a small town on the Mediterranean coast, working in a laboratory of a not yet open Secondary Education Institute, with the simple tools of a dissection forceps, hearts of animals acquired in the local slaughter houses and many ideas and listened to with awe and wonder in the National Heart Hospital of London. Naturally I could not remain indifferent to this situation.

Since then, my Department is honoured periodically with Dr. Torrent's visits in which he shows us his first productions of his very beautiful preparations and tells us about his new findings which he does every day. This is the reason that has made him — I feel — to ask me for an introduction to his monograph «The Cardiac Muscle» whose publication is sponsored by the Juan March Foundation. And this presentation to the English speaking public I make with immense satisfaction not exempt of pride.

In biological sciences there are theories and facts. «The Cardiac Muscle» is an exposition of facts, the most important facts found by Torrent in almost 20 years of research. There is naturally a theory that links facts like the beads of a necklace, but facts are the primary thing. As Warwick, Professor of Anatomy at Guy's Hospital says in a letter to Torrent, his works «are the only extensive research on the cardiac muscles made in the XXth century». And I feel that all of us will agree with Warwick. It is enough to go through this paper to see the unveilling of the incomprehensible mysteries of the superficial and deep bulbospiral bundles, the middle constrictor fibres, etc., and there emerges a three dimension image of a sole muscle oriented and tressed in space. We physicians are in debt with Torrent for having made accessible to us the apparently inintelligible anatomy of this piece of muscle the size of a fist, with a weight of less than 300 grams, that the heart is. His talented theory of the tressed chord, satisfactorily accounts for the anatomical findings of his preparations made with admirable nicety and finesse.

In the history of Science there happen coincidences which are casual in appearance, but which no doubt obey roots that are deeper than luck. When a certain cultural level is reached, from remote places rise scientific concepts — or artistic — which are parallel, tending to a common objective. It can not be casual that Torrent's contribution on the anatomy of the cardiac muscles coincides in time with the new focusing of cardiac Physiology that considers the heart as a muscle in lieu of a pump. The colossal work of Braunwald and Sonnenblick and their school during the past decade to translate the haemodynamic classical concepts in simple terms of muscular physiology, coincides with Torrent's no less important ones clarifying the macroscopic structure of the myocardium. The most developed physiological technology in the world at the side of a simple dissection forceps, but both with a common objective: the cardiac muscle. Parallelly, and with perfect independence, there is developing prodigiously in the clinical field a chapter almost unknown in previous decades, myocardiopathies. So, there is a wide advance front with a common objective: anatomy, physiology and pathology of the cardiac muscle, considered as such a muscle. And the pieces are being put together, to complete a complicated puzzle.

At this point I would wish to call the attention of physicians, above all physiologists, on a concrete aspect of physiology that Torrent's anatomy may light up in a near future. I refer to the geometry of the cardiac contraction. We begin to visualize that the cardiac contraction has an element of rotation — or expression — whose anatomical basis is stated in this publication. It is very plausible that the anatomical concepts brought here have a physiological translation in the mechanisms of systolic expression and diastolic suction.

I am sure that future readers of this monograph will be enthused with this version of cardiac anatomy, full of answers to many problems and of suggestions for many others.

Denia, Labor Day, May 1sr 1972.

PEDRO ZARCO

THE STARTING HYPOTHESIS

In 1953, while studying Medicine in the University of Salamanca, I had the opportunity of studying the left ventricular cavity of a human heart. The observation of the anatomical group formed by the ventricular wall, the papillary muscles and the valve structures was the stimulus for a series of reflections on the function of these structures in life. With it I began a study which I have not yet finished and do not expect to finish.

As a result of the state of mind brought about by the dangerous combination of enthusiasm and lack of experience, I published in a short monograph (22) my doubts and more tentatively, my conclusions. Some of them are still in good standing today. Others, lacking a sound foundation have been discarded.

Initially, in my reasoning I was faced with the following accepted facts:

1) The volume of the papillary muscles represents about 5 to 10 per cent of the whole ventricular muscle mass.
2) The papillary muscles are joined to the cusps of the mitral valve by means of tendinous chords.
3) The intraventricular pressure is lowest at the beginning of ventricular systole.
4) The diameter of the atrioventricular orifice is at its greatest at the beginning of ventricular systole.
5) The papillary muscles contract at the commencement of ventricular systole.
6) The mitral valve closes at the commencement of ventricular systole.

It was disconcerting to think that the ventricular wall and the papillary muscles could be functionally antagonistic structures. The former, by an increase in intraventricular pressure, tends to raise the mitral cusps towards the atrial cavity while the latter by their shortening and subsequent traction would tend to lower them, yet they are claimed to develop their activity simultaneously during systole. If in this context, we bear in mind the disproportion between the massive mechanical potential of the ventricular wall and relatively weak papillary muscles, we may more easily understand how the contractility of the papillars muscles may be overcome by intraventricular pressure at any phase of systole.

However my doubts did not end there. On linking the other five premises already referred to, an erroneous conclusion must result namely that at the beginning of systole, when the intraventricular pressure is minimal and the atrioventricular orifice has its maximum diameter, contraction of the papillary muscle is said to take place with resultant closure of the mitral valve. In other words one is expected to believe, that the cusps — which are hanging open due to dilatation of the ring in end diastole — are closed by sudden tensing of the chordae tendineae from early papillary muscle contraction when in fact it can be seen that if this occurred at this time with cusps in that position, the cusps would be pulled down and the mitral valve would remain open at least in early and middle systole.

It is evident that such a mass of facts in completely inadmissible. Since there is no doubt about the closure of the mitral valve at the beginning of systole, the papillary muscles as part of the ventricular muscle mass should of necesity be relaxed at this time of the cardiac cycle. To imply the contrary supposed an incorrect line of reasoning.

Alternatively, it was possible to venture the supposition that the contractile activity of the papillary muscles took place at the end of systole, initiating the descent of the cusps and the consequent opening of the mitral valve. Such a sequence might suggest itself to any inexperienced observer on seeing the open left ventricle for the first time.

Recently ARMOUR and RANDALL (1), in an experimental paper on the electrical and mechanical activity of the papillary muscles, wrote that «... we must accept the evidence that although the papillary muscles are excited earlier than the epicardial surfaces, mechanical contraction occurs first in the epicardium». They also stated that: «... the sequence of mechanical contraction reported in this communication, was quite unexpected».

Earlier, SMITH, ESSEX and BALDES (19) also expressed their surprise as follows: «It has been believed for years that increased pressure in the auricles is an important factor, if not the sole cause, of the opening of the auriculoventricular valves. We were very much interested and surprised to note that the auriculoventricular valves would open vigorously in the perfused hearts when the pressure in the auricles was the same as atmospheric pressure and was not greater than the pressure in the ventricles».

In 1959, when I worked in the Department of Physiology and Pharmacology of the Eugene Talmadge Hospital in Augusta, Georgia, I observed experimentally that the contraction of the papillary muscles was coincident with the instantaneous fall of pressure in the aorta, usually referred to as the aortic incisura (24). From the reasoning referred to in the beginning, I concluded that the functional significance of the papillary muscles was diastolic and connected with the opening of the atrioventricular valves and not systolic, as it is still considered today.

However other problems arose, particularly the need to explain on a morphological basis the apparent antagonism and functional independence existing between the ventricular wall and the papillary muscles.

Anatomical studies from dissection of the papillary muscles (23), showed that their constituent fibres were only a prolongation of some of the bundles running through the internal half of the ventricular wall. It was not possible, at least anatomically, to demonstrate any structural separation between them. This suggested to me that the subendocardial part of the ventricular wall, of which the papillary muscles were an integral part, could also have a diastolic functional significance. Its action could well be that of dilating the ventricles actively and by the creation of a negative pressure, sucking blood from the atria.

I then reviewed in Physiology texts the factors determining the venous return and soon concluded that even if they all acted at the same time, they could not explain the decreasing pressure gradient within the venous tree from the periphery towards the heart. Thus it was probable that the contractile activity of the internal half of the ventricular wall was responsible for that diminishing gradient.

Although at first Brecher (2) believed that the hypothesis was improbable, he subsequently carried out at my suggestion, some experimental work entitled «Experimental Evidence of Diastolic Ventricular Suction».

These observations, posed a new problem namely to determine any structural fact or morphological evidence which would differentiate anatomically the two strata of the ventricular wall, an external or subepicardial systolic component, and an internal or subendocardial diastolic component.

That provided the stimulus for this monograph.

MATERIAL AND METHODS

In carrying out this work, human, bovine, sheep, dog, pig, cat and hen hearts have been employed but generally it has been more convenient to use the material at hand which has been obtained from oxen, pigs and sheep. Our subsequent studies on human, dog and cat hearts have confirmed the validity of our findings in the species originally examined. This is in keeping with the experienced PETTIGREW (15) who asserts in his work on myocardial structure, «... it is the same in all mammals, *man* included...». The preparation represented in the lower reproduction of figure 1, corresponds to a human heart; those of figures 28, 53, 63 (left) and 64, to a pig heart; those of figures 7 (right), 18, 29 (below), 43, 55 (below) and 85, to a sheep heart; the remainder to cow heart.

Some of the hearts were from embryos. It was not possible to determine accurately the embryological stage to which they belonged, but generally they varied between three and six months of gestation.

It is impossible to be sure of the number of hearts studied, but taking into account the average work load during 19 years, the number may be close to a thousand.

The hearts have always been prepared by the same method: boiling in water to which previously has been added glacial acetic acid in approximately 10 ml per liter. The boiling time depends on the size of the specimen. It varies between two hours for an adult ox heart to five minutes or less for young embryo hearts.

After boiling, the remnants of both atria, aorta and pulmonary artery, are resected. Then the fat of the atrioventricular grove is separated and all the superficial coronary vessels are excised. The ventricles are then ready for study.

It is preferable to use the hearts of young animals.

The instruments required are non-tooth forceps, a scalped and scissors. However, it is recommended to rely as much as possible on blunt dissection with the fingers.

THE MYOCARDIUM. HISTORICAL BACKGROUND

During the last four centuries, various authors have shown their interest in clarifying the complex structure of the cardiac mulculature. They have evolved various and uneven concepts of the macroscopic structure of the myocardium. On reviewing such works, one can see that in fact, even if some of their ideas coincide with certain observed facts, the theses differ substantially.

The first useful contribution was made by LOWER (1669) (10), who showed that the most superficial subepicardial fibres in the left ventricle, underwent a characteristic torsion at the apex, to become subendocardial. In 1749, SENAC (18) stated that the fibres of the external and internal surfaces of the ventricular wall, adopted an arrangement close to the vertical in contrast to the most central fibres, which had a tendency to be horizontal. Later on, PETTIGREW (1863) (15) described the opposite arrangement of the internal and external myocardial fibres of the ventricular wall. MALL (11), in 1911, identified three types of fibres in the form of a V, whose angle varied progressively from the most superficial to the deepest.

The conclusions reached by these four authors, although they are only partial interpretations of the same morphological fact, indicate progress in the study of the myocardial structure.

In this way we come to the present time when it may seem surprising but the anatomical problem at a macroscopial level, still does not have a satisfactory explanation. As TANDLER (21) says, «on studying the history of the works carried out by anatomists with the object of ordering the complicated texture of the musculature of the heart, one ascertains beside the reality of those efforts, the repeated times in which the products resulting from an artificial preparation, have been taken for natural formations, describing as morphological elements, what really were nothing but artificial products».

What explanation can be offered for such disappointing results? Perhaps one is that the solution to the problem is completely alien to the technological progress of the present day research establishment. The macroscopical study of the myocardium, at the most requires only simple dissecting forceps. Perhaps the present day technology is too sophisticated and elaborate to solve the problem.

The fundamental difficulty that has always faced anatomists in the study of the cardiac muscle, is that at macroscopical level, the usual concept of a muscular fibre cannot be applied to the myocardium. The alleged myocardial fibre, in an artificial product which may adopt infinite forms and dimensions, according to the idea of the person doing the dissection. Morphologically and macroscopically, the myocardial fibre cannot be defined. The connective tissue which lies within cardiac muscle, does not single out muscular entities totally independent from neighbouring homologous structures. It would be easy to follow a fibre that was embedded in its entirity in a sturdy connective sheath and if such were the case, the problem of the structure of the myocardium would have been solved long ago.

Although the muscular and connective tissue of the myocardium, is not organized according to the fibre concept, systematic study of its characteristics discloses the general plan of the arrangement of the cardiac musculature. It appears that the connective and muscular tissues of the myocardium are arranged in the form of tubes and bodies of a more or less polygonal or cylindrical transverse section, which on all sides give and receive oblique side branches. The existence of these side branches is not an obstacle to defining a clear and predominant axis of direction of the muscle bundles. By gentle traction on a particular muscular mass, it can be separated from the rest of myocardium in a pre-established direction, which does not depend on the line of pull given by the traction. In other words there is a natural plane of cleavage, and any deviation by forceful pulling will rupture the individual muscular tract.

If the clamping and subsequent traction are carried out on and individual fibre or simultaneously on several fibres in the same plane, the effect will be different. With the single fibre, a linear pathway will be shown, while with the bundle of fibres will be uncovered a cleavage plane, resembling a sliding surface. Such concepts, linear pathway and sliding surface, are usually mistakenly identified with muscular fibre and band or layer, respectively.

The number of muscular bundles that may be defined in the ventricular myocardium is infinite, the characteristics of each of them always depending on the thickness of the muscular mass selected by the forceps in the dissection. However, the spatial arrangement of the longitudinal axis is constant and invariable at any given level of a particular area of the ventricular wall. This is the fact on which to base the study of the muscular structure of the heart. There exists in the myocardium a big diversity of predominant directional axes arranged in orderly planes, to which the corresponding myocardial «fibre» owes its personality, a functional personality, not a morphological one, depending solely on the arrangement in space adopted by those axes.

In summary, in the ventricular myocardium one cannot think in terms of muscular fibres and layers. It is better to refer to linear pathways and sliding planes. However, usage has consecrated the words fibre and layer and we will continue to use them in this description for the sake of clarity, since it is easier to grasp the concepts of a fibre and a layer than the concepts of a trajectory and a cleavage plane.

THE ORGANIZATION OF THE CARDIAC MUSCULATURE

In the first place a series of nine anatomical facts derived from simple dissection will be described separately. An attempt will be made to integrate these apparently unrelated observations into an orderly anatomical entity.

FIRST ANATOMICAL FACT

When traction is applied to a particular group of fibres on the epicardial surface of the apical half of the ventricular wall, a cleavage plane is developed which deepens progressively into the thickness of the ventricular wall (23). This cleavage describes a helix-like pathway from epicardium to endocardium (fig. 1). Depending on the skill and competence of the dissector several such planes can be developed (fig. 2).

Therefore the apical half of the left ventricle, can be shown to be made up of a series of myocardial layers or sheets, circularly imbricated that following and helical pathway, run from epicardium to endocardium (23).

If extended on a plane of flat surface, each muscular layer takes the form of a half-moon (fig. 4 a). Twisting both ends (fig. 4 b and c), reproduces the arrangement which is found in the left ventricular wall. The characteristic torsion of the epicardial-endocardial fibres at the apex is shown in fig. 4 c. At the point where these fibres are reflected from the external to the internal surface of the ventricular wall, a virtual orifice (fig. 5) can be defined. This is the centre of the apical vortex and is the only point in the ventricle where epicardium and endocardium are in direct contact.

As fibres are peeled off successively, this apical orifice changes from potential to real (fig. 6) and progressively increases its diameter (fig. 7), which implies a corresponding decrease in the dimensions of the muscular layers. This process is illustrated in figure 8.

The upper scheme of figure 9, reproduces an apex with six muscular layers represented in black and white, alternately. The lower scheme of the same figure, shows that the white layers have been eliminated; it reproduces in sketch form, the anatomical preparation reproduced in figure 10.

When dissection is carried out from epicardium to endocardium as shown in figures 6, 7 and 10, after eliminating the most superficial fibres, several muscular layers can be evidenced. But when the deep fibres from within outwards are peeled off successively instead of the superficial ones — fig. 11 — a circular channel will be obtained in the full thickness of the ventricular wall and not a muscular layer. Thus arises the concept of the «double cone» (6, 7, 8), which partly serves, as one structural concept of the ventricular wall (fig. 12). Nevertheless both the muscular layer and the double cone, are unconvincing as anatominal entities, as they appear to be defined only after the ventricles are divided by a transverse cut. However, such concepts can be useful for teaching purposes until more is known of the organization of the ventricular myocardium.

The circular configuration of the ventricular wall implies two concentric surfaces, one epicardial and the other endocardial. This fact, together with its structural characteristics consisting of the myocardial fibres arranged in muscular layers which twist spirally and run from epicardium to endocardium, helps to explain the morphological significance of the anatomical entity known, rather arbitrarily, as the papillary muscle (23). In effect, the convergence of all the muscular layers on the endocardial surface (fig. 13 a), creates a problem of space solved only by the separation off of some fibres from the rest of the layer. Such fibres appear within the ventricular cavity as an orderly grouping to form the papillary muscles (fig. 13 b, c and d). Others are arranged irregularly inside the ventricular cavity giving the endocardial surface its irregular appearance.

SECOND ANATOMICAL FACT

On starting the study of the basal half of the left ventricle, it was surprising to note that except for a small group of the most superficial fibres, the rest of the myocardial bundles ran from the external to the internal surface of the ventricular wall (32, 33) without being inserted in the mitral fibrous ring (fig. 14).

As was found at the apex (fig. 2), the basal half of the left ventricle is also formed of cleavage planes (fig. 15) which start in the epicardium, follow a helical pathway (fig. 16, upper preparation), are reflected at the valve ring and reach the endocardium (32, 33).

A similar dissection to that in figure 6, again produces evidence of a series of muscular layers such as those demonstrated in figure 17 and 18. Extended on a plane surface, such a layer, as at the apex, adopts the form of a half-moon (fig. 19).

In the light of these facts, the basal half of the left ventricle (32, 33) may also be considered to be made up of a series of circularly imbricated layers (fig. 20), which follow a helical pathway from epicardium to endocardium.

As at the apex (figs. 11 and 12), it is possible in the basal half of the ventricle to carry out a dissection from within eliminating the deep fibres instead of the superficial ones. Again a channel is evident (fig. 21) within the thickness of the ventricular wall (32, 33). For these reasons, the basal half of the left ventricle may be considered to be formed by a series of double cones (fig. 22) of progressively increasing dimensions fitting one another in orderly fashion just as at the apex (fig. 12).

One fundamental feature, however, distinguishes the structure of the basal half from that of the apical half and that is the opposed spatial arrangement of the constituent myocardial layers.

Figure 23 reproduces a base — upper preparation — and an apex — lower preparation — in anatomical position. At the base, the muscular layers run from subepicardial to subendocardial and from right to left while at the apex, they run from left to right (32, 33).

To explain the opposed arrangement of the basal and apical myocardial layers, requires an anatomical structure with a geometrical configuration similar to an 8 (fig. 24; compare with fig. 23).

Figure 25 explains in sketch form the «assembly» of such an 8. Also a transverse cut across it results in two layers which assume the shape of a half moon when laid flat.

In figure 26, there are represented several cardboard models of the 8 referred to. In figure 27, one sees an anatomical preparation with the same pattern. One can appreciate from it the apical lacing of the 8, but not the basal, which appears poorly defined as it reaches the right ventricle. As may be seen in figures 2 — lower preparation —, 7 and 15, in the area corresponding to the ventricular septum, the regularity of the myocardial structure seems to be interrupted. After the study of the right ventricle, this apparent variation becomes clear.

As may be appreciated from figures 17 and 18, the free wall of the left ventricle and the interventricular septum, defines one large basal orifice which embraces both the mitral and aortic valve structures. Consequently the dynamics of both valves must be fundamentally interdependent so that an increase in the diameter of the mitral orifice in diastole, implies a corresponding decrease in the diameter of the aortic orifice and the reverse during systole (24, 30, 32, 33). Such facts are ignored in the design and use of valve prosthesis surgically (14, 17). This is referred to later.

THIRD ANATOMICAL FACT

A dissection of the basal half of the free wall of the right ventricle, shows that the majority of the myocardial fibres (figure 28), run from subepicardial to subendocardial surface without being inserted at the tricuspid fibrous ring, an arrangement similar to that at the mitral ring (fig. 17). In addition, these fibres, equally grouped in layers (fig. 29), also appear imbricated except in the zone that corresponds to the interventricular septum. In all these respects there is a parallelism between the two ventricles. In effect as in the basal half of the left ventricle (fig. 14), the layers run from subepicardial to subendocardial and from right to left.

In fact, except for a small group of superficial fibres, the myocardial bundles of both ventricles run from epicardium to endocardium with no insertion into the fibrous skeleton. This highlights the error of the classical concepts based on the function of skeletal muscles in which the fibrous skeleton of the heart is believed to provide the support or point of insertion of the myocardial fibres during their contraction. The circular morphology concept illustrated by the two circles of the figure-of-eight, suggests as with the circular fibres of the digestive tract or of blood vessels, that the point of action of the myocardial bundles is on the contents — in this case blood — of the cavity they enclose. Abandoning the purely mechanical concept, one has therefore to speak in terms of a «haemoskeleton» of the heart and not of a fibrous skeleton.

FOURTH ANATOMICAL FACT

The lower limit or «apex» of the cavity of the right ventricle, is determined by the junction of the free wall and the interventricular septum. Dissection confirms the basic structural characteristics already referred to (figs. 30 and 31). Again the myocardial fibres are grouped in imbricated layers running from subepicardial to subendocardial surface, as in the basal half.

There is, however, a fundamental difference between the basal and apical sections of the free wall of the right ventricule. In the base, the myocardial layers deepen from right to left (figures 28, 29 and 32, upper preparation); in the apical part they deepen from left to right (figs. 30, 31 and 32, lower preparation). A comparison of figure 32 with figure 23, again emphasizes the close structural similarity between the left and right ventricles.

The free wall of the right ventricle is constructed in the same way as that of the left, by a series of imbricated layers, as it is shown by dissection (fig. 33). From the most superficial to the deepest, the fibres comprising the successive layers, slowly change direction so that the subepicardial and the subendocardial, appear crossed in an X (fig. 34). Again the image of an 8 emerges. In figure 35 one again sees the crossing of the superficial and deep fibres.

FIFTH ANATOMICAL FACT

Two separate groups of fibres may be distinguished in the myocardial configuration of the front wall of the right ventricle. The first consists of a series of subepicardial fibres, which run from the free wall of the right ventricle to the anterior surface of the left and adapt themselves to the depression of the anterior interventricular groove (fig. 36).

The second deeper group of fibres, is represented by a series of subendocardial bundles, which running from the free wall are reflected onto the interventricular septum (fig. 36, right preparation, 37 and 38).

SIXTH ANATOMICAL FACT

Similarly, two separate groups of fibres may be identified on the posterior wall of the right ventricle. The first consists of a series of subepicardial fibres which run from the free wall of the ventricle onto the posterior aspect of the left, and adapt themselves to the depression defining the posterior interventricular groove (figs. 40, 41 and 42).

The second and deeper group (see also figs. 40, 42, 43 and 44) as on the anterior surface, is reflected onto the interventricular septum.

SEVENTH ANATOMICAL FACT

From the basal aspect of the free wall of the right ventricle, a series of subendocardial fibres arise some of which arch over to the septum in the manner of a bridge to form the supraventricular crest. Others, follow an upward course to end in the ring of the pulmonary artery where they are inserted (figs. 45, 46, 47 and 48).

EIGHT ANATOMICAL FACT

After their reflexion, the deep fibres forming the supraventricular crest and the deep posterior ones of the free wall, descend vertically on the ventricular septum toward the apex (fig. 49). This is the only place in the ventricular myocardial mass where two contiguous groups of fibres lie at right angles (fig. 50).

In figures 51 and 52 various specimens show the myocardial bundles reflecting from the supraventricular crest and the posterior contour of the tricuspid orifice to run vertically toward the apex in the shape of a waterfall.

NINTH ANATOMICAL FACT

The anatomical facts referred to above were observed as isolated morphological findings during the course of these dissections but a general plan linking them together in a coherent pattern was not inmediately obvious. After several fruitless attempts I decided to investigate the problem in embryo hearts with the hope that it would be easier to find a clue to the solution in the earliest stages of cardiac development.

In an embryo heart, an incision along the anterior interventricular groove, divides that group of fibres (fig. 36, a) which runs from the free wall of the right ventricle onto the anterior surface of the left. This bring into view a distinct cleavage plane, which runs through the interventricular septum. Unwrapping the preparation further along, that cleavage plane (fig. 53, *3*) defines two partially separate ventricles. If the unwrapping process is continued, it then becomes apparent that the left is arranged as a spiral muscular band (fig. 53, *4* and *5*).

The successive stages of the dissection have been sketched in figure 54 and with different specimens in figure 55.

Looking more closely at this muscular band, one can see that the myocardial fibres constituting it, adopt an oblique arrangement in space. Again the subepicardial and subendocardial components run in opposing directions. This structure can be compared to a ribbon twisted in the shape of a flattened rope (fig. 56).

Uniting both preparations of figure 23 with those of figure 32, they suggest a rope-like arrangement.

In figures 57, 58 and 59, may be observed a myocardial band with the opposite arrangement in space of the epicardial fibres and the endocardial ones. Both fibres are crossed in the form of an X.

The fibres constituting this flattened rope-like band, do not end or begin in the upper or lower edge of the band. Without interruption, they run successively from one surface to the other. It explains four basical anatomical findings: The direct passage of the superficial fibres to the inside of the ventricular cavity, in the base of the left ventricle (32, 33) (figs. 14, 17 and 18); in the base of the right ventricle (figs. 28 and 29); in the apex of the left ventricle (figs. 5 and 6); in the apex of the right ventricle (figs. 30 and 31). As happened in the apical contour of both ventricles, in the basal one of them, the fibres from subepicardial becomes subendocardial, without making any insertion in any fibrous ring. It is done in a rope-like form. The ventricles are therefore tubular cavities, not ventricular cavities.

The rope concept suggested by the twisted muscular band flattened laterally, permits one to conceive a unifying structural plan in which each of the anatomical fact described are linked.

THE MORPHOLOGICAL SEQUENCE OF THE ANATOMICAL FACTS

A short length of rope is shown (fig. 60). After arranging it in the shape of a curl (fig. 61) its two ends have been united (fig. 62). The sketch of the rope so arranged constitutes the clearest and at the same time the simplest reproduction of the general plan of organization of the ventricular myocardium. In any event, it is at present the only pattern which offers an explanation of the structural particularities of the ventricular muscle in its various aspects.

In figure 63, one sees a comparison between figures 17 and 18 and the sketch of figure 62. The close parallel between the arrangement of the myocardial fibres along the upper edge of the free wall of both ventricles and those adopted by the fibres of the rope may also be appreciated in figure 64.

Inverting the rope (fig. 65) and again comparing it with the arrangement of the myocardial fibres at the apex of both ventricles, we may again observe the similar arrangement of their respective components.

Continuing the comparison, figure 66 explains the fact that in the basal and apical halves of the left ventricle the myocardial layers run in opposite directions — right-left and left-right —. The observation that the fibres comprising the basal and apical halves of the free wall of the right ventricle pass from the external to internal surfaces in opposite directions is also explained (fig. 67).

If instead of joining the ends of the rope as they appear in figure 62, we place them in the manner depicted in figure 68 and latter in figure 69, we will obtain a more complete representation of the general plan of organization of the ventricular myocardium. Such a model may be compared with the anatomical preparations in figures 70, 71, 72, 73, 74 and 75. In figures 76 and 77, the same rope model can be compared with previous anatomical preparations, already studied.

In figure 78, may be seen an anatomical preparation of both ventricles viewed from their anterior aspect, in which the great myocardial band appears extended from top to bottom in the shape of a spring. In figure 79 the same preparation, may be compared with the rope. If the ends are fused perfectly and both twists placed in the same plane, the same configuration as shown in figure 62, is obtained.

The fifth anatomical fact (figs. 37 and 38), is not explained by figure 69. However if one starts with the arrangement adopted by the rope in figure 68 and it is successively arranged as represented in figure 80, all the anatomical facts indicated, without exception, are reproduced (figs. 81, 82 and 83).

A simple tranverse cut though both ventricles (fig. 84) discloses an outline of the general plan of the organization of the ventricular myocardium; a few minutes dissection (fig. 85) will completeyl clarify this architecture.

In summary, the ventricular myocardium when unrolled presents as a flat muscular band. By its special arrangement, in the intact heart it forms two cavities. It is not therefore correct to speak of right and left ventricles but only of right and left ventricular cavities, one single muscle and two cavities, one single morphology and two functions.

THE GOWN OF THE HEART

The description of the ventricular myocardium presented in the preceding pages, would be incomplete if mention were not made of the muscular layer (23) which runs from the supraventricular crest toward the apex and anterior and posterior surfaces of the left ventricle. It is thickest at the level of the supraventricular crest and thins progressively as it extends toward the apex and both sides.

Even macroscopically, its fibres appear different from those of the rest of the ventricular mass, being weaker, finer and thread-like. Such features and their position, allow easy identification.

It seems unlikely that its function is mechanical; it is possibly related to the system of impulse conduction (23).

THE VALVULAR DYNAMICS

Although in previous publications (24, 30, 14) this subject has been discussed more extensively, the following is a brief summary of what has been observed to date.

On making a transverse cut at the base of the atria and large vessels a short distance above the fibrous rings, one sees four orifices (fig. 86, upper left preparation): mitral, aortic, pulmonary and tricuspid. If another cut is made transversely at the base of the ventricles, also a short distance below the fibrous rings, three orifices will be seen: pulmonary, tricuspid and the one which should be called mitroaortic (fig. 86, upper right preparation; see also fig. 18). Another cut in the middle third of both ventricles shows two orifices, that of the right cavity and that of the left cavity (fig. 86, lower left preparation). Lastly, another cut near the apex, will show only one orifice: that of the left cavity (fig. 86, lower right preparation). At the base of the ventricles there exist therefore only three orifices and not four.

Two facts emerge, (a) the apex corresponds solely to the left ventricle while (b) the aortic and mitral orifices are mere subdivisions of a common orifice, the mitroaortic. In effect, between the aortic and mitral rings there is no ventricular myocardial tissue to separate them. This anatomical feature is of special importance in relation to the mitral and aortic valvular dynamics. In figures 17 and 18, the single mitroaortic orifice, the big orifice defined by the base of the left ventricle, is shown.

All the blood passing into the left ventricle during diastole is ejected during systole into the aorta. This implies a simultaneous reduction of the diameter of the mitroaortic orifice and at the same time an increase in the diameter of the aortic orifice, that is a constriction of the ventricle and a dilation of the aorta (figs. 87 and 88). The closure of the mitral orifice is concurrent with the opening of the aortic orifice and *vice versa* (figs. 89 b, c, d, and f, g, h, respectively).

In considering valve closure and opening, one must therefore bear in mind not only the ascent and descent of the valves — the axial component — but also their approximation and separation — the transverse component — (fig. 90).

In the dynamics of the atrio ventricular valves, the transverse component predominates. In the aortic and pulmonary valves, the opposite obtains, the axial component dominating closure and opening.

From the foregoing it may be easily inferred that valvular prosthesis mounted on a rigid ring will result in the inmediate cancellation of the transverse component, which is of primary importance in the atrioventricular valvular dynamics. The ventricular mechanics will also be seriously affected since the rigidity of the rings prevent full ventricular constriction and dilatation.

Since the transverse component is of secondary importance in aortic valve dynamics, valvular prosthesis with rigid rings in the aorta will not be associated with such functional disturbances as in the mitral.

In the closure and opening mechanism of the tricuspide orifice, the transverse component is even more important than in the mitral orifice and so has a bearing on valve replacement surgery.

* * *

The observations described in this monograph represent no more than a beginning of what can be done. There are many other morphological problems. I hope to have time and spiritual calmness to be able to reach its solution.

I am longing too for the study of the mechanical, electrical and accoustic aspects of the heart function, starting from the morphological bases stablished in this work. No doubt they will provide clinical suggerences.

I am anxious too, to study the phylogenetical steps of the heart evolution. I have the conviction that this field will provide the bases of the future Cardiology.

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ILUSTRATIONS

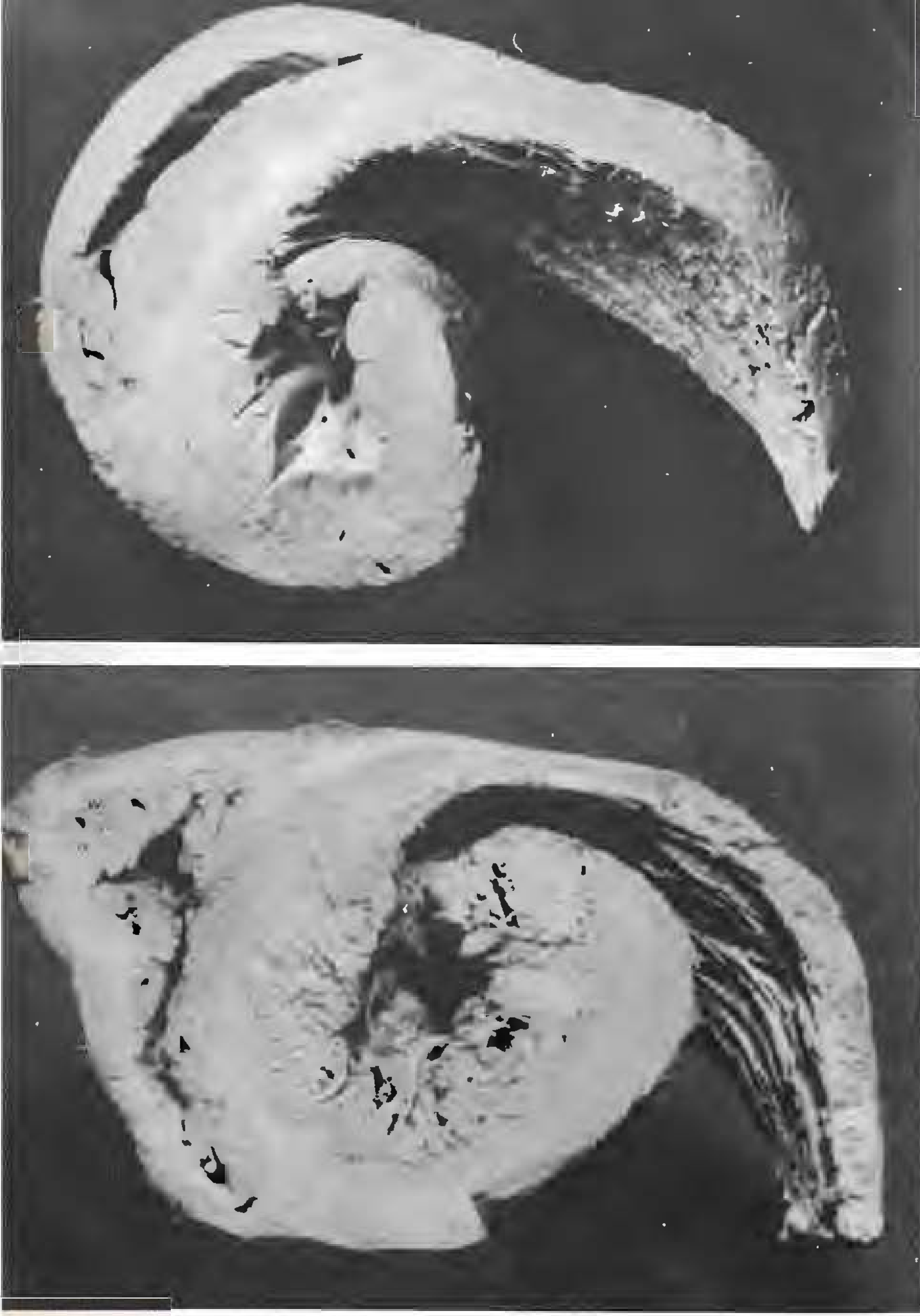
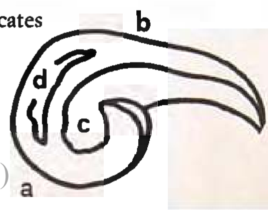


Fig. 1

Transverse cut through both ventricles. Apical half: a, indicates the anterior interventricular groove; b, posterior interventricular groove; c, left ventricle; d, right ventricle.



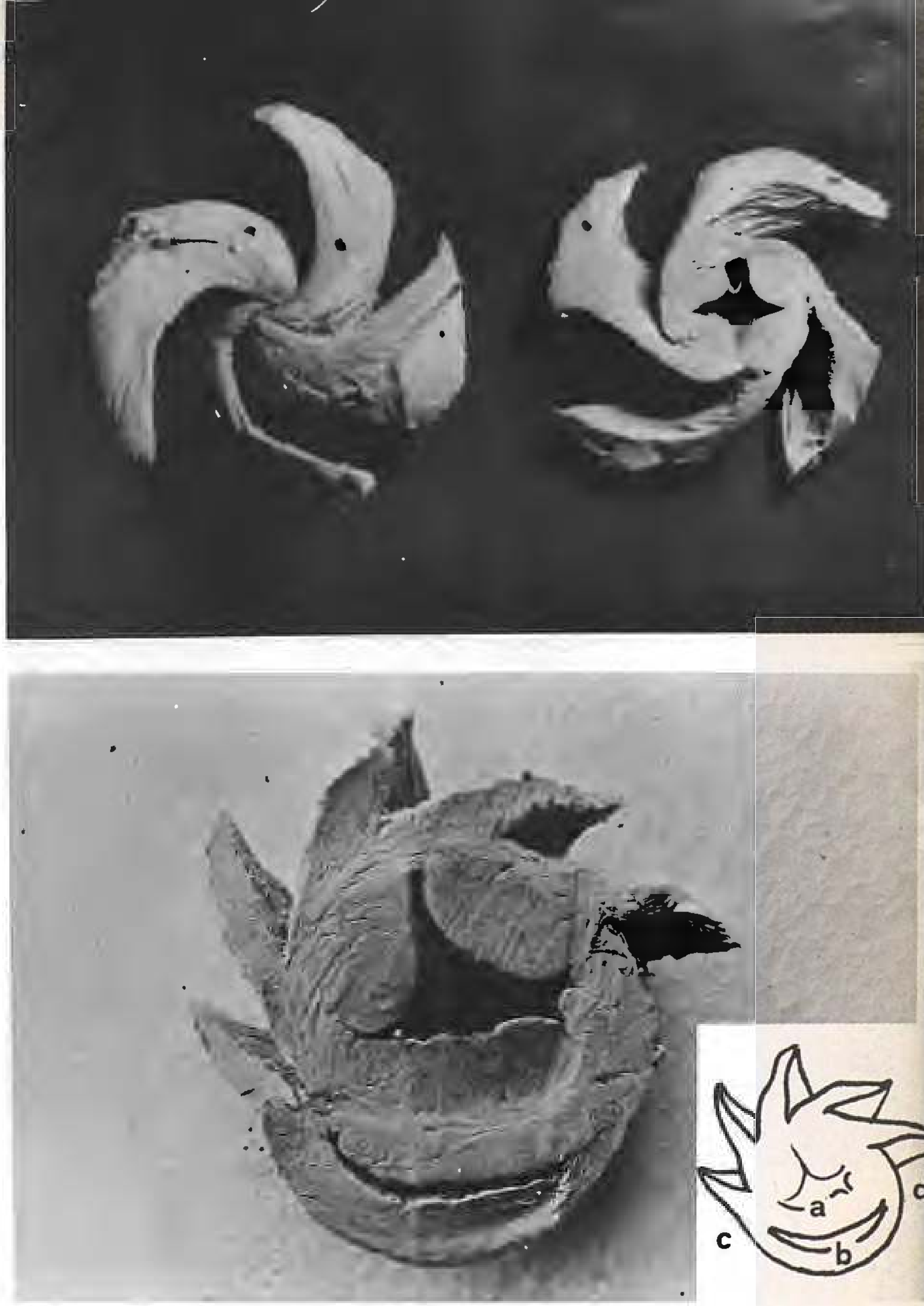


Fig. 2

Top: two anatomical preparations showing an apex seen from the epicardial surface — left — and the cut surface — right —. Four cleavage planes have been shown in both. Bottom: apical half shows cut surface. Five cleavage planes have been demonstrated; a, indicates the left ventricle; b, right ventricle; c, posterior interventricular groove; d, anterior interventricular groove.

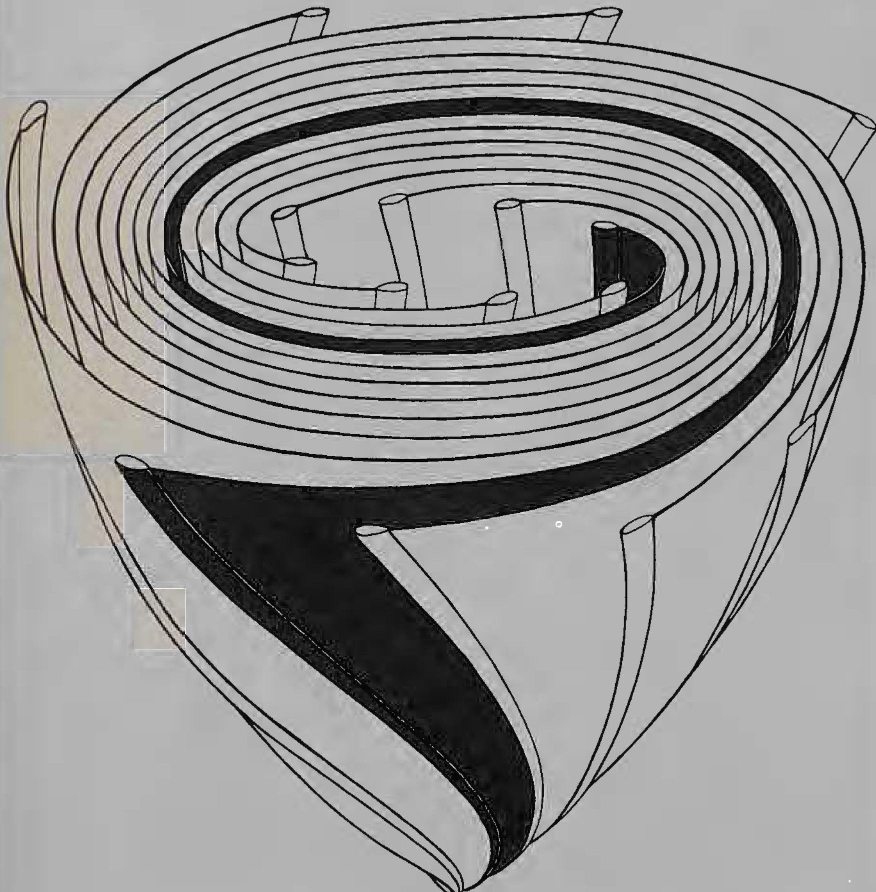


Fig. 3

Layered structure of the apical half of the left ventricle. Explanation in the text.

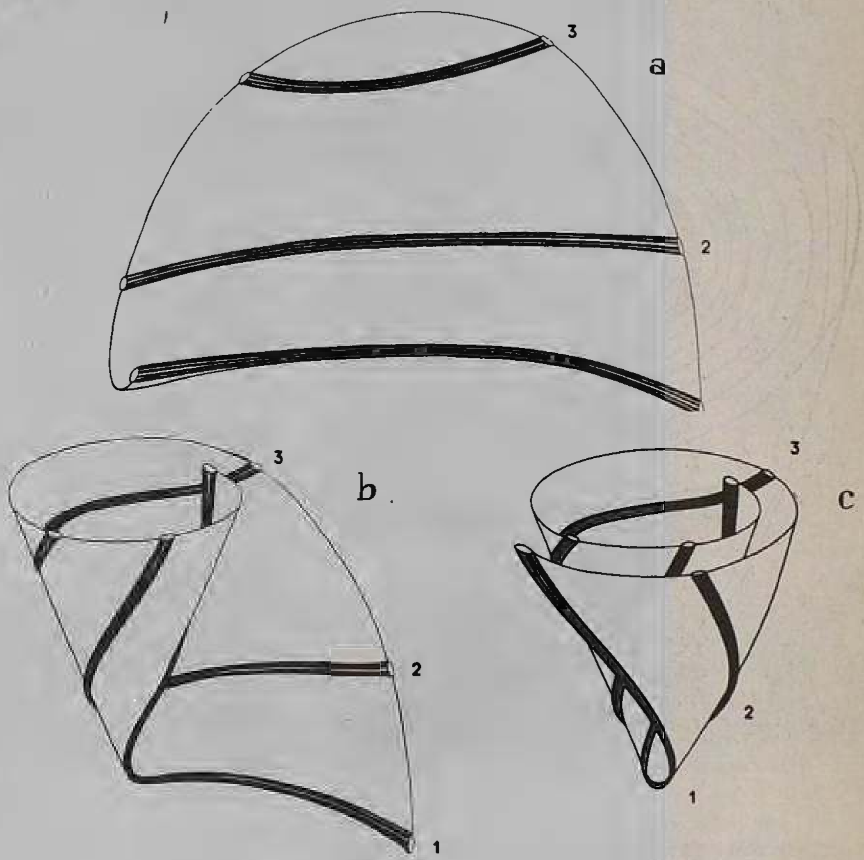


Fig. 4

A myocardial layer from the apical half of the left ventricle. Explanation in the text.

Fig. 5

At the apex, the most superficial subepicardial fibres, become subendocardial around a point which defines a virtual orifice between the ventricular cavity and the outside. In the intact heart, this orifice is closed by a double layer of endocardium and epicardium.

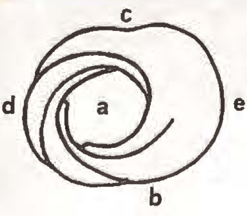


Fig. 6

Layer structure of the ventricular wall at the apex. Compare this preparation with the sketch of figure 3. a, indicates the left ventricular cavity; b, anterior interventricular groove; d, left border of the heart; e, right border.

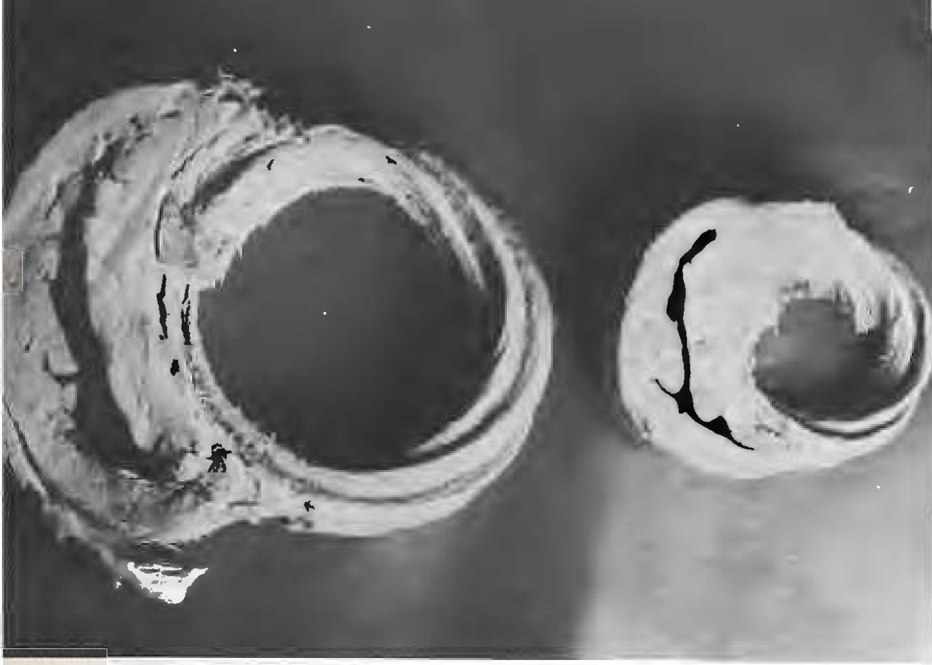
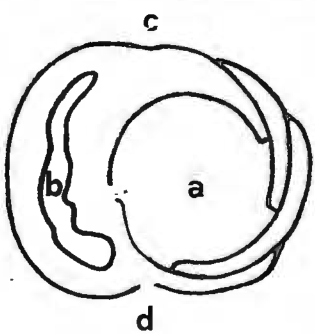


Fig. 7

Transverse section of both ventricles, seen from the apical aspect.
a, indicates the left ventricle; b, the right ventricle; c, anterior interventricular groove; d, posterior interventricular groove.



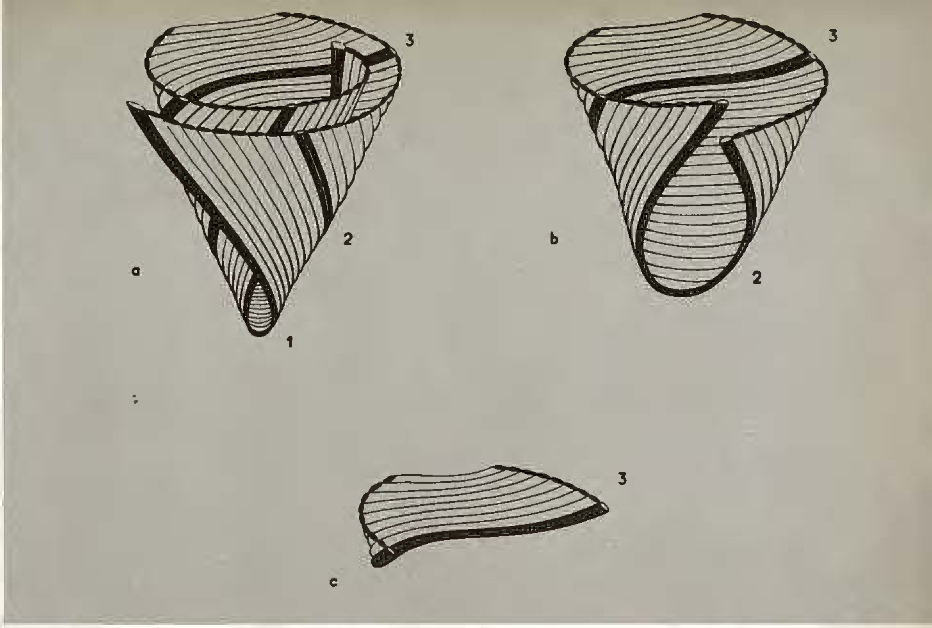


Fig. 8

A single myocardial layer. Number 1, 2 and 3, indicate the fibres represented with the same numbers in the sketchs of figure 4. a, corresponds to an intact heart; b, to the specimen of figure 6; c, to the specimens reproduced in figure 7.

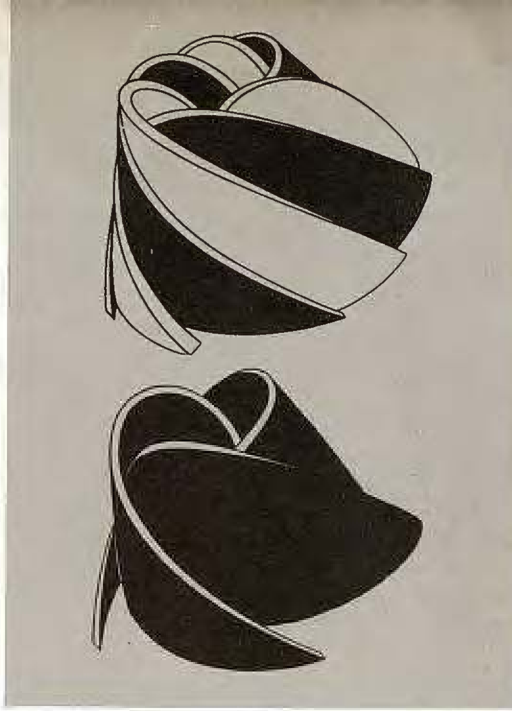


Fig. 9

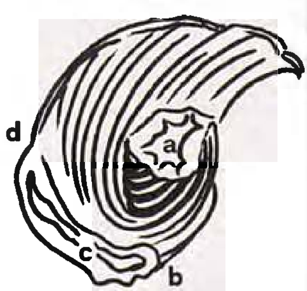
Diagramatic representation of the apical half of the left ventricle. Explanation in the text.

Fig. 10

Apical half of the left ventricle in which three muscular layers have been isolated. a, indicates the anterior interventricular groove; b, right border of the heart.

Fig. 11

In this preparation, the most central fibres of the left ventricular
wall and septum, have been eliminated. It may be observed how the subendocardial fibres become subepicardial.
As a reault of the reflexion of the fibres, a channel is defined.
a, indicates the left ventricular cavity;
b, anterior interventricular groove; c, right ventricle;
d, posterior interventricular groove.



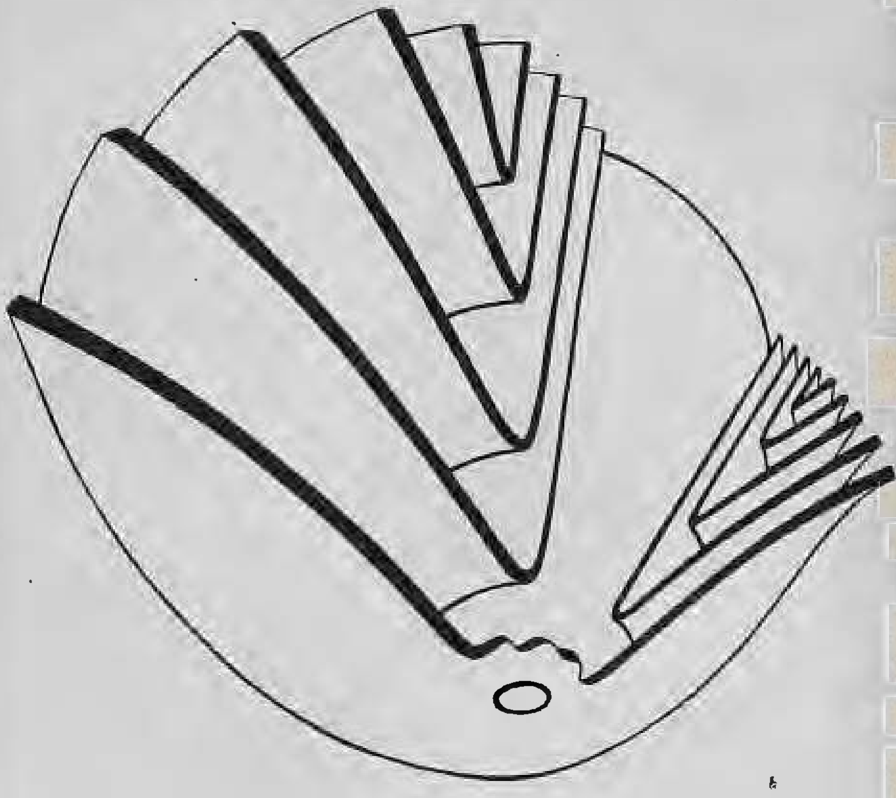


Fig. 12

The ventricular wall of the apical half of the left ventricle, may be considered constituted by a series of double conical elements, of progressively changing dimensions.

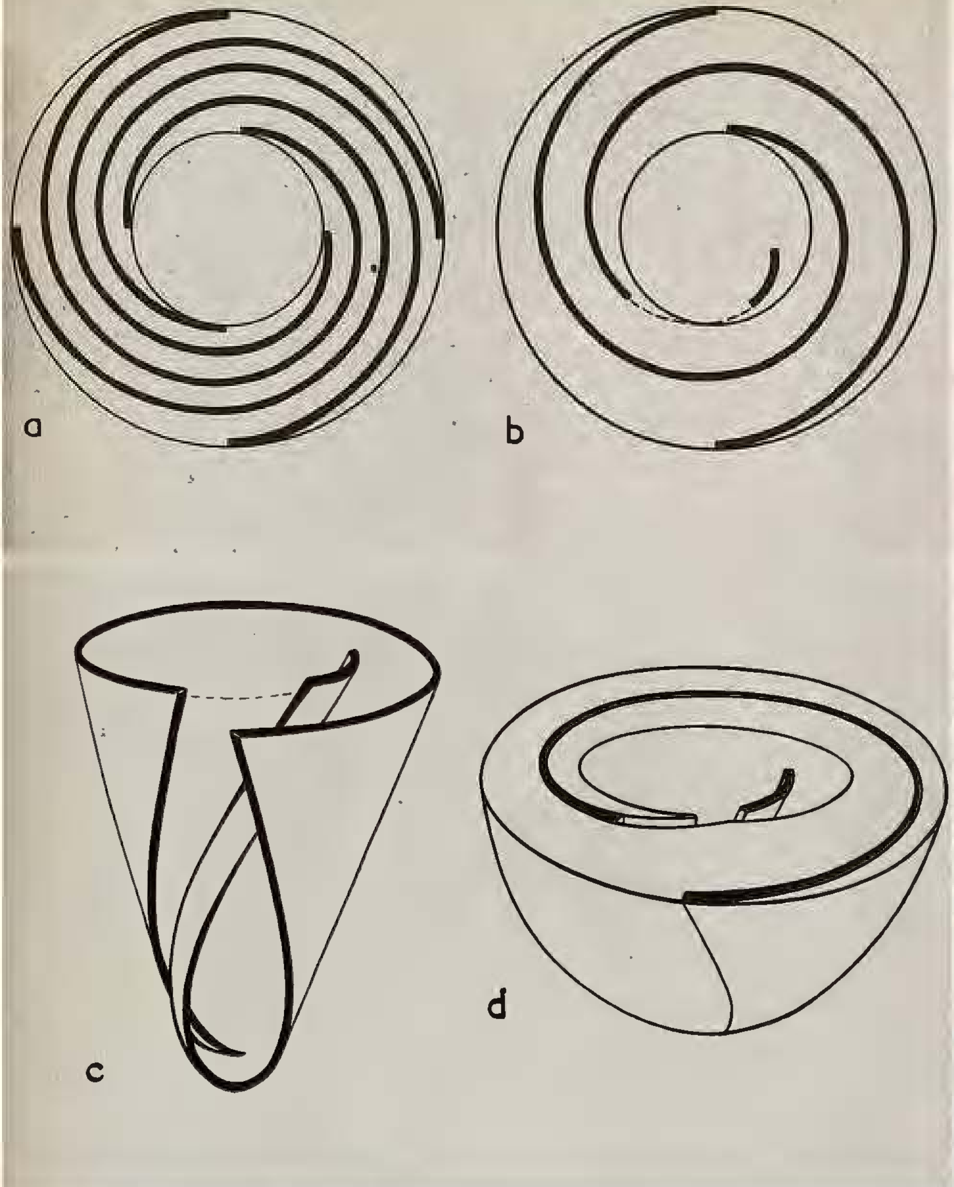


Fig. 13

Origin and morphological significance of the papillary muscles. a, transversely cut ventricle with some muscular layers represented in thick lines. b, two muscular layers, one of which prior to reaching the endocardial circumference, appears interrupted — and continued by the dotted line — to appear later in the ventricular cavity. This layer is reproduced in c, seen laterally, and in d, together with the rest of the ventricular wall.

Fig. 14

The base of the left ventricle, seen from above — upper drawing — and laterally — lower drawing —. a, indicates the wall of the left auricle, cut transversely a few milimeters from de fibrous mitral ring; b, anterior interventricular groove; c, left border of the heart.

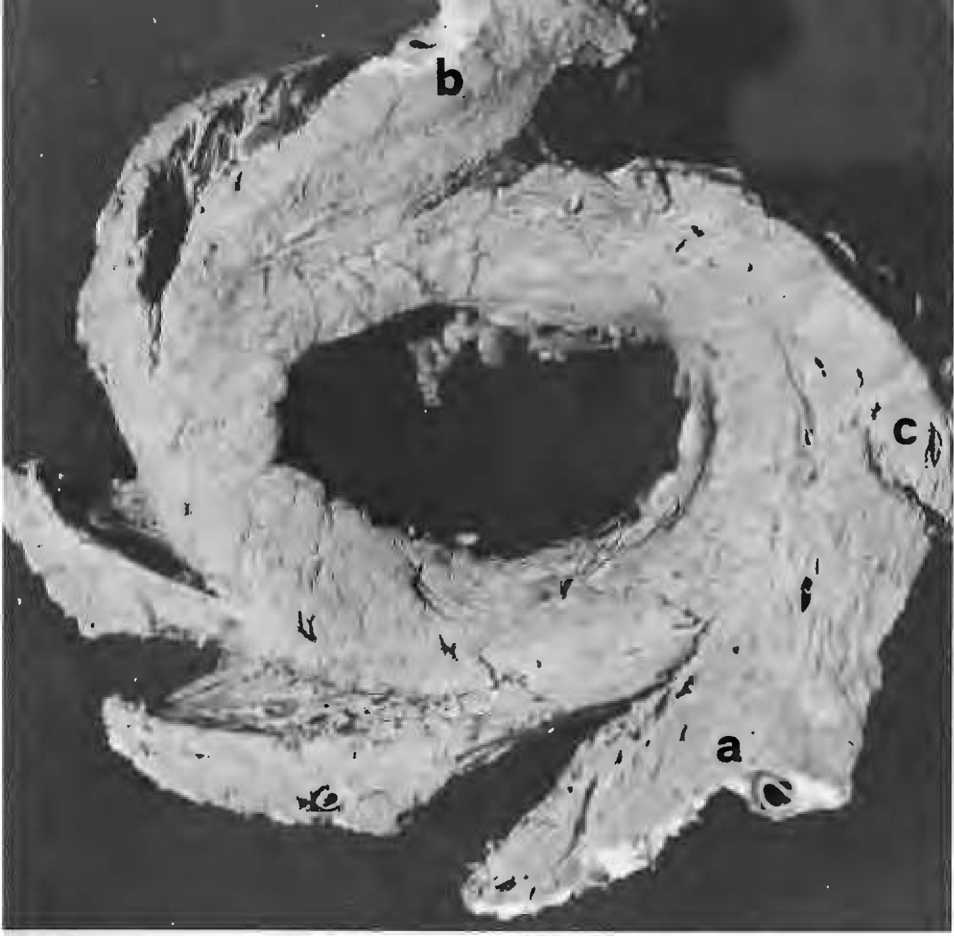


Fig. 15

Transverse cut of the left ventricular wall and septum. Basal half seen from the cut surface. a, indicates the anterior interventricular groove; b, posterior interventricular groove; c, interventricular septum. The start of four cleavage planes has been individualized. At level c, in the septum, it was intended to develop a cleavage plane like the others. The result was a disorderly rupture of fibres. The explanation of this fact will be given later in the study of the right ventricle.

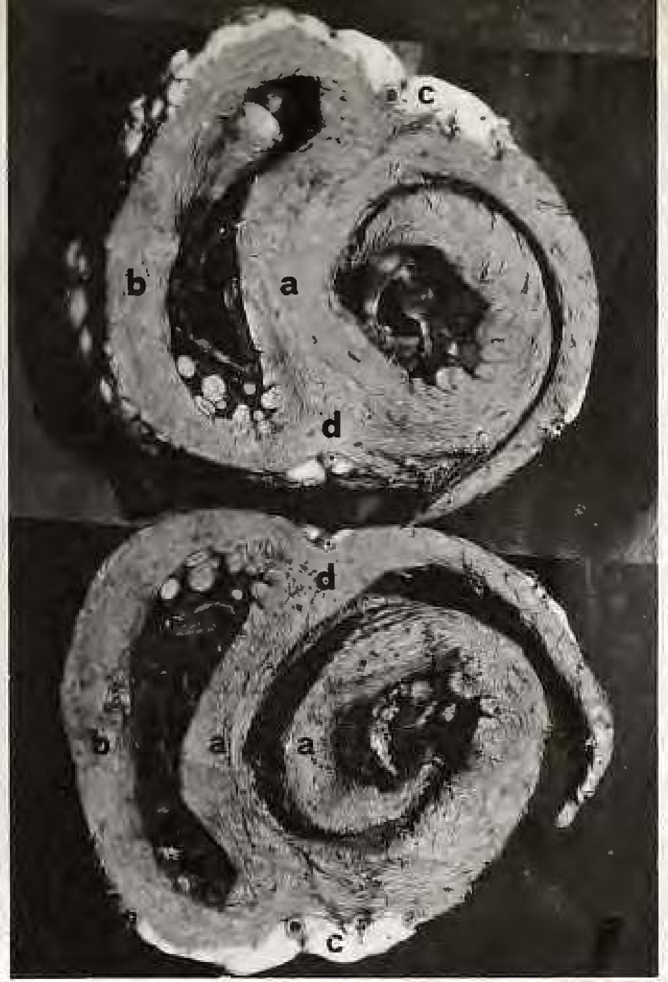


Fig. 16

Transverse cut of both ventricles, viewed from the cut surface. Above, basal half; below, apical half. a, indicates the interventricular septum; b, right ventricular wall; c, anterior interventricular groove; d, posterior interventricular groove. A cleavage plane is in evidence in both preparations.

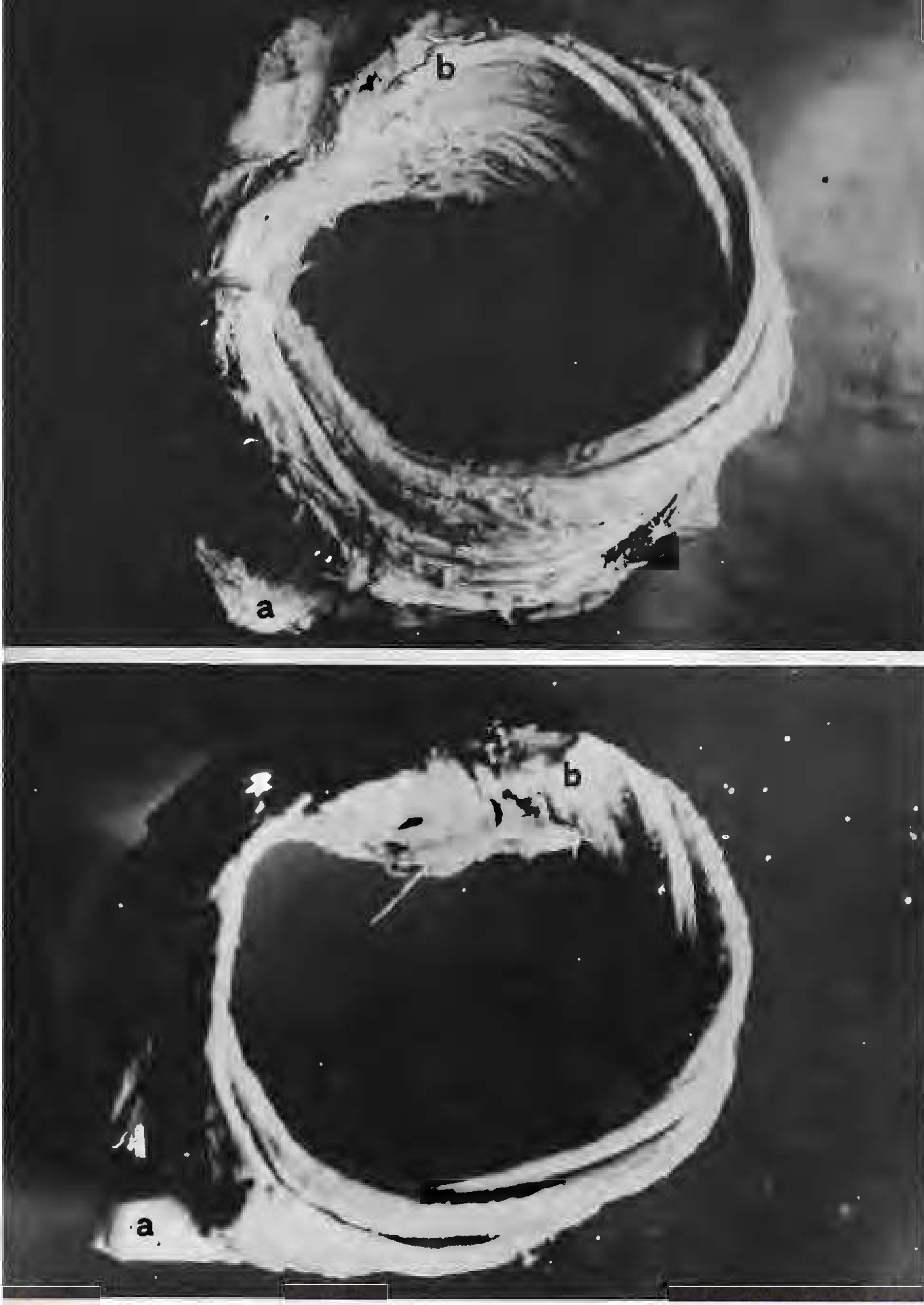


Fig. 17

Base of the left ventricle. Several myocardial layers are shown with their typical circular imbrication. a, indicates the anterior interventricular groove; b, the posterior interventricular groove.

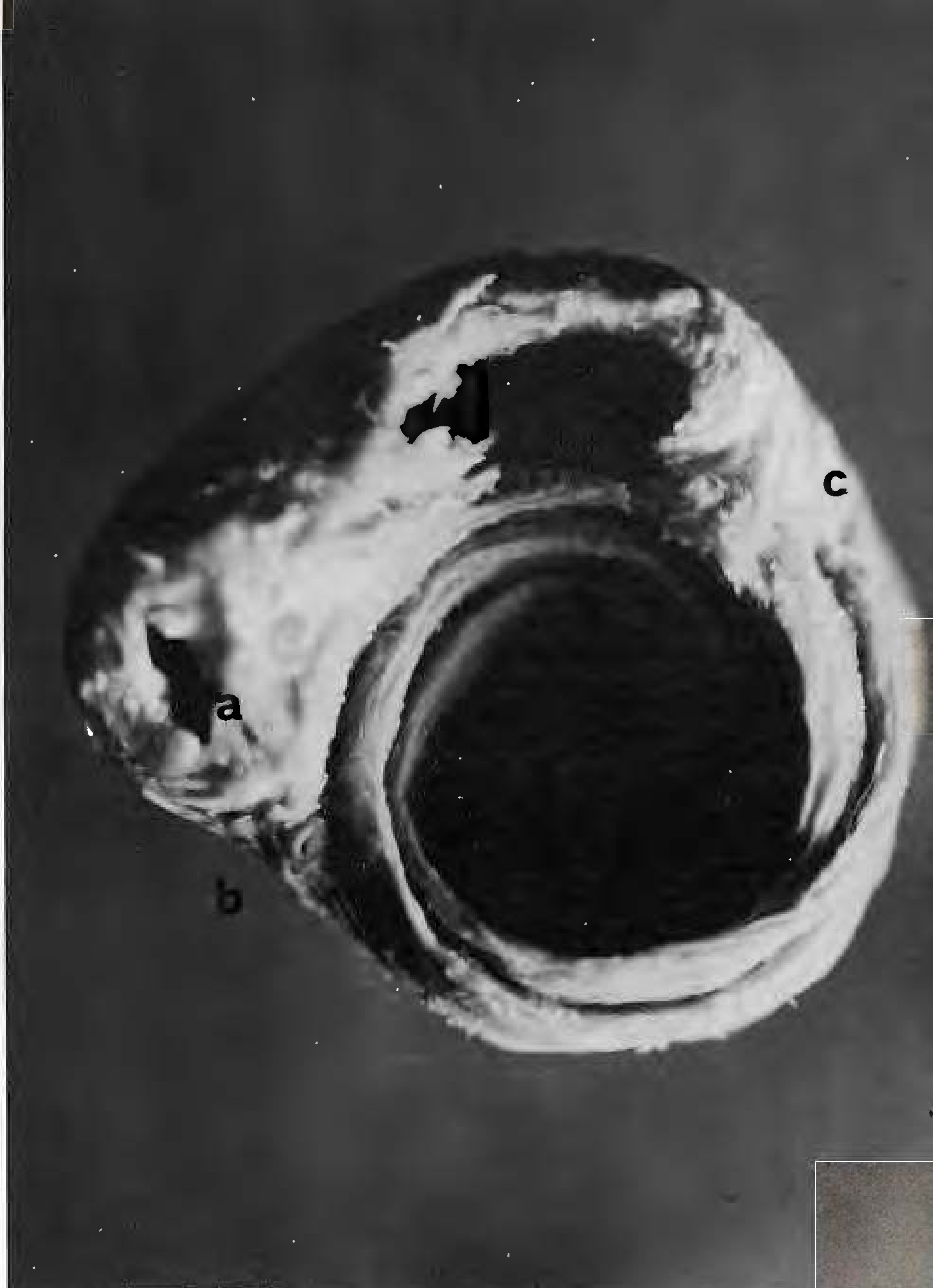


Fig. 18

The large mitroaortic orifice with the imbricated circular arrangement of the muscular layers constituting the base of the left ventricle. a, indicates the pulmonary artery; b, anterior interventricular groove; c, posterior interventricular groove.

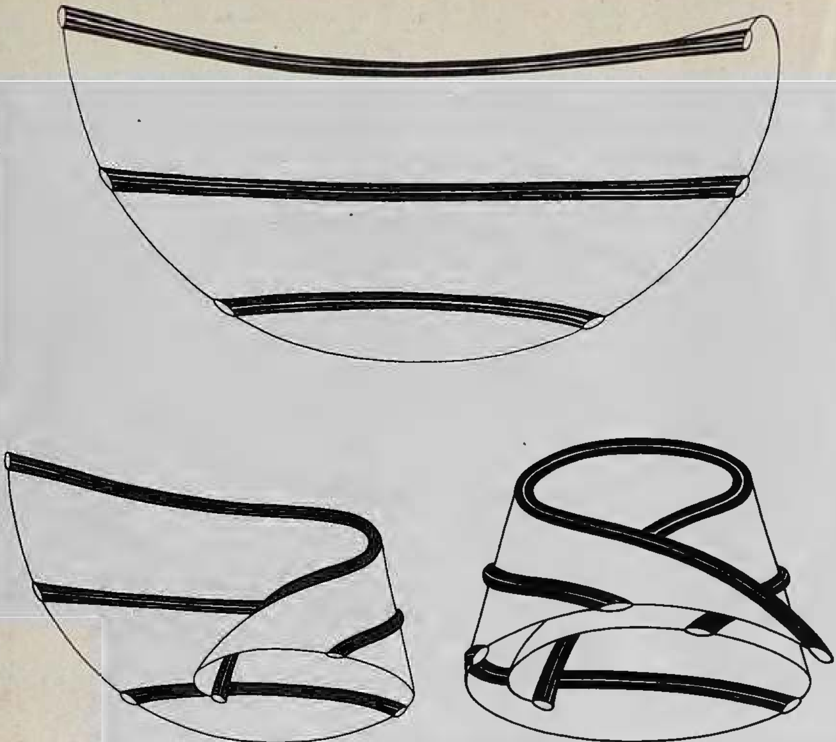


Fig. 19

Diagramatic reproduction of a basal layer of the left ventricle.
Explanation in the text. Compare with fig. 4.

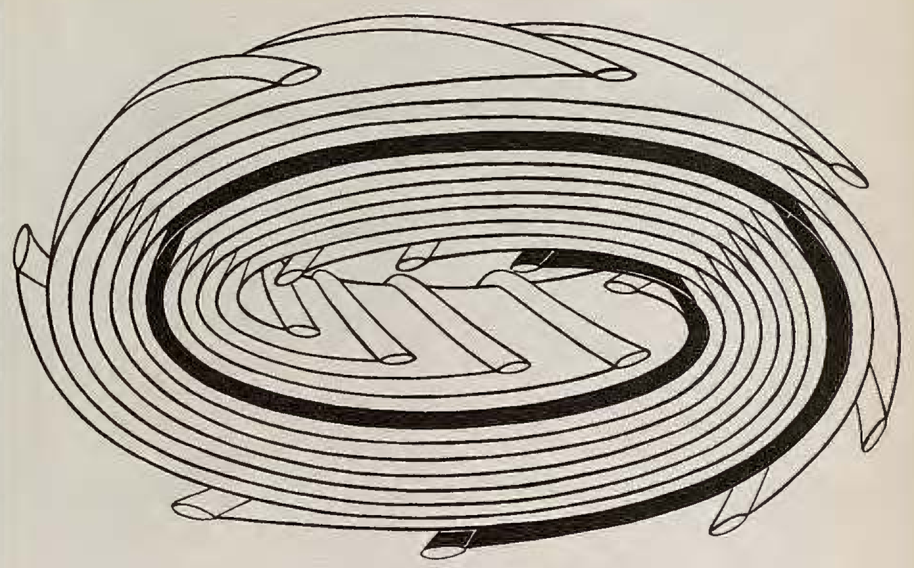


Fig. 20

Sketch of the basal half of the left ventricle. Compare with fig. 3.

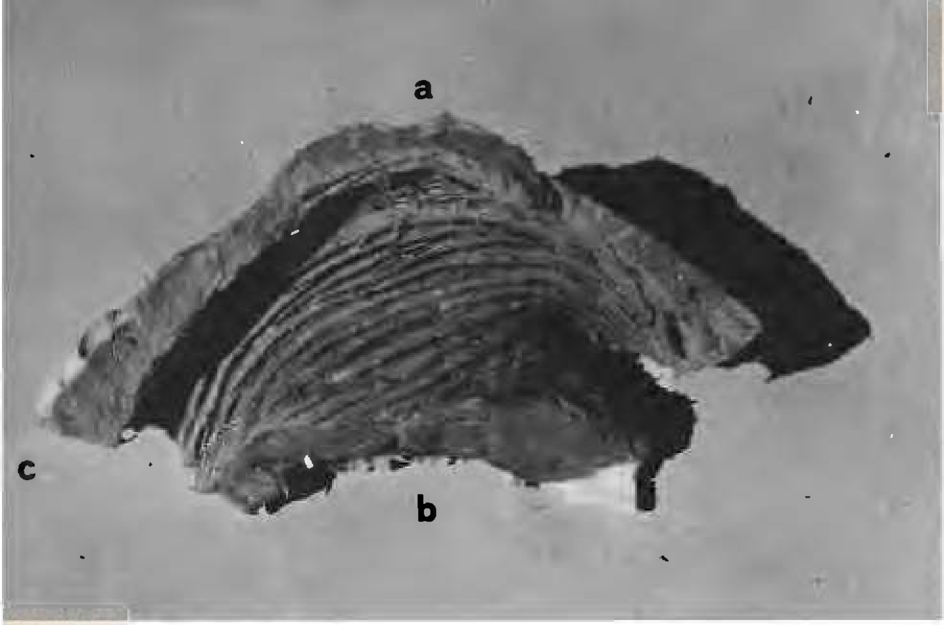


Fig. 21

In the basal half, as at the apex (fig. 11), on eliminating the central fibres of the ventricular wall, there arises a channel of similar characteristics and significance to that in the apex. a, indicates the epicardial contour; b, endocardial contour; c, left border of the heart.

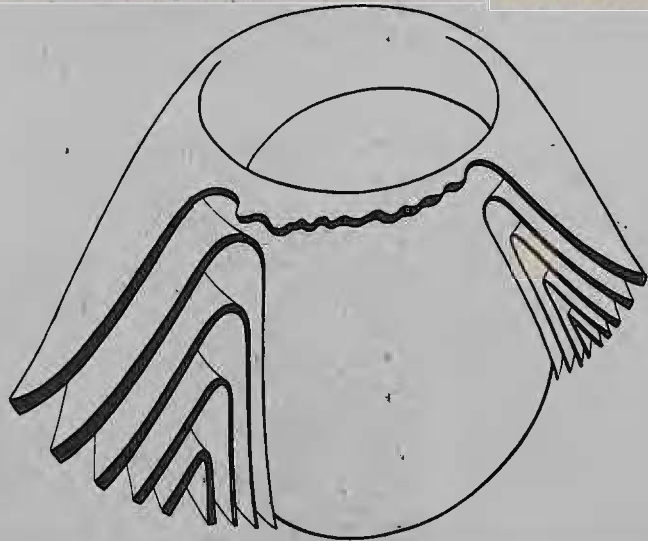


Fig. 22

The double cone construction of the basal half of the left ventricle. Compare with fig. 12.

Fig. 23

Basal half — top — and apical half — bottom —, seen laterally from the left border of the heart. Observe the opposing arrangement in space of their constituent layers.

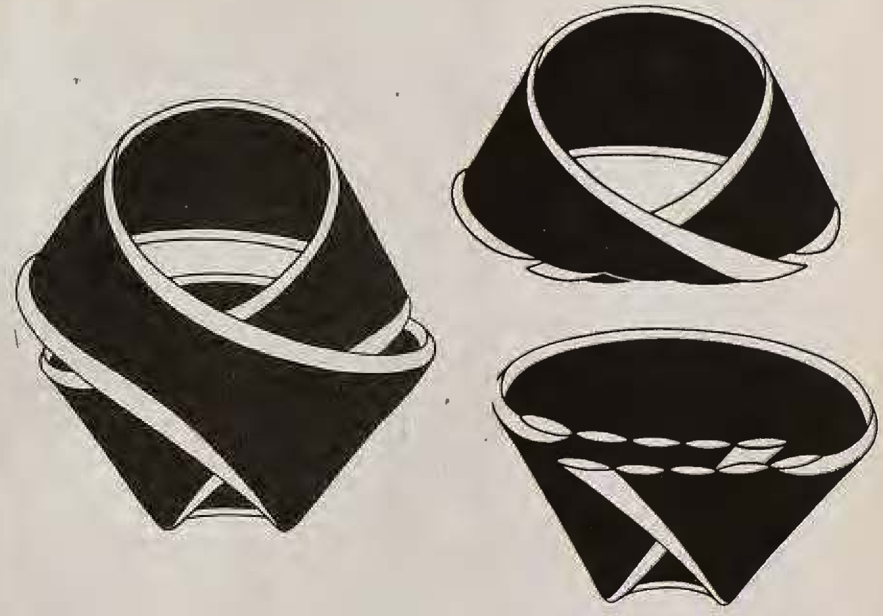


Fig. 24

An intact myocardial figure-of-eight — left — and cut transversely — right — to demonstrate the basal myocardial layer — top — and the apical — bottom —. The myocardial layer is fully defined, only when the ventricles are transversely sectioned. Therefore it cannot be considered as an anatomical entity. The same applies to the double cone.

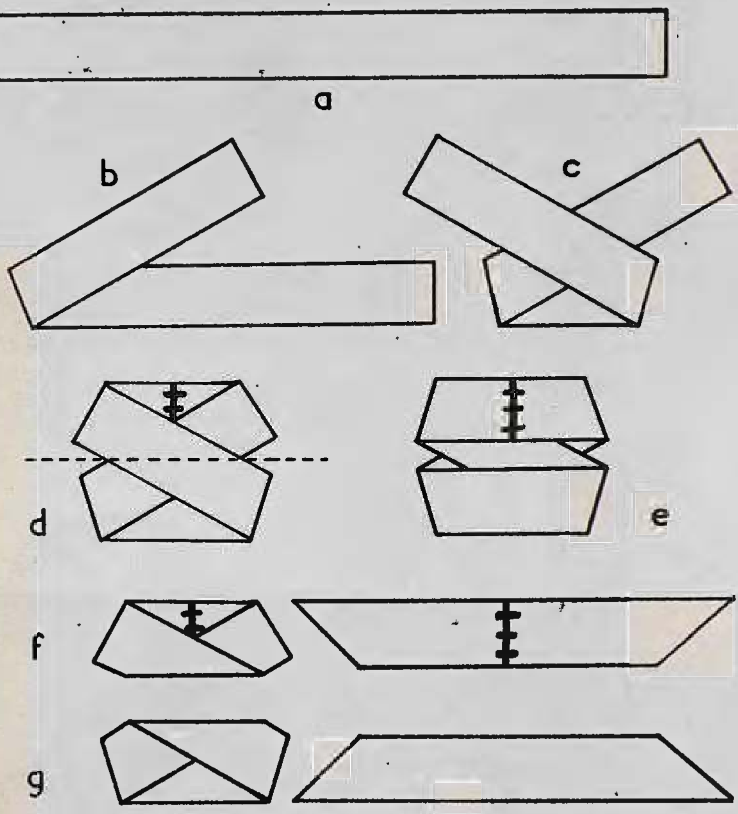


Fig. 25

A ribbon a, has both ends — b and c — folded and later joined — d and e, anterior and posterior view, respectively —.
On making a transverse section — d, dotted line — two pieces are demonstrated — f and g — which on being extended take a trapezoid shape like the half-moon characteristic of the myocardial layers. Again the trapezoids adopt an opposing spatial arrangement.

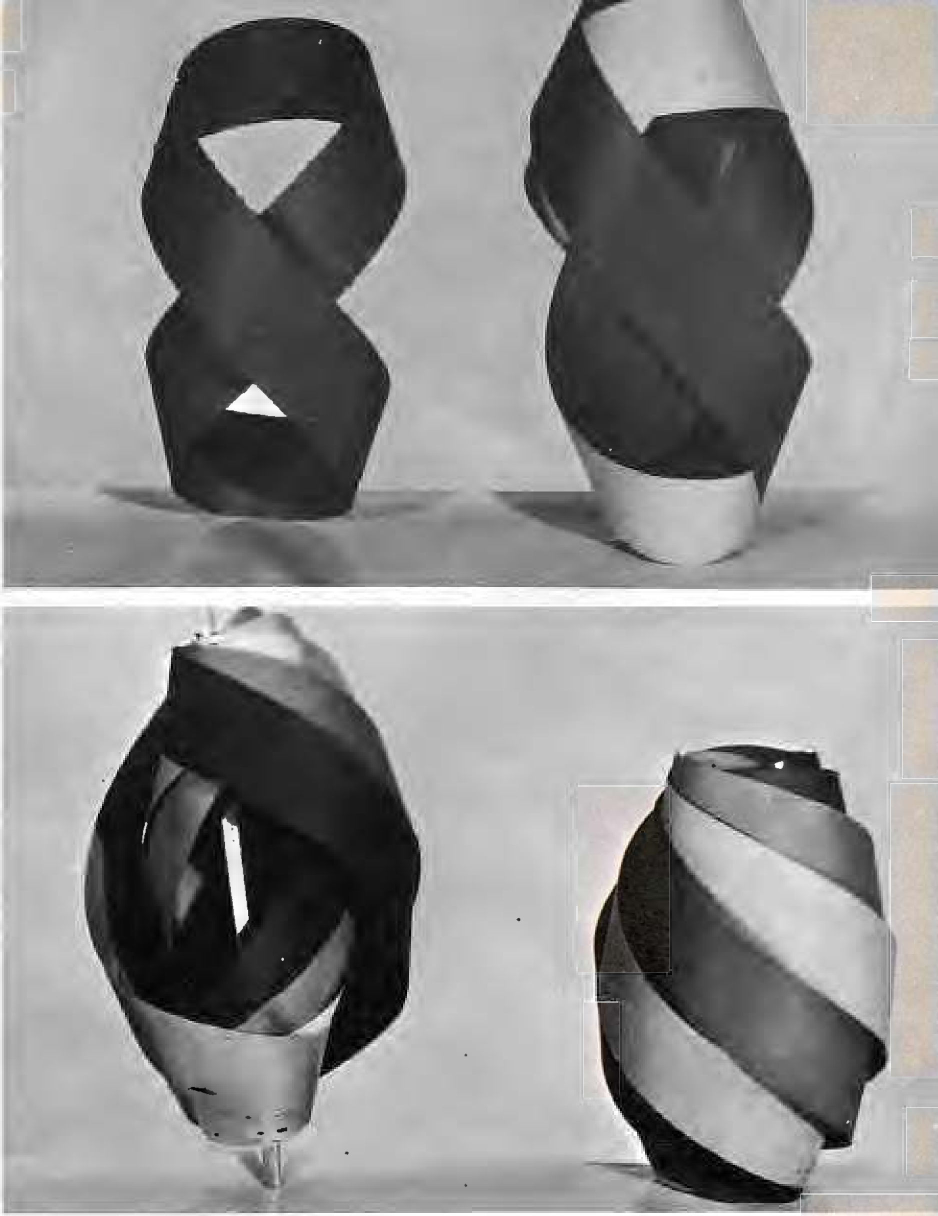
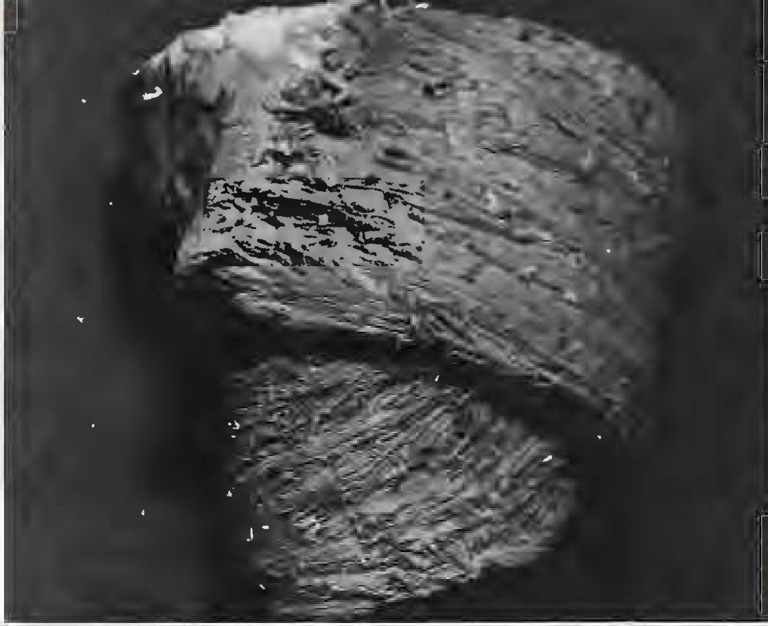


Fig. 26

Cardboard reproduction of the myocardial figure-of-eight.
Top an isolated 8 on the left; two 8s on the right, opposed.
Bottom, a complete «ventricle», on the right; on the left, opening the 8s to show the opposing arrangement in space of the «subendocardial» and «subepicardial» trajectories.



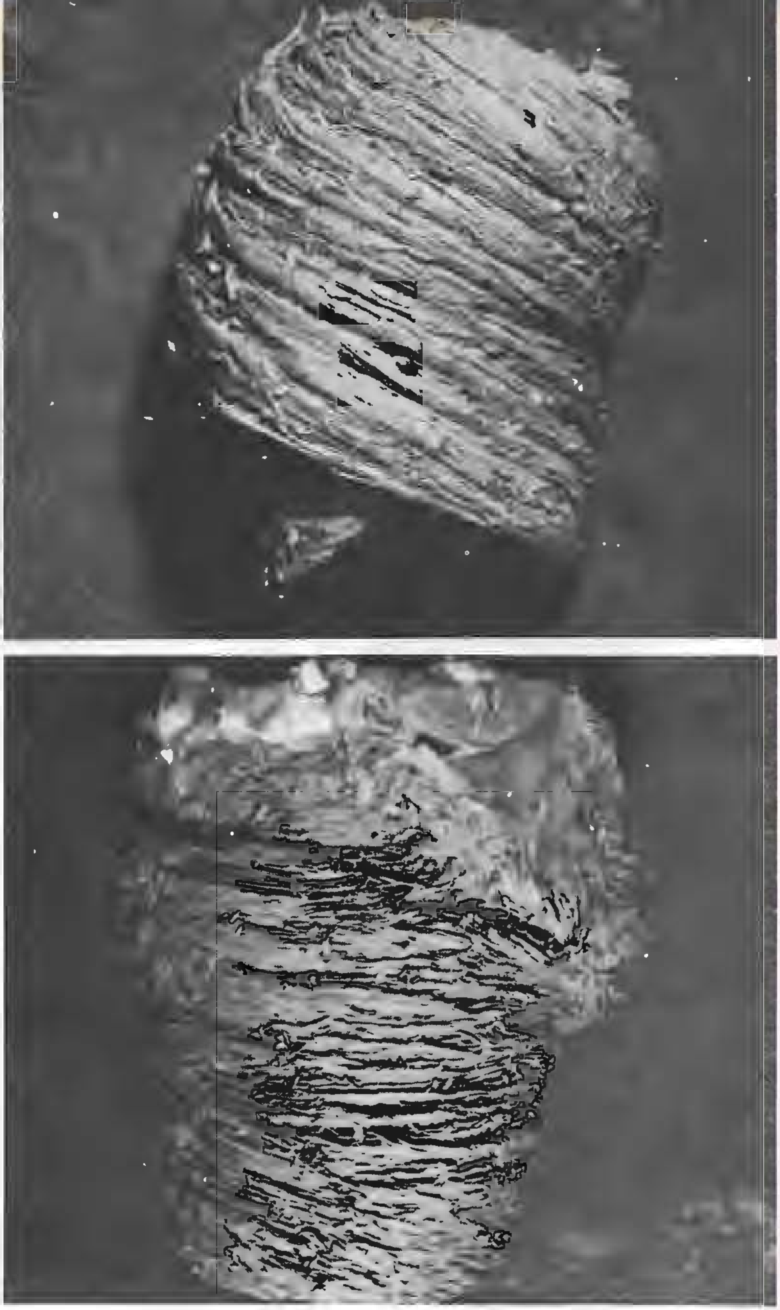


Fig. 27

An anatomical preparation, demonstrating a figure-of-eight. Top left, anterior surface of the ventricles; right, left border. Bottom left, posterior surface; right, right border.

Fig. 28

Upper border of the free wall of the right ventricle, showing the passing of the fibres from the external to the internal surface of the ventricular wall, without making any insertion in the so-called tricuspide fibrous ring. a, indicates the pulmonary conus; b, posterior interventricular groove; c, interventricular septum; d, left ventricular wall.

Fig. 29

Imbricated layers construction of the basal half of the free wall of the right ventricle. a, indicates the anterior interventricular groove; b, posterior interventricular groove.

Fig. 30

Imbricated layer construction of the apical half of the free wall of the right ventricle. a, indicates the posterior interventricular groove; b, free wall of the right ventricle. Apical half of both ventricles, seen from the apex.

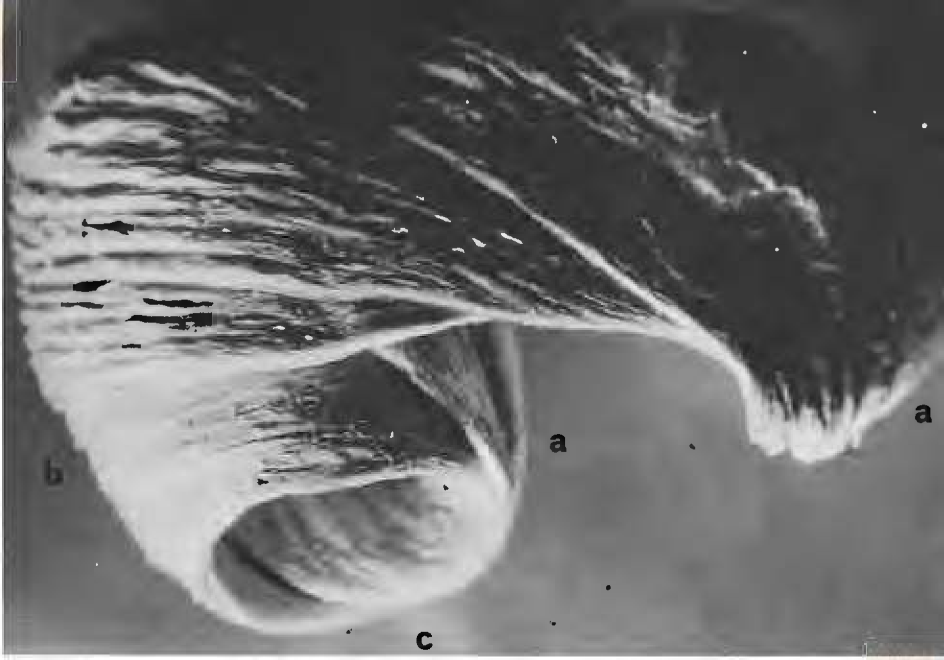


Fig. 31

Dorsal view of ventricles. The free wall of the right ventricle has been sectioned along the anterior interventricular groove: a, interior interventricular groove; b, left border of heart; c, apex. Note the imbricated arrangement of the layers constituting the free wall of the right ventricle.

Fig. 32

The opposite trajectory followed by the muscular layers, as they go from epicardium to endocardium, in the basal half — upper preparation — and apical half — lower preparation — of the free wall of the right ventricle. Ventricles seen laterally from the right border of the heart. a, pulmonary conus; b, apex.

Fig. 33

Imbricated layers construction of the free wall of the right ventricle. The wall referred to, appears sectioned along the anterior interventricular groove — a — and unfolded in several layers. Left border of the heart, b. Ventricles seen from the apex.

Fig. 34

Ventricles seen laterally from the right border of the heart.
Top right, pulmonary conus; bottom, apex. The superficial fibres, subepicardial, and the deep fibres, subendocardial, appear crossed in an X

Fig. 35

Ventricles seen from their anterior surface. a, apex; b, left border of the heart. Note, in the right ventricle, the crossing of the subepicardial and subendocardial fibres.

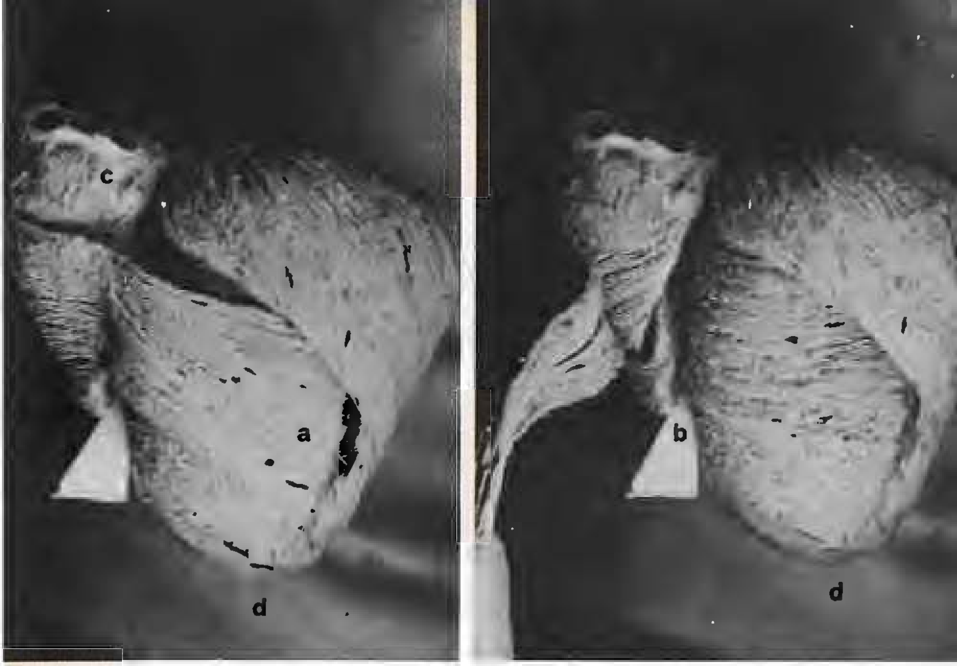


Fig. 36

Left ventrolateral view of both ventricles. On the left, the muscular band indicated with a, appears manually separated in the sketch on the right. With this there is shown another group of fibres which, from the free wall of the right ventricle, after reflection go to drape the interventricular septum — b —, c, pulmonary conus; d, apex.

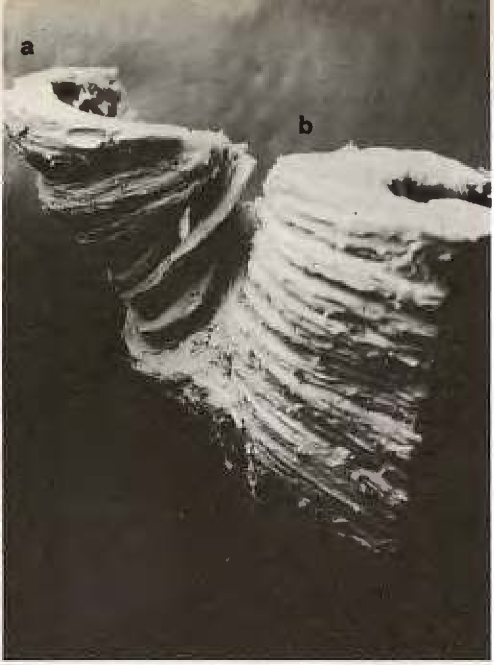


Fig. 37

Ventricles seen from their anterior surface. Note how fibres coming from the free wall of the right ventricle — a —, after reflection at the level of the anterior interventricular groove, follow an upward course to drape the interventricular septum — b —.

Fig. 38

Right lateral aspect of the ventricles. After making a longitudinal cut of the free wall of the right ventricle, which ends next to the anterior interventricular groove — a —, the anterior half of that wall is separated to show the passing of its subendocardial fibres to the interventricular septum — b —.

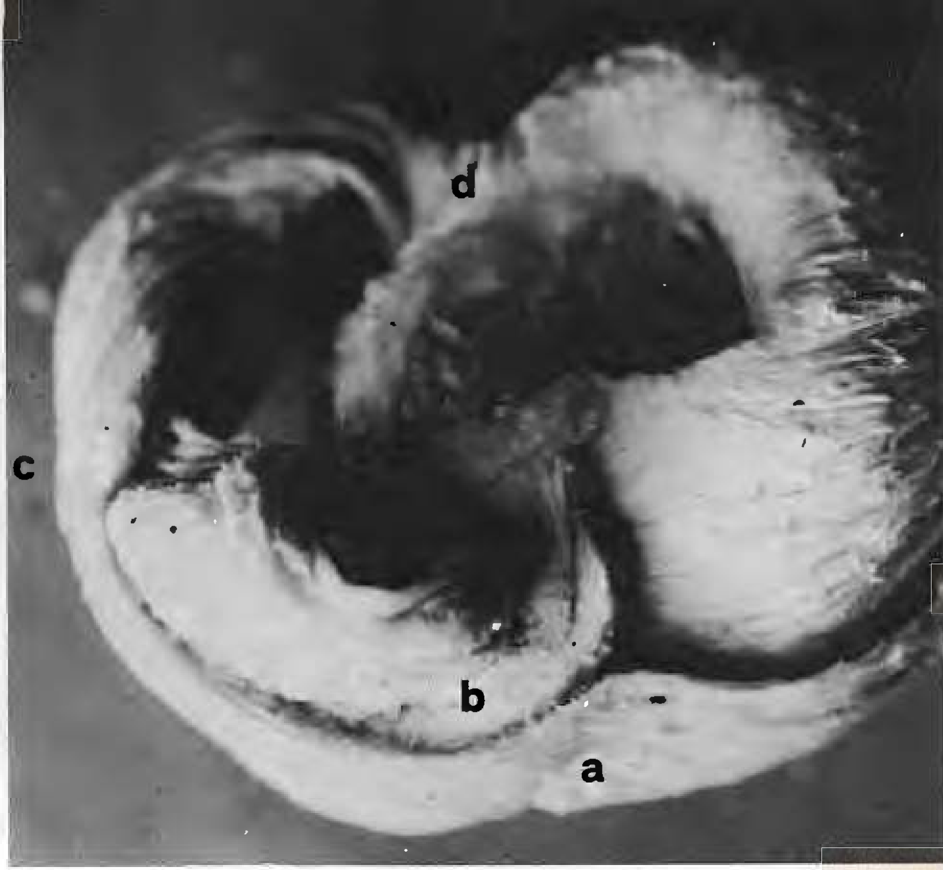


Fig. 39

Ventricles seen from the base. Two groups of fibres pass from the free wall of the right ventricle to the anterior surface of the left one and to the interventricular septum. They have been indicated with a and b respectively. Right border of the heart, c; posterior interventricular groove, d.

Fig. 40

Dorsolateral view of both ventricles. Pulmonary conus, a; apex, b. The muscular band, c, is divided into two groups of fibres. One of them passes to the posterior surface of the left ventricle; the others to the interventricular septum.

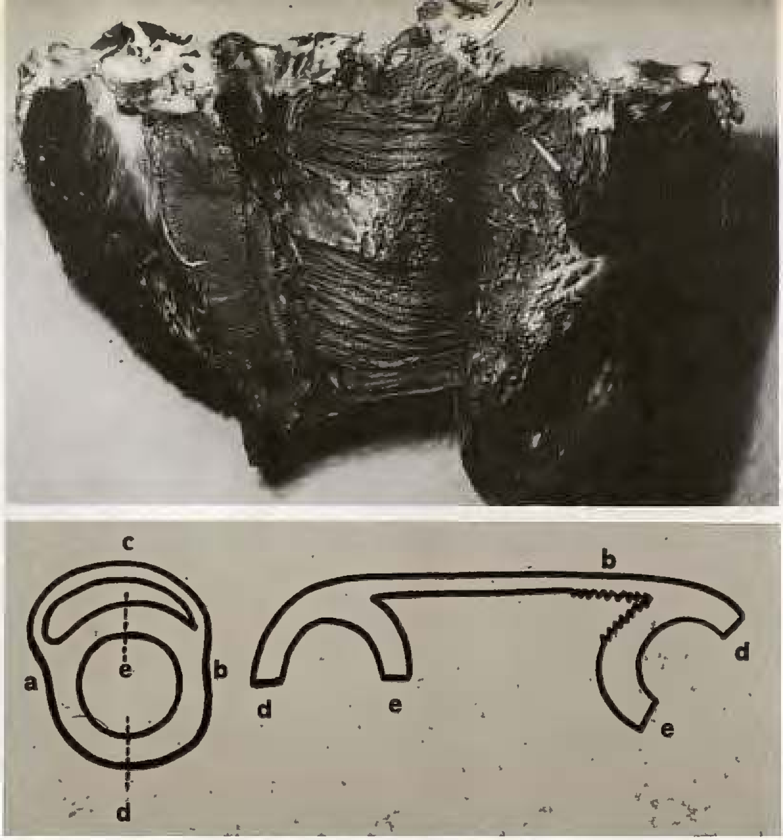


Fig. 41

Anatomical preparation to show the passing of the fibres from the free wall of the right ventricle — c, left sketch — to the posterior surface of the left ventricle — b, same sketch —. a, anterior interventricular groove; b, posterior. Longitudinal cut in the left border of the heart — d — and in the septum — e —, uncovers the endocardial surface of the free wall of the right ventricle. In this preparation a small area has been left with endocardium, to indicate the posterior limit of the right ventricular cavity. Note the passing of the fibres from one ventricle to the other.

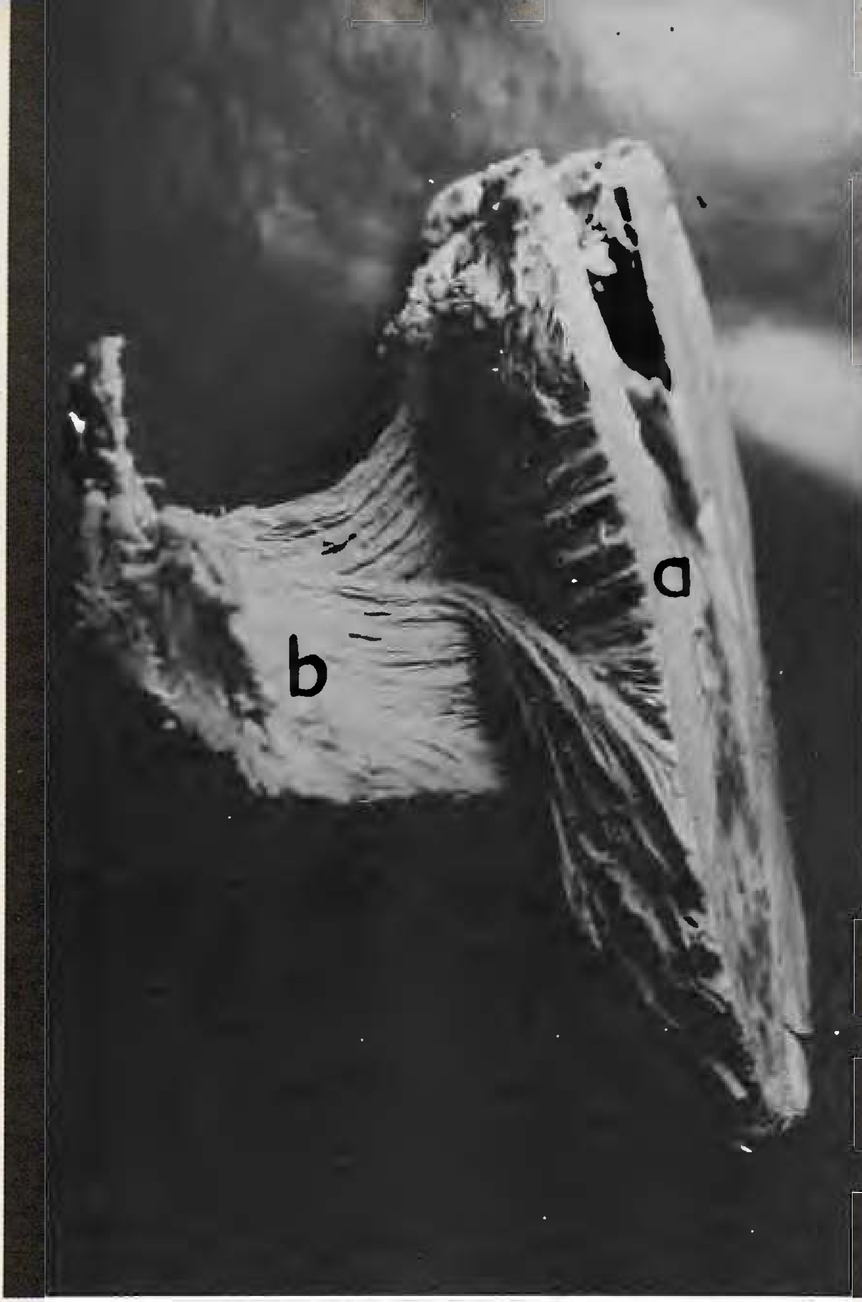


Fig. 42

Posterior limit of the right ventricular cavity. a, interventricular septum; b, free wall of the right ventricle. Note the division of the wall into two groups of fibres. One passes to the posterior surface of the left ventricle; the other, after reflection to the interventricular septum.

Fig. 43

After sectioning the free wall of the right ventricle along the anterior interventricular groove — a —, the wall has been separated to show the passing of the fibres to the interventricular septum. b, posterior interventricular groove.

Fig. 44

Anatomical preparation to show the two groups of fibres limiting the right ventricular cavity, posteriorly. Left, mitroaortic orifice; right, tricuspid; top, pulmonary.

Fig. 45

The right ventricle seen laterally from the right border of the heart and the base from above, in the upper and lower sketches respectively. Left, tricuspid orifice; right, pulmonary.

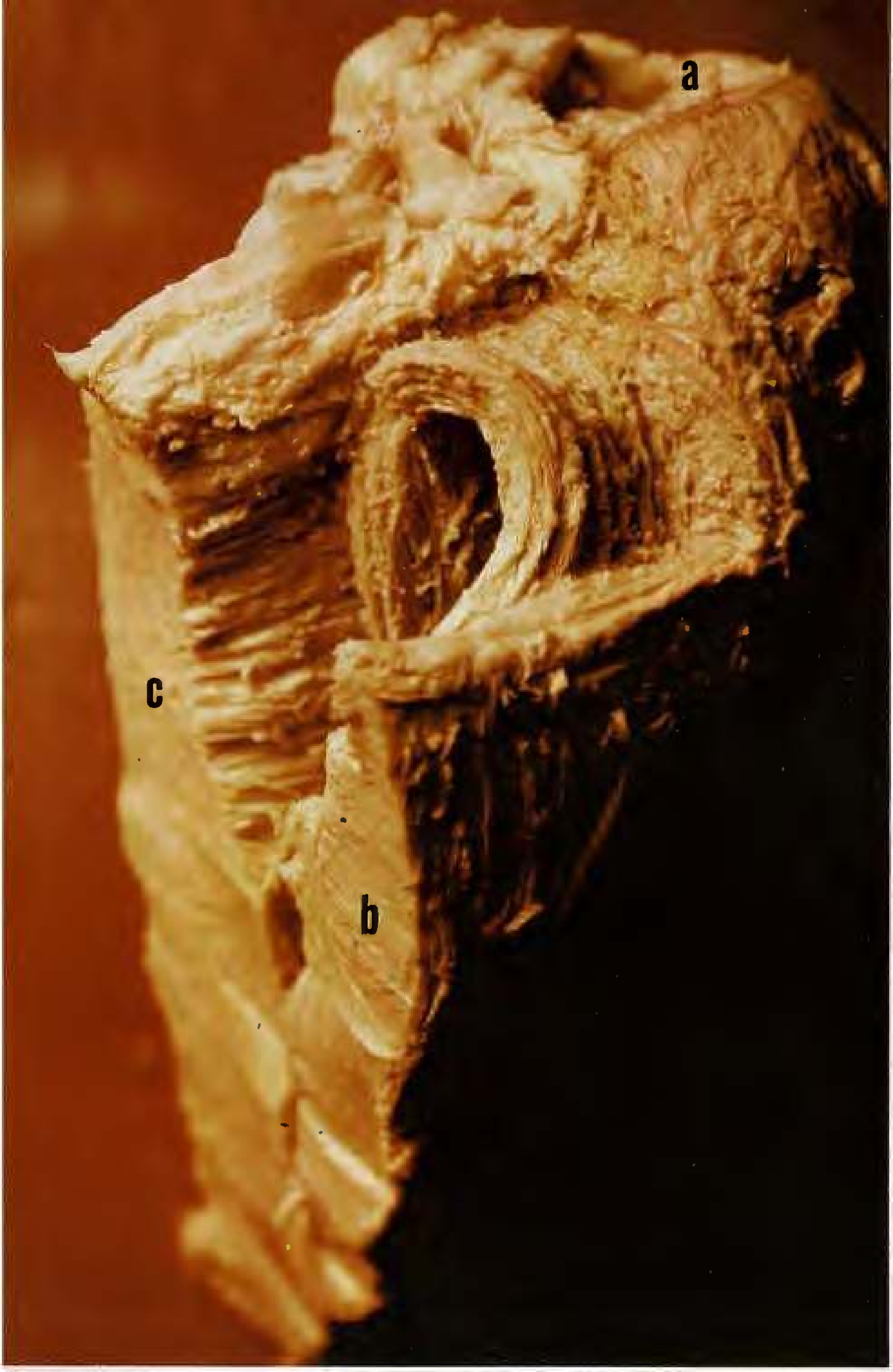


Fig. 46

Anatomical preparation to show the formation of the supraventricular crest. a, pulmonary artery; b, free wall of the right ventricle; c, interventricular septum.

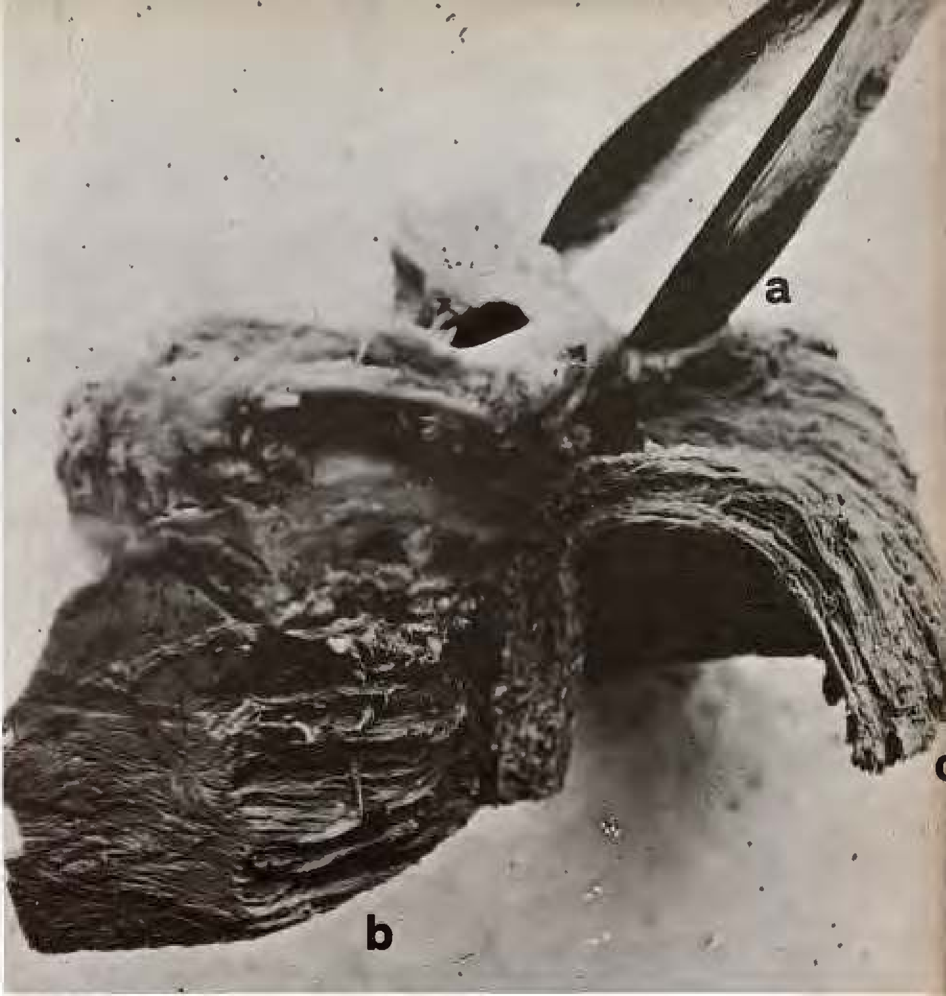


Fig. 47

The supraventricular crest. a, pulmonary artery; b, interventricular septum; c, free wall of the right ventricle.

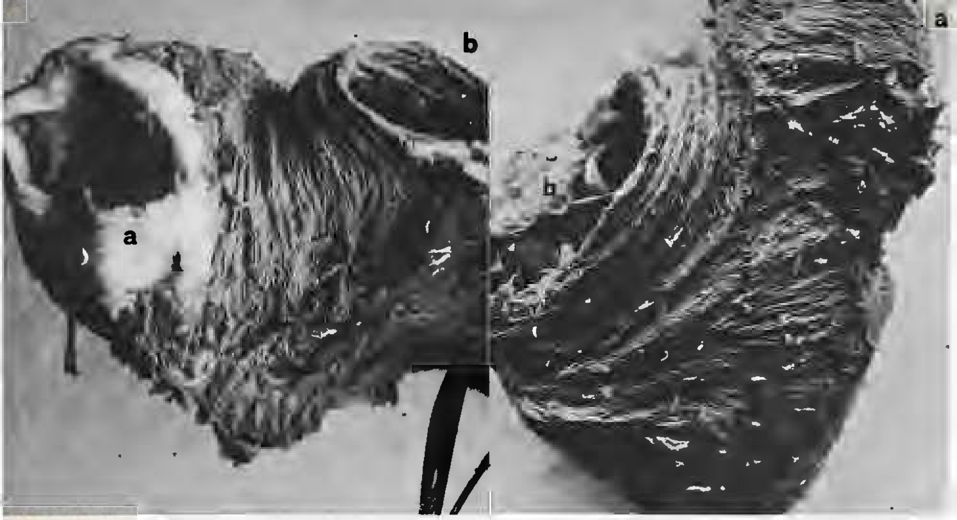


Fig. 48

The supraventricular crest. a, pulmonary artery; b, tricuspide orifice. The preparation shows on the left the septal wall; on the right, the free wall.

Fig. 49

Right ventricle seen from the base and laterally. a, anterior intraventricular groove; b, posterior interventricular groove. b, posterior interventricular groove. The group of fibres which after reflection form the back wall of the right ventricular cavity and the fibres constituting the supraventricular crest, come together on the interventricular septum down.

Fig. 50

The ventricles seen dorsally. The posterior half of the right ventricle has been resected. Left, left ventricle with its fibres arranged transversely; right, anterior half of the right ventricle with its septal fibres running vertically.

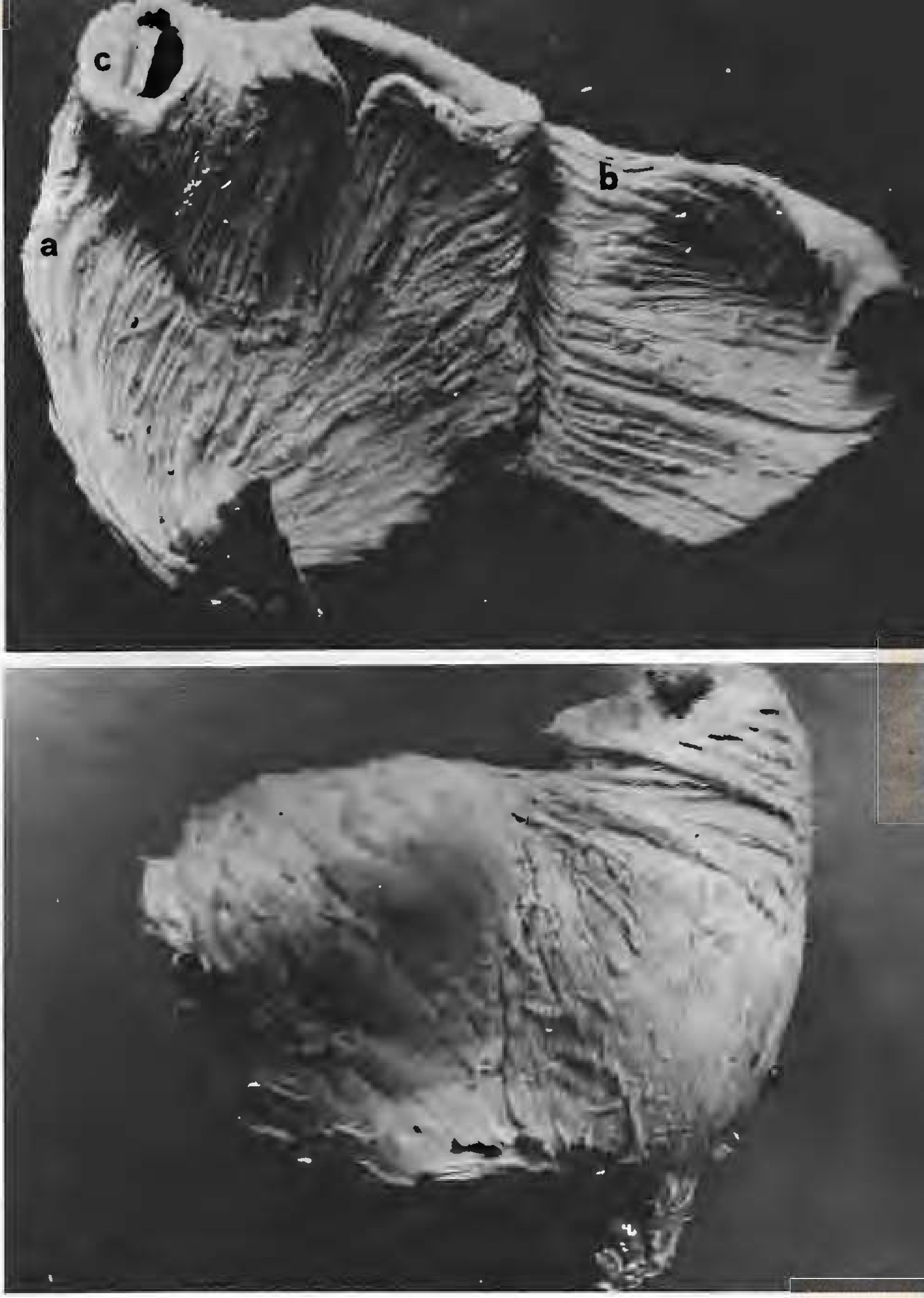


Fig. 51

The right ventricle seen from its septal surface — top — and from behind. The upper shows the vertical descent of the fibres defining anteriorly — supraventricular crest — and posteriorly, the tricuspid orifice. a, anterior interventricular groove; b, posterior interventricular groove; c, pulmonary artery.

Fig. 52

Two anatomical preparations similar to the previous figure, in which the right ventricle is isolated.

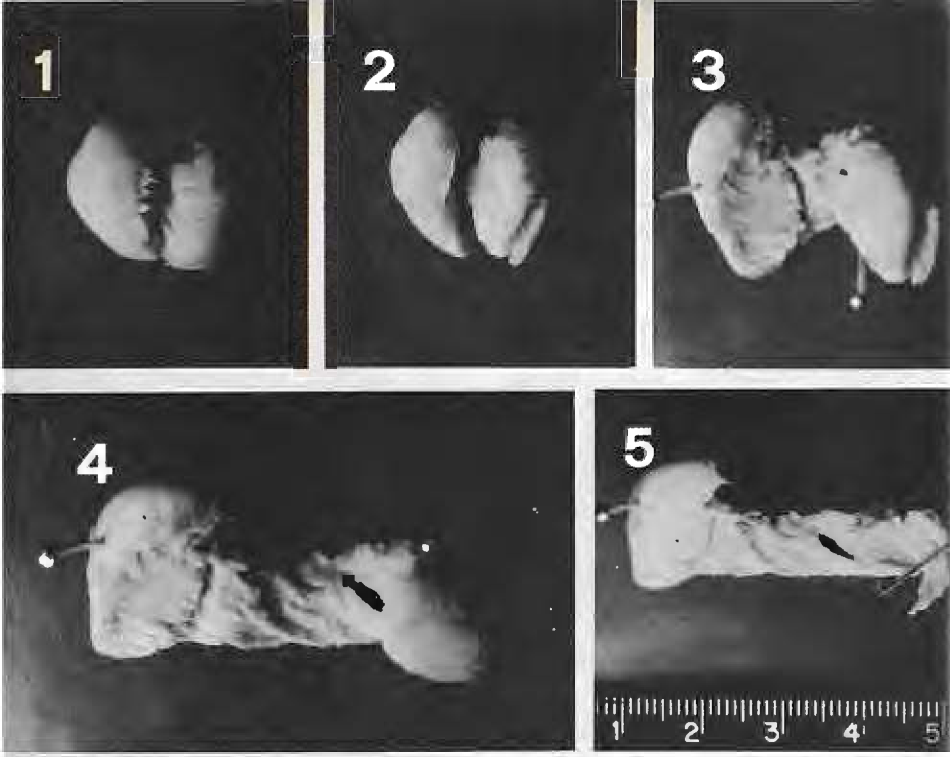


Fig. 53

Embryo heart — pig —, in successive stages of dissection. In the first one, 1, is shown the cleavage plane which starting in the anterior interventricular groove, runs along the length and width of the interventricular septum, to appear later in the thickness of the ventricular wall — 2 and 3 —. In all five sketches, the anatomical specimen lies in the same position and both ventricles are seen from their anterior face.

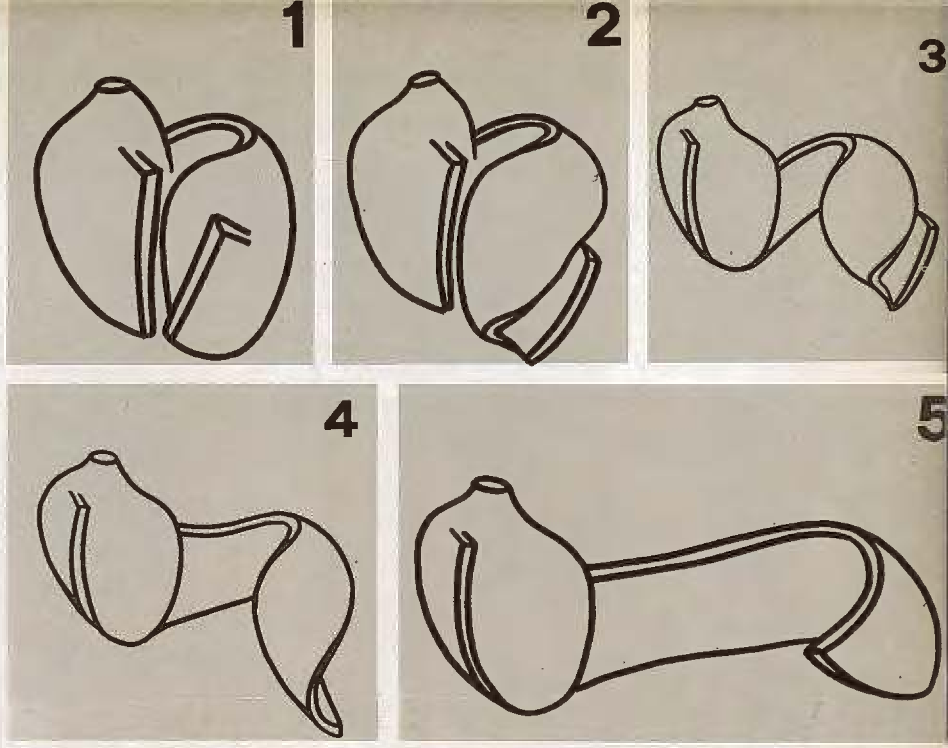


Fig. 54

The successive stages in the dissection of the muscular band, during its trajectory in the left ventricle.

Fig. 55

Embryo hearts — cow, the two upper preparations and sheep the two lower ones —, in successive stages of dissection.
From top to bottom, in the first one is shown the cleavage plane of the interventricular septum; in the second one, both ventricles are separated; in the third one it is still possible to appreciate the spiral defining the left ventricle; in the fourth, the extended muscular band.

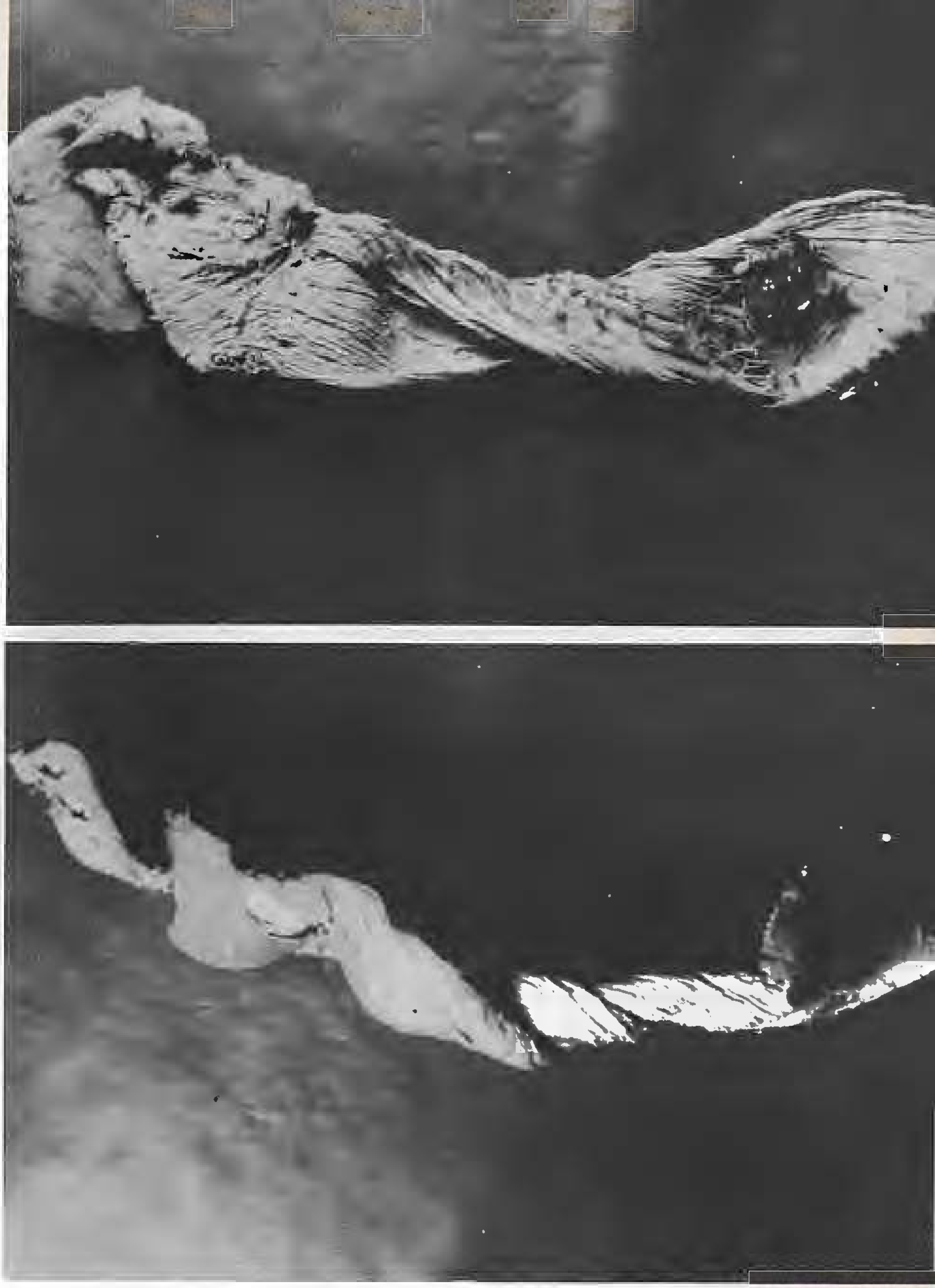


Fig. 56

The extended muscular band of a young adult heart. Top, side view as seen from the concavity; bottom, view from the apex.

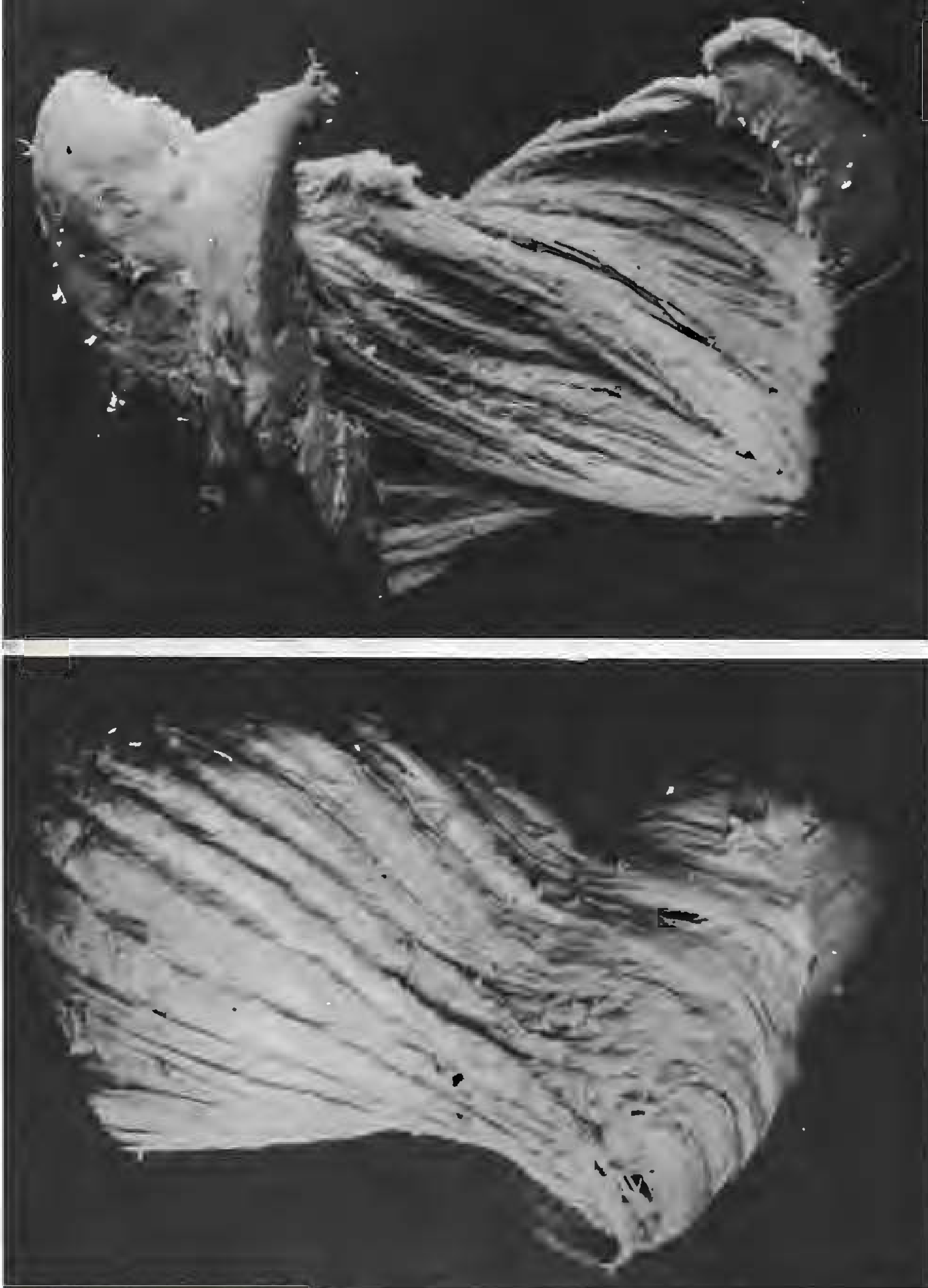


Fig. 57

Longitudinal cut through the left border of the heart.
Note the muscular band showing its concavity — top — and its convexity — bottom —; also note the opposing arrangement in space of the subendocardial and subepicardial fibres.

Fig. 58

A preparation similar to the previous one, showing the muscular band through its concavity — top sketch — and convexity — bottom sketch —. a, anterior interventricular groove; b, posterior interventricular groove.

Fig. 59

A fragment of ventricular wall from the left border of the heart, in which there is shown the opposing arrangement of the subendocardial — left — and subepicardial fibres — right —.

Fig. 60

A length of rope, arbitrarily arranged.

Fig. 61

The fragment of rope referred to in the previous figure, arranged in a curl manner.

Fig. 62

Arrangement of the rope, imitating that adopted by the muscular band in the intact heart.

Fig. 63

The rope model of figure 62, exposed together with the base of the right and left ventricles. All of them are viewed from the same perspective — equivalent anatomical position —.

Fig. 64

A preparation similar to the previous one, viewed from the base.

Fig. 65

The rope model, shown with an anatomical preparation of both ventricles. Both, model and preparation are seen from the apex.

Fig. 66

From above down, left ventricular base, rope model and apex. All correspond with a view from the left border of the heart.

Fig. 67

From above down, base of right ventricle, rope model and lower contour of the free wall of the right ventricle. All are seen as from the right border of the heart.

Fig. 68

Explanation in the text.

Fig. 69

Explanation in the text.

Fig. 70

Anatomical preparation of both ventricles, seen from the anterior surface, shown with the rope model of figure 69.
Both are viewed from the same perspective.

Fig. 71

The same preparation as figure 70 and the rope model of figure 69, both keeping their relative positions as seen from the left border of the heart.

Fig. 72

The same preparation as figure 70 and the rope model of figure 69, both keeping their relative position as seen from the posterior surface of the heart.

Fig. 73

The same preparation of figure 70 and the rope model of figure 69, both keeping their relative position as seen from the right border of the heart.

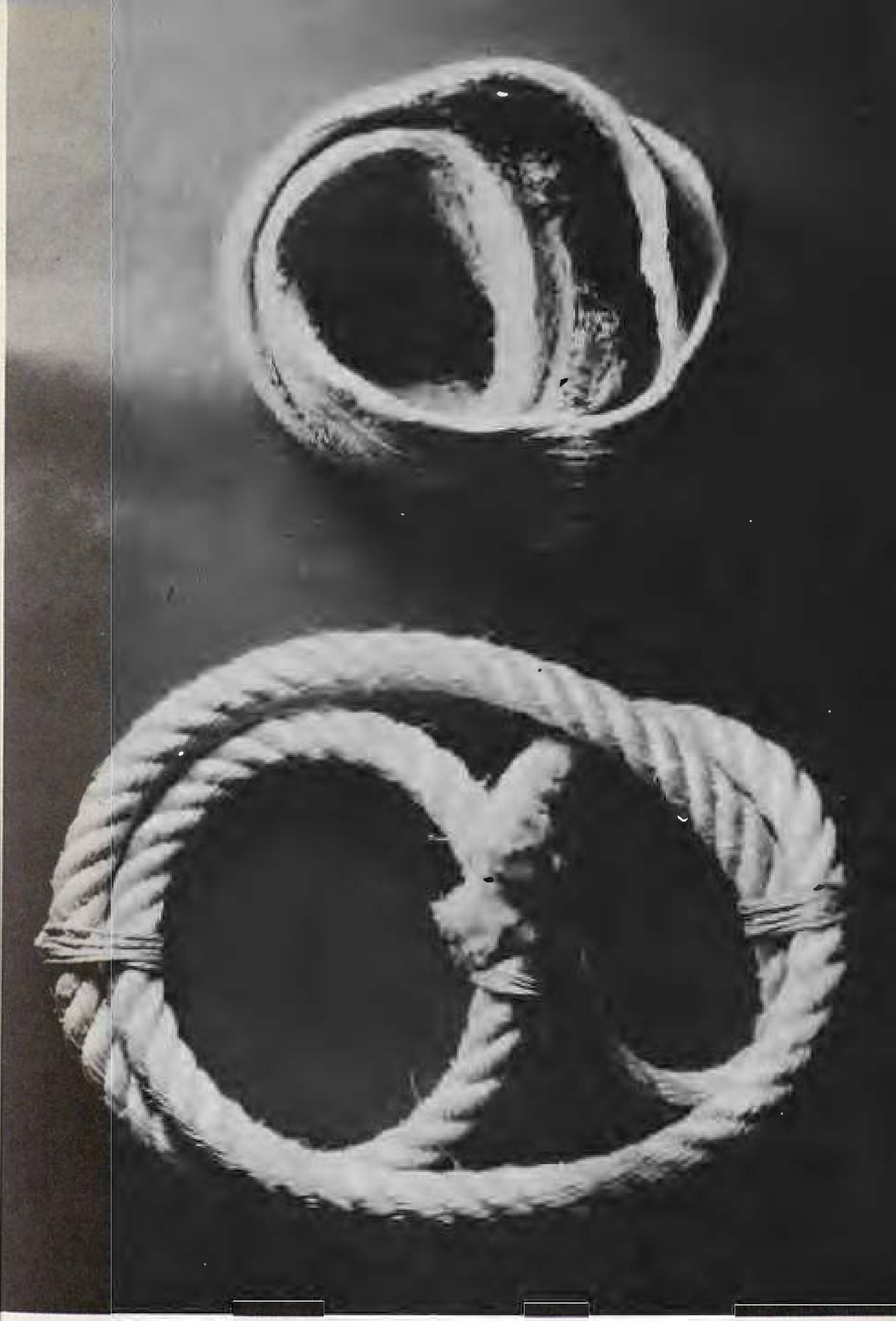


Fig. 74

The same preparation of figure 70 and the rope model of figure 69. Both maintain their relative positions as seen from the apex.

Fig. 75

The same preparation of figure 70 and the rope model of figure 69 as viewed from the base.

Fig. 76

The model of figure 69 and the anatomical preparation of figure 49 to show the coincidence in the interventricular septum of the two groups of fibres defining the tricuspide orifice anteriorly and posteriorly.

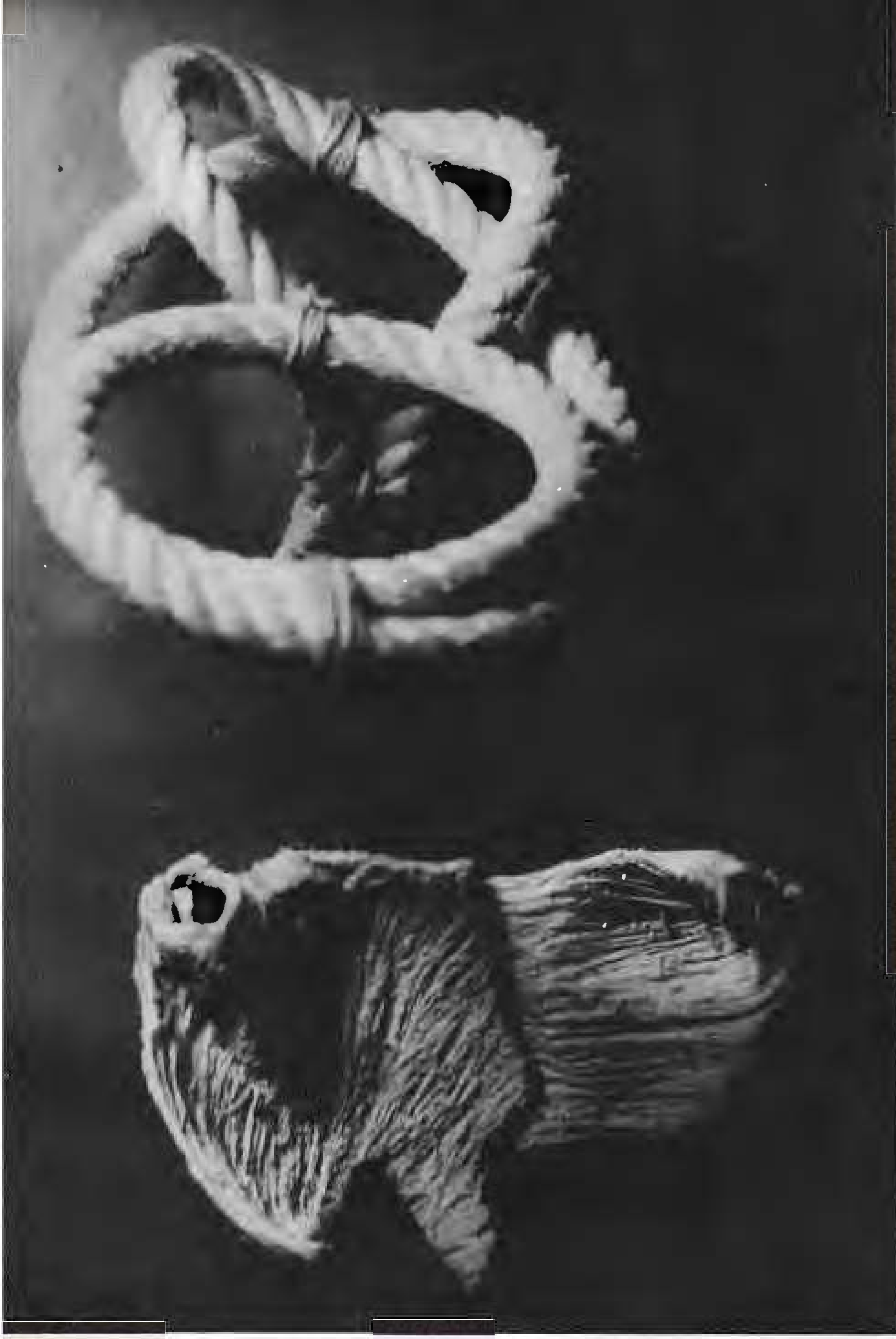


Fig. 77

The model of figure 69 and the corresponding anatomical preparation of figure 51, to show the coincidence in the interventricular septum of the two groups of fibres defining the tricuspide orifice anteriorly and posteriorly.

Fig. 78

Anatomical preparation of both ventricles, seen from their anterior surface. The muscular band has been isolated and its cut ends appear at the level of the anterior interventricular groove. Right border of the heart, a; left border, b. Compare with fig. 54.

Fig. 79

The same preparation of the previous figure, compared with the rope model. Note the position of the cut ends of the muscular band and the rope.

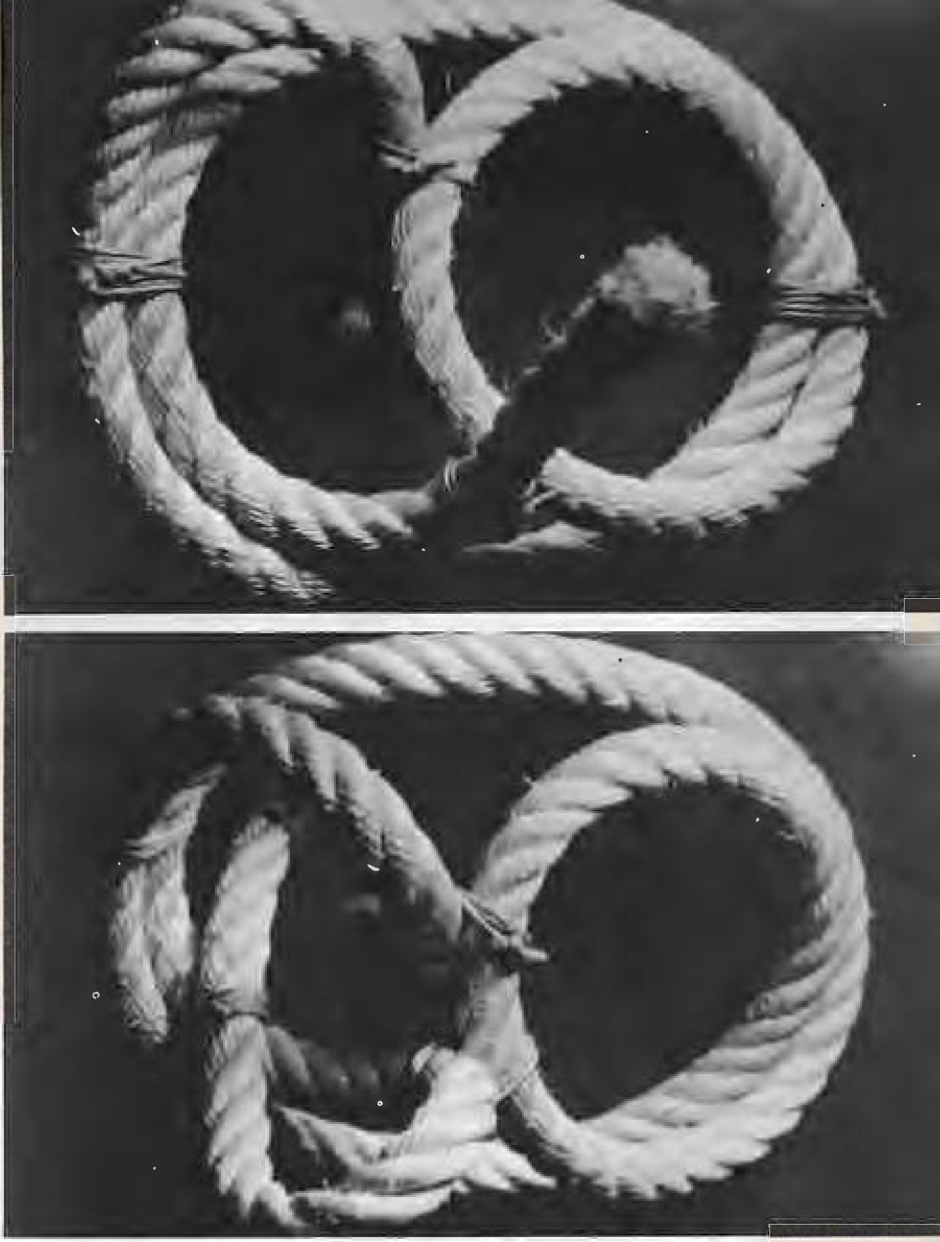


Fig. 80
Explanation in the text.

Fig. 81

Explanation in the text. Compare with figures 74 and 75
— the anatomical preparation is the same in all —

Fig. 83

Explanation in the text. Compare with figures 74 and 75 — the anatomical preparation is the same in all —.

Fig. 82

Explanation in the text.

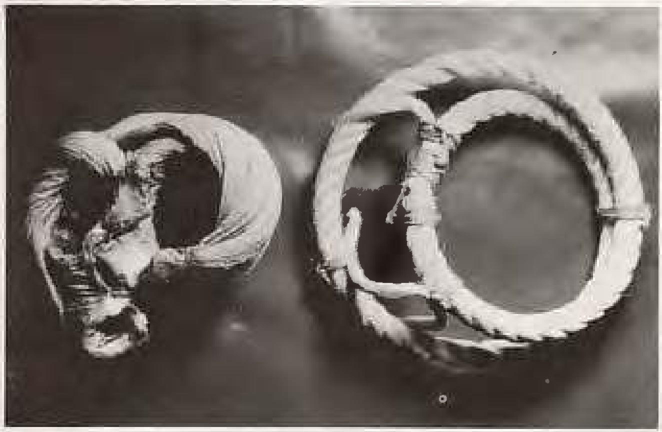


Fig. 84

Transverse section of both ventricles, shown together with the rope model. Both maintain their corresponding situation.
a, the posterior interventricular groove and b, the left border of the heart.

Fig. 85

The rope model and the corresponding anatomical preparation of the ventricular base. a, the posterior interventricular groove; b, the left border of the heart.

Fig. 86

Successive and parallel transverse cuts of the heart. Explanation in the text.

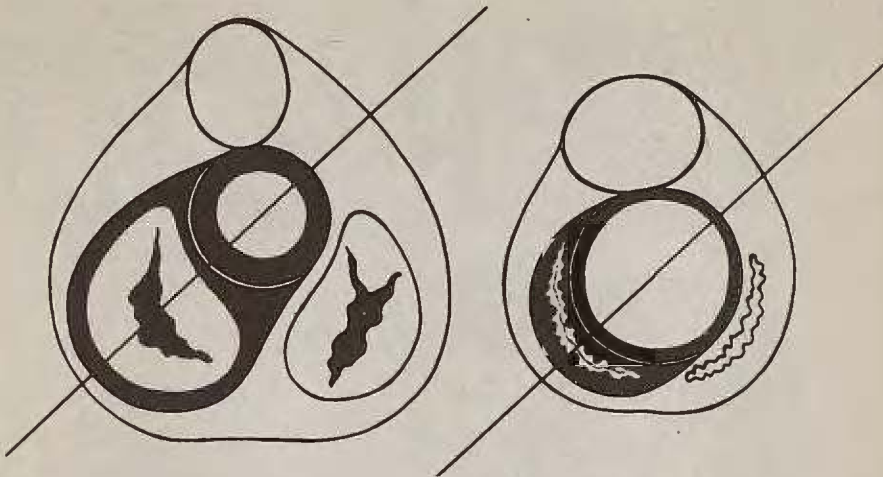


Fig. 87

The aortic and mitral orifices — thick tracing — in diastole — left sketch — and systole — right sketch —. Ventricular contraction and aortic dilation during systole reduce the mitral orifice to a sinuous line. The convers occurs during diastole.

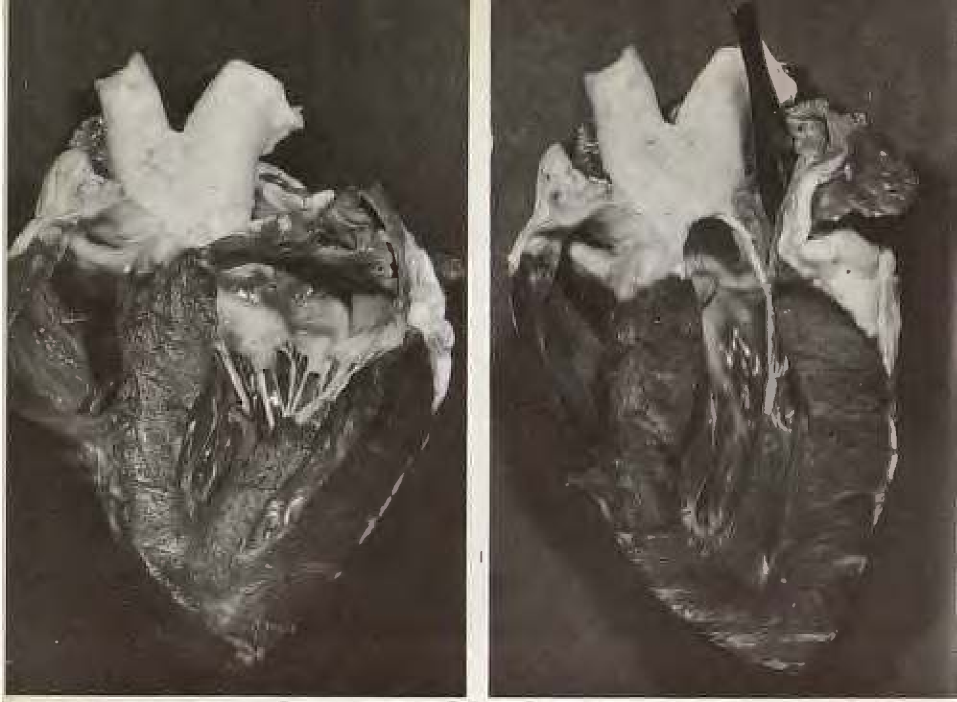


Fig. 88

The same ventricle in diastole — left sketch — and systole — right sketch —. During diastole the mitral cusps are far from one another; the auriculoventricular diameter is maximum; the whole ventricular cavity is directed toward the auricle, arranged for receiving blood. During systole the mitral cusps are abutted one to the other; the auriculoventricular diameter is minimum; the whole ventricular cavity is directed toward the aorta, arranged for the ejection of blood.

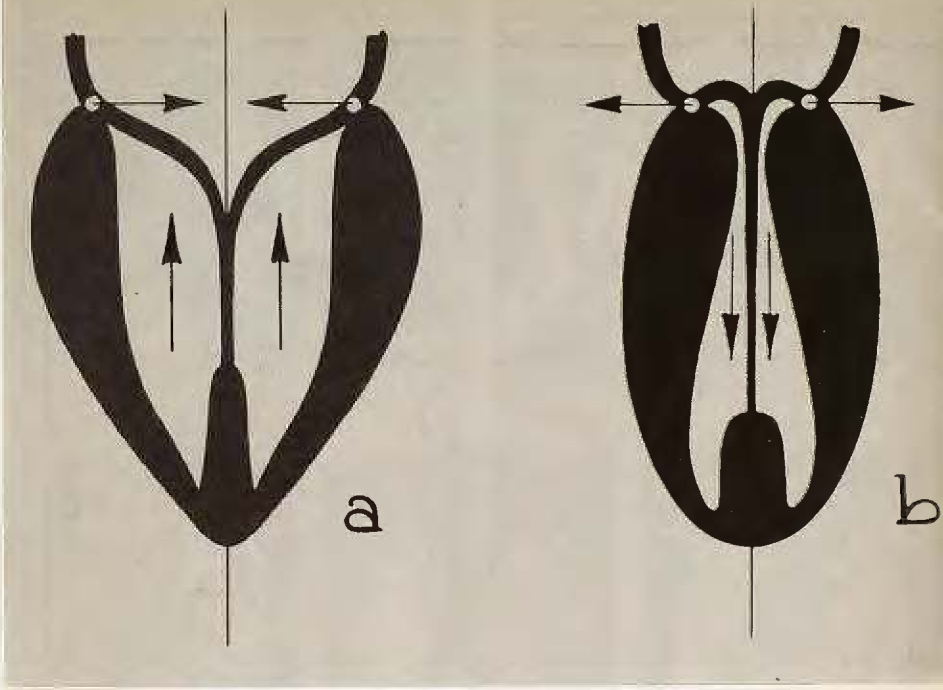


Fig. 89

The transverse and axial components — horizontal and vertical vectors respectively — of the closing — a — and opening — b — mechanisms of the auriculoventricular orifice.

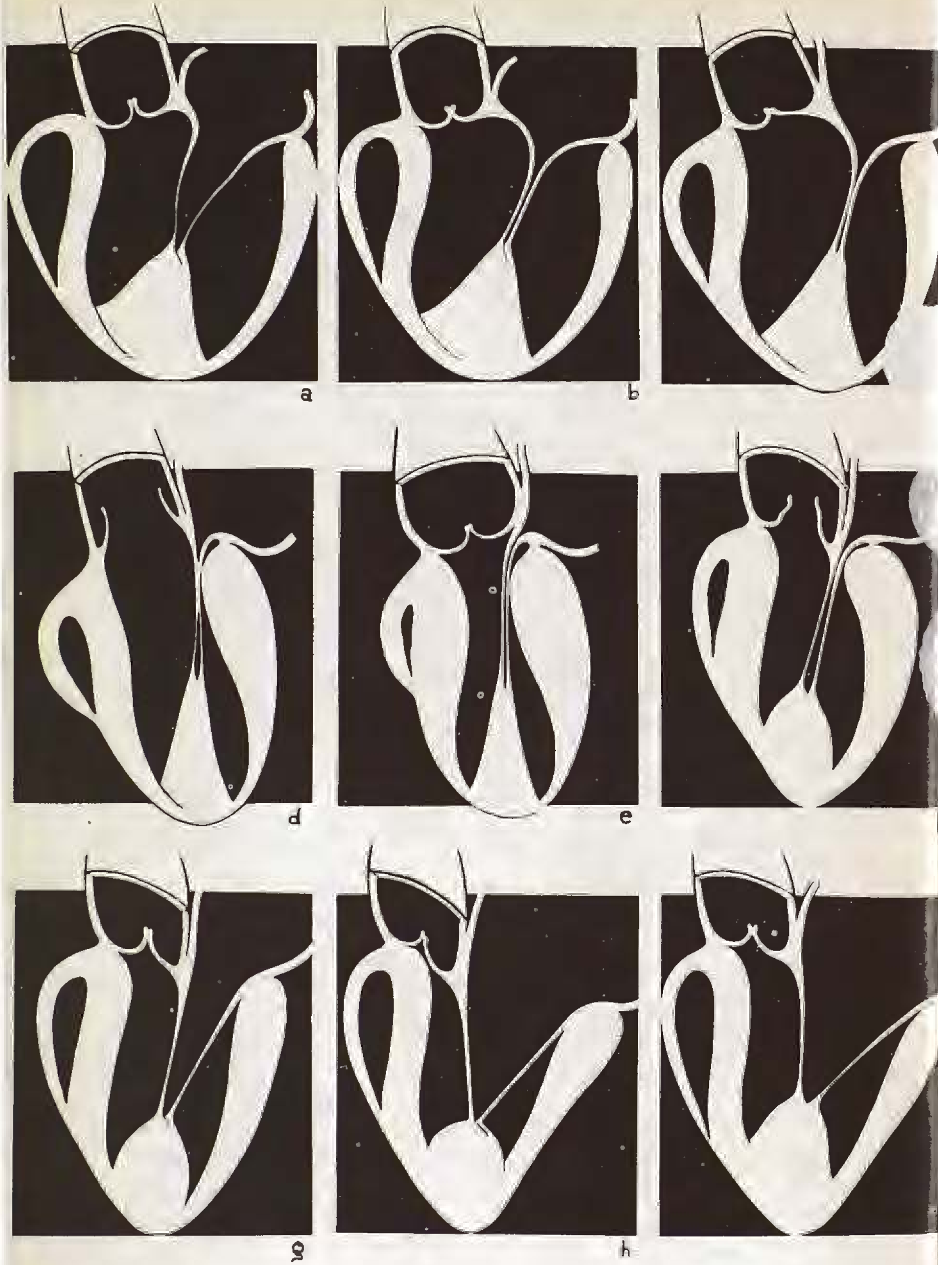


Fig. 90

Successive stages of the cardiac cycle, to show the intimate relationship between the mitral and aortic valvular dynamics.