THE STERNUM

BY

A. MELVILLE PATERSON

THE HUMAN STERNUM

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THREE LECTURES

DELIVERED AT THE

ROYAL COLLEGE OF SURGEONS, ENGLAND

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BY

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TO

THE MEMORY OF

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PREFACE

THERE are so many features of interest to the anatomist, morphologist, and embryologist, associated with the subject of this memoir: so much has been written about the sternum in detached papers: one's conclusions from a prolonged study of the subject agree so little with accepted notions of its morphology and development: that it seemed desirable to gather up the facts at one's disposal, and present one's ideas in book form rather than a series of separate papers. At the same time, it is recognized that the following pages present no complete account, and form by no means a survey of the entire field.

Having been collecting materials for many years, I have to express my thanks to many friends, associated with hospitals in Dundee, Edinburgh, and Liverpool. For the personal observations I have made on the comparative anatomy of the sternum, I am greatly indebted to Professor STEWART, of the Royal College of Surgeons of England, and to Dr. H. O. FORBES, of the Liverpool Museum, for the facilities which they have afforded to me for the examination of the collections under their charge.

I have also to express my grateful thanks for the valuable assistance rendered in different ways by Mr. DOUGLAS-CRAWFORD and Mr. EDWARD WHITLEY in the preparation and publication of this memoir.

A. M. PATERSON

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INTRODUCTION

THE subject of this memoir furnished the material for three Hunterian Lectures delivered at the College of Surgeons of England, in November, 1903. In preparing the lectures, one was forcibly struck with the difference between our outlook on anatomical problems and the view which HUNTER took. He was essentially practical, teleological, and a strict adherent of nature. All his works are strikingly illustrative of the correlation of structure and function, and his writings are singularly devoid of transcendentalism. While he invariably takes a broad and comprehensive view of any anatomical problem, his investigations are never disturbed or warped by the influence of nebulous hypotheses. He had the insight, the imagination of the investigator, but it was controlled by sanity and common sense.

HUNTER's writings, further, do not contain a single suggestion bearing upon the subject of these lectures. The difficulties that we are now grappling with had not then arisen. He never uses the work 'Morphology,' and homologies had not then acquired the importance that they now possess.

VERTEBRAL SEGMENTATION

The sternum is as good an illustration as any part of the animal economy of the tendency of modern anatomical thought, which, essentially morphological and architectural, has been influenced by views of vertebral segmentation to regard the sternum as a part of the skeleton intrinsically associated with the costal arches.

It is conceivable that we are going too far in our adherence to the idea of segmentation of the vertebrate body. In the construction of the skull, and the relation of the limbs to the trunk, evidence may be adduced to show that the notion of segmentation may be stretched too far. And even in regard to the trunk itself, where segmentation is most obvious, each particular segment has its specific differences. Segmentation, indeed, may be looked upon as an architectural device utilized for what it is worth, both in invertebrates and in vertebrates, and modified and discarded where it would be hurtful. Modifications of segmentation occur in the formation of the sacrum, in the cervical vertebrae of cetacea ; and there is no real segmentation in the urostyle of the frog, or in the mammalian *basis cranii.*

Segmentation, as HERBERT SPENCER points out, is essentially connected with progressive movement. The elongated worm-like organism for purposes of progression becomes segmented, on account possibly of alternate stress and strain produced by the attempt at a wriggling movement. Where stability and fixation are required segmental features are modified or absent.

In a mammal, the thorax presents the most complete and characteristic example of segmentation, by the association together of the vertebrae, ribs, and sternum. In other regions the costal elements are rudimentary or absent, and it is almost certain that no element comparable to the sternum exists elsewhere in the mid-ventral line of the trunk.

In such an animal as the ant-eater (*Myrmecophaga jubata*, Pl. IX, Fig. 63), the sternum consists of presternum, mesosternum, and metasternum. The mesosternum is composed of eight separate median pieces, which regularly alternate with costal attachments.

In most other quadrupedal mammals the general structure of the bone is the same, but (*e.g.*, jackal, Pl. IX, Fig. 64) there is a failure in the segmental alternation of mesosternal and costal elements ; and the costal cartilages of the last two sternal ribs unite at the same point with the junction of mesosternum and metasternum.

Again, in reptiles, birds, and certain mammals (notably bipeds) the same three elements are present—presternum, mesosternum, metasternum—but the mesosternum here consists only of a single bone, or fewer pieces, without any proper segmental relation to the ribs, but affording by its lateral margins attachment for a certain number of costal cartilages.

Lastly, by a study of comparative anatomy of lower forms, we are faced with the presence, in certain reptiles and amphibia, of a sternum which is not connected with ribs at all, but is associated with the shoulder-girdle only ; and in fishes, with one exception, an entire absence of the sternum, although there is a complex development of both shoulder-girdle and ribs.

The commonly accepted view of the morphology of the sternum is that it is made up of 'sternebrae,' derived from the costal cartilages ; and that each 'sternebra,' with a pair of ribs and a vertebra, constitute a typical and complete body segment.

The more one examines the subject (and even admitting the attractiveness and plausibility of this view) the more one feels that it is founded upon an insufficient basis, and presents such unsatisfactory features, that one is forced to enquire for some other hypotheses for the formation of the bone which will more adequately account for its special characteristics, and for the differences which it presents throughout the vertebrate series.

Apart from any hypotheses or theoretical considerations, the sternum is a bone which occurs in air-breathing animals possessing four limbs ; and its chief modifications are dependent upon differences in the mode of progression. It is the central bone of the thorax, comparable in that way to the *basis cranii*, an adjunct of the shoulder girdle, of prime importance especially in bipeds, and an essential factor in the construction of the osseous respiratory chamber. At the same time it forms a platform or a shield for the heart, and serves important mechanical purposes. Muscles radiate from it for the neck, fore limbs, thorax, and abdomen.*

The main thesis which I have to present is that there is insufficient evidence of the origin of the sternum from the rib elements, and indeed that the association of sternum with costal cartilages is a secondary one, and that the primary condition of the sternum is one in which it is in association with the shoulder-girdle. One does not claim originality for this view. It has been already foreshadowed by T. J. Parker, and Professor Cleland apparently does not accept the view held by most anatomists.

* One may draw particular attention to the correlation of the infra-hyoid muscles and the diaphragm, and the fact of their associated innervation, with the intervention of the sternum : and also to the presence of the internal mammary artery, and its prolongation downwards to the abdomen.

Professor Cleland's position as one of the most independent and philosophical anatomists of the present day, entitles any view which he expresses to weighty consideration. 'The sternum,' he says, 'there can be no doubt, is at first laid down in the form of two lateral slips at right angles to the tips of the costal cartilages. It is impossible, however, to refer these slips to prolongations from the costal tips. Judging from the appearance in the third month, the manubrium may be originally continuous with the first pair of costal cartilages, but the mesosternum takes its origin distinct from costal cartilages, and the xiphisternum is at first separated from the mesosternum by the sixth and seventh costal cartilages meeting in the middle line.

'The origination of the sternum in lateral parts explains the well-known case of M. Groux, in whom the two halves remained ununited, and could be pulled separate by the great pectoral muscles when the hands were clasped. Less complete division also occurs. The original distinctness of the lower parts of the sternum from the costal arches may be well kept in mind when comparing it with the chelonian plastron.' *

This is the main idea that I have to bring forward. The studies into which one has been led in this investigation have, however, brought to the front several minor questions of some importance to which one may be allowed to draw attention in due course.

Fissura Sterni

One aspect of the subject has not been personally studied—teratology of the sternum; so that it may be contended that thereby one of the strongest arguments (namely, the existence of a sternal fissure) in favour of the bilateral and costal origin of the sternum is evaded. Now the occurrence of fissura sterni has been one's greatest difficulty in an *a priori* acceptance of the orthodox view of the origin of the bone. From a study of the literature of the subject and from searches in museums, one finds it an extreme rarity. The museum of the Royal College of Surgeons does not possess a specimen. If the sternum is costal in origin this ought surely not to be so. All the factors engaged are tending, during the process of growth and ossification,

* Cleland and Mackay, *Text-Book of Anatomy*, pp. 130-131.

to expand the chest well and keep the halves separate. The expansion of the thoracic viscera, and the tendency of the curved ribs to straighten themselves, should offer every inducement to the occurrence of a cleft sternum.

On the other hand, fissura sterni may possibly be explained on other grounds. May it not be caused by an abnormal ratio of growth of the thoracic viscera and the chest walls at an early period, which may cause a stretching of the embryonic pre-chondral tissue out of which the sternum is normally produced? This in consequence does not chondrify or ossify, but instead gives rise to the membrane described as connecting together the two hemisterna or the ventral ends of the sternal ribs, in cases of fissured sternum. In the embryo chick, where the sternum is in two halves at first, there is a genuine ectopia cordis, and the two halves of the sternum are united by a thin layer of embryonic mesenchyme.

I. DEVELOPMENT AND OSSIFICATION OF THE STERNUM

A. General Considerations. The Materials and the Process

One of the fundamental difficulties in the study of the growth of all mesoblastic tissues arises from the gradual alteration of the primitive embryonic cellular tissue into more complex tissues—connective tissue, cartilage, and bone. At first there is a simple uniform tissue, in which and out of which, in definite areas, conglomerations of cells occur so as to produce a clearly demarcated mass in the situations in which, for example, vertebral column, ribs, sternum, and shoulder-girdle are to arise. Out of this mass of cells are produced connective tissues, cartilages, and bones. The usual mode of proceeding is the conversion of the cellular mass into cellular and afterwards hyaline cartilage, and in that, either by a perichondral or an endochondral mode of ossification, the cartilaginous model is converted into bone.

Besides the histological changes, there are also fundamental chemical differences to be remembered in the conversion of this embryonic tissue into its more stable and permanent form ; a gelatinogenic change in the formation of fibrous tissue, a chondrinogenic change in the formation of cartilage, and an osteogenic change in the formation of bone.

In exceptional cases (*e.g.*, lower jaw, vault of skull, and clavicle in part), the chondral stage is omitted and a process of periosteal or membrane bone formation takes place before any cartilaginous *anlage* can appear.

It is important in connexion with the development of the sternum particularly to be conversant with the pre-chondral stage in its formation, as by a recognition of this it can be demonstrated that the shoulder-girdle is associated with it, that the girdle becomes cartilaginous, while the sternal anlage is still in the cellular condition, and that the ribs are independent of the sternum at first, and in mammals become joined to it as cartilaginous bars, when the sternum itself is a cellular layer. And, further, after the bone has been modelled out into its definite form in cartilage, the process of ossification which sets in presents somewhat difficult characteristics. In man the process is endochondral. In the rat it is perichondral. In man the ossification of the sternum proceeds in the way characteristic of the development of epiphyses of long bones, the bodies of the vertebrae and the basis cranii. The bone is deposited as separate nuclei in the interior of the cartilage, and replaces it by gradual absorption of the latter, only a thin layer on the surface being formed as perichondral or periosteal bone. In the rat, on the other hand, each part (or so-called segment) of the sternum is produced like a digit, by a cylindrical growth of perichondral bone, which encloses the primitive cartilage and replaces it.

Much stress—probably too much—has been laid upon the occurrence of centres of ossification. At the lower end of the humerus there are four; at the lower end of the femur only one. One inclines to the belief that in such cases—and the sternum appears to be an exactly parallel case—the difference in the two bones named is due to the difference in the forces applied. In the case of the lower epiphysis of the humerus there are four forces acting upon it; the masses of muscles attached to the two epicondyles and the contact of radius and ulna. In the case of the femur, a single mechanical force is at work in the pressure of the upper end of the tibia.

So in the case of the sternum. While it has been the subject of considerable research and the most conflicting statements, we cannot regard the centres of ossification in the sternum as of essential morphological importance. There are three reasons which may be named in support of this opinion. (1) They are subject to enormous variation; (2) the ossifying process is one which is delayed till a comparatively late period; and (3) it is not inconceivable that mechanical forces, such as the expansion of the chest, associated with the growth of the contained viscera, and pressure and traction due to the attachment of the costal cartilages, may be the cause of the excitement which induces ossification.

Another important consideration of a general kind may be mentioned here. In the attempt to form a clear idea of the individuality of a particular structure, such as the sternum, what features are to be looked upon as typical and characteristic? At what stage in its growth are we to compare it with the corresponding structure in another organism? Is it the adult bone, or the separate centres of ossification, the cartilaginous model, or the pre-chondral tissue which is the most important feature in its history? Obviously, the only fair picture can be obtained by a composite view. All these phases in the growth of the bone must be taken into account, and it is only from a complete knowledge of its development, structure and variations that we can form a proper notion of its morphological position.

B. Early Development of the Sternum

(*a*) *Fishes*.

Elasmobranchs. In *Acanthias vulgaris* (Pl. III, Figs. 25, 26), I find that in young embryos the appearance of the shoulder-girdle and fore limb is foreshadowed by the occurrence of a conglomeration of cells such as has been described above, which is ultimately converted into hyaline cartilage. This stretches across the median ventral line and forms a continuous bar, without any differentiation into sternum and coracoids.

(*b*) *Amphibia* (*Anura*).

In the frog, the sternum (Marshall[42]) appears to be developed subsequently to the formation of the limb girdles. After the approximation of the precoracoid and coracoid bars, and the formation of the longitudinal epicoracoid elements on each side, further growths occur anteriorly and posteriorly. The *omosternum* is formed in front by the growth of bilateral processes, as continuations forward of the epicoracoids, which fuse to form a median cartilage. The *sternum* and *xiphisternum* are formed in the same way by an extension backwards and fusion together of similar bilateral projections from the hinder end of the epicoracoids.

(*c*) *Reptiles*.

Rathke[59] describes two distinct bilateral strips in *Lacerta agilis*, which unite to form the sternum. They are not at first continuous with the ribs; and in *Anguis fragilis* he finds the embryonic sternum further removed from the ribs in earlier than in later stages, thus indicating a separate origin for the sternum. The two halves of the sternum fuse together from before backwards.

GOETTE's observations[21] differ, to some extent, from RATHKE's, but bear them out in the essential point under consideration. In *Cnemidophorus* he found the sternum formed in two triangular halves, each portion being united at its proximal end with the distal end of the corresponding coracoid, and united at the lateral border with one rib. Later on he finds three ribs, and still later four ribs, associated with the sternal border. At the same time, he expresses his adherence to the view of the origin of the sternum from the ribs. In *Anguis fragilis* he finds, as RATHKE did, the sternum in two lateral halves, and admits that at an early stage the union of the ribs to the sternum cannot be demonstrated, or else they have already separated from the sternum. He maintains, however, that the anlage of the sternum is the distal end of the first rib, which is successively joined by the succeeding ribs.

(*d*) *Birds.*

In the chick (Pl. III, Figs. 27, 28) the formation of the sternum is characterized by the presence, at an early stage, of two separate cartilaginous halves, between which is suspended the heart in the pericardium, with a thin connecting cellular layer beneath it, joining together the two halves of the sternum. It is generally described as being derived on each side from the ventral ends of costal elements (two cervical and five thoracic), of which the two cervical lose connexion with the half sternum, and the fifth thoracic ribs become abortive and disappear.

I have made personal observations of the development of the sternum in the chick, and may summarize my observations here. At the end of the sixth day one finds no sternum and no ribs. The shoulder-girdle is present in a cartilaginous form, but the clavicle is not distinct. During the seventh day the halves of the sternum appear, cellular at first, and later on becoming cartilaginous. The coracoids are joined to the cellular sternum at first directly; afterwards, when the sternum becomes cartilaginous, by the intervention of a joint cavity; the ribs appear, become cartilaginous, and grow forwards to get connected with the half sternum on each side. The clavicles are now present and are becoming ossified. The ninth day shows fusion of the halves of the sternum, and formation of the keel out of the median border of each half sternum.

In the chick, during this process of growth, there is a distinct difference in the development of the sternum and of the ribs. When the ribs are cartilaginous the sternum is still cellular; when the latter first appears the ribs are unconnected with it, and it is only secondarily and after the sternum becomes cartilaginous that fusion occurs.

The existence of two lateral halves in the chick's sternum is a feature which is characteristic. It is to be associated, probably, with the early and excessive development of the heart in the embryo bird, which has heavy work to perform in the period of incubation; and by its excessive size delays the fusion of the parts, and causes a condition of embryonic *ectopia cordis*.

As in the frog, the sternum in its development succeeds the shoulder-girdle and the ribs, and is in a cellular condition when both of the other series have become cartilaginous. GOETTE[21] mentions that in the chick (four to five days) the sternal anlage was separate from the ribs.

He regards the avian sternum as formed in two distinct parts, a costal sternal plate and a clavicular anlage, the episternalia forming the crista sterni. Both portions are paired and laid down as widely separated halves. He considers that each half of the costal sternum arises *probably* from rib-ends.

HOFFMANN[23] also maintains that in the formation of the presternum an interclavicular element is present uniting with the costal sternum, and forming the keel.

Miss B. LINDSAY[38] in a valuable paper, in which, however, the costal view of the origin of the sternum is unquestionably accepted, describes in the *Gannet* the occurrence (first stage) of eight ribs which end freely with no trace of a sternum. Later (second stage), 'the sternum is indicated by thick opaque aggregations in a layer of mesoblast.' In the next stage 'the sternum is fully formed and fused with the ribs.' 'There are seven sternal ribs.' In the fourth stage the lateral halves of the sternum are closed, and the keel is formed.

She describes more particularly in the ostrich the metasternum and its processes as a backward extension from the mesosternum.

(*e*) *Mammals.*

My own observations* upon the early development of the sternum were made on rat and human embryos.

(*a*) In a series of continuous sagittal sections through a human embryo in the second month, prepared and placed at my disposal by Professor PAUL, the first anlage of the sternum (Pl. I, Fig. 1) is to be seen as a dense conglomeration of mesoblastic cells, occupying the anterior part of the thoracic wall in the middle line, and tapering off posteriorly : disappearing as a separate structure about the middle in length of the thoracic wall.

There is no indication of any bilateral arrangement of this cellular tissue. The inner end of the clavicle and the costal cartilages are composed of cartilage. The first three costal cartilages join the cellular median sternum ; the fourth and fifth cartilages join those above them ; the sixth and seventh have free pointed ends.

In rat embryos of 9 mm. in length a very similar condition is found (Pl. I, Figs. 2, 3, and 4). In the angle between the jaw and the thoracic wall (prae-cervical sinus) there is a conglomeration in the middle line of mesoblastic cellular tissue ; traceable laterally into association with the shoulder girdle, and concerned with the formation of the clavicles, thinning off as it passes backwards in the thoracic wall on the ventral aspect of the bulging heart.

At this stage this cellular mass is not connected with any of the costal cartilages, which are extending in a ventral direction, and ending distally in tapering points (Pl. I, Fig. 4). There is, moreover, no indication of bilateral subdivision of the mass, except at its cephalic end ; there the cells are consolidated into two horns, which are concerned with the formation of the clavicles and sterno-clavicular articulations, and with the anterior parts of the presternum.

(*b*) In rat embryos, 10 mm. in length, an advance in development has occurred (Pl. I, Figs. 5-10). The sternum is still cellular. The presternum is single and median (Fig. 5), and at its cephalic end the component cells are more distinctly massed together on each side to produce the

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* Read at the Manchester meeting of the Anatomical Society of Great Britain and Ireland, June, 1900, and published in the *Journal of Anatomy and Physiology*, October, 1900.

sterno-clavicular joints, and the inner ends of the clavicles. The cellular mesosternum (Figs. 8, 9) consists of two definitely separate strands of mesoblastic cells, which are separated in the middle line by a layer of sparser and more loosely arranged cells. The cellular sternum is now joined by the first six costal cartilages (the seventh is still separate on each side), but there is an obvious distinction in the character of the cells composing sternum and costal cartilages (Pls. I, II, Figs. 11, 12). The eighth costal cartilages are not in any way related to the sternum, and there is no indication of a metasternum.

In rat embryos, 13 mm. in length, the process of development has perceptibly advanced. Though the sternum is still cellular, and not yet converted into cartilage, the median separation between the two halves of the mesosternum has disappeared, and the mesosternum consists of a single median band of cellular tissue (Pl. II, Fig. 14). The metasternum (Fig. 15) has appeared; cellular in character and tapering off in the angle between the chest wall and the diaphragm. The clavicle in its outer part is undergoing ossification, and its inner end is cartilaginous. It is clearly demarcated from the presternum, although no joint cavity has yet appeared in the sterno-clavicular articulation (Fig. 13). All the seven costal cartilages are now connected with the sternum; but there is still an obvious distinction between the character of the tissues composing the sternum on the one hand and the costal cartilages on the other (Fig. 14).

(*c*) The third stage in the development of the sternum is associated with the conversion of its cellular tissue into cartilage—at first cellular, afterwards hyaline. The process begins in the presternum in the upper lateral angles, along with the formation of the clavicle (Pl. I, Fig. 11). In the mesosternum, cartilage cells first appear at the periphery of the band, in the intervals between the attachment of the costal cartilages (Pl. II, Fig. 12). The parts of the sternum opposite the costal attachments remain longest in a cellular condition. In the metasternum, cartilage formation begins at the anterior end (Pl. II, Fig. 15).

Ultimately the sternum is laid down—a model of the future bone—as a simple median band of hyaline cartilage, separated at this stage from the clavicles by cellular connective tissue, but in complete fusion with the costal cartilages on each side, and presenting absolutely no differentiation of its component parts.

Three human sterna of the third month, measuring respectively, 8, 9, and 10 mm., show clearly this condition (Pl. II, Figs. 17, 18, 19). The demarcation of sternal elements and of costal cartilages is shown in the special arrangements of the cartilage cells in lines, along which, later on, the joint cavities will be formed. In all three sterna the sterno-clavicular joint is completely formed, with its inter-articular fibro-cartilage. But in only one case is there a definite costo-sternal joint cavity (between the mesosternum and the second right costal cartilage) (Fig. 18F).

(*d*) The further changes in the cartilaginous sternum preceding ossification occurs in rodents (rat, mouse) without cleavage of the parts of the sternum or separation of costal cartilages. Opposite to the costal attachments the cartilage is distinctly hyaline, poorer in cells, and stained less deeply than in the intervals between the costal cartilages. In these intervals the cells are massed together, stain deeply, and the process of ossification is foreshadowed by the formation of 'primary areolae,' which occur in the centre of the presternum, in the metasternum, and in the first four so-called segments of the mesosternum (Pl. III, Figs. 20, 21, 22).

These areolae increase in size, while at the same time the perichondrium becomes enormously thickened, followed by the formation of periosteal temporary bone in the usual way (Fig. 22).

Thus at birth (in the mouse, Pl. III, Fig. 23), while there is complete fusion of the sternal elements together, and of the costal cartilages with them, there is a distinct differentiation of elements entering into the constitution of the sternum. Bone formation has begun, and cartilage only exists at the extremities of the presternum and metasternum, in the mesosternum opposite the costal attachments, and in the interval between the attachments of the sixth and seventh costal cartilages (Fig. 24).

These observations do not harmonize with accepted views, which have been derived from the observations of distinguished and accurate observers, notably Ruge,[60] whose monograph on the subject has long been accepted as having settled the question of the early development of the sternum. There are several points in that memoir, however, which, on careful perusal, compel us to hesitate before accepting the conclusions arrived at by the author as final.

It is extremely difficult to summarize and classify the views of authors regarding the development and morphology of the sternum. RATHKE,[59] who first described its development in the chick, gives nowhere any suggestion that the sternum is not originally separate from the ribs. BRUCH later describes it as formed independently, and secondarily connected with the ribs. RUGE,[59] HOFFMANN,[23] and others have maintained the opposite view, that the sternum is wholly derived from costal elements, while GOETTE[21] inclines to a middle view, which appears to me to contain a certain fallacy and at the same time to possess a certain basis in fact. He holds that the presternum is partly derived from the shoulder-girdle (clavicle), partly from the ribs, that the mesosternum is wholly costal, and that the metasternum is a derivative of the mesosternum.

On account of the fact that RUGE's memoir has been the mainstay of the exponents of the theory of the costal origin of the sternum, one has had to examine it with the greatest care. It is an admirable piece of investigation. But, writing with all deference, I venture to submit that, granting the accuracy of all the observations made, exactly the opposite conclusion may be drawn from the memoir ; and it is further open to observe that most of the writers who have followed RUGE have been more dogmatic than he is in their statements of RUGE's observations.

RUGE's evidence in this matter is of such importance, and his observations of such material assistance in the elucidation of this problem, that it is desirable to review a few of his statements.

The points brought out by a careful examination of his memoir may be stated in the following propositions :—

1. The sternum in the earliest stages examined by RUGE consists of two longitudinal strips (*sternal leiste*), which may be traced into the abdominal wall, and there fade away into indifferent tissue without a distinct line of demarcation. But no statement is made of the character of the tissue that occurs in the middle line between the two strips.

2. These sternal strips are joined by the distal ends of the ribs. But the earliest stage shown is one in which, while the three proximal ribs

have fused with it, the succeeding (fourth and fifth) ribs have as yet no connexion with the sternal leiste. Yet the sternal strip is continuous, so that either the fourth and fifth ribs have advanced and afterwards receded, or their connexion with the sternum is a secondary one.

3. At this admittedly early period there is no indication of segmentation of the sternum, and no proof is given of any growth of the rib ends to produce it by their fusion.

4. It is shown that the inner ends of the clavicles and the presternum are in intimate organic association at an early period : the parts of the sterno-clavicular joint, the ligaments, menisci and suprasternal ossicles, as well as the upper end of the presternum itself, being differentiated out of a homogeneous material.

5. The presternum Ruge derives from the cartilages of the first and second ribs, but he cannot determine that the suprasternal ossicles have a costal origin.

6. With regard to the formation of the sternum and ribs, he states twice that there is a difference in the microscopic structure of the two. Once he states that the sternal leiste appear purely cellular, while (in the same specimen) the ribs have a considerable amount of intercellular tissue ; and in another place, speaking of the appearance of the elemental structure of the cartilage, he states that the rib cartilage contains cells larger than those of the sternum.

7. The metasternum Ruge derives from the distal ends of the eighth and ninth costal cartilages, which he supposes have lost a primitive connexion with the sternum. Albeit, he describes a pre-existing tissue continuous with the mesosternum, extending into the abdominal wall, and, when first seen, unconnected with the ribs in question.

There are other points of detail which, in addition to those named, support my contention that Ruge's observations can be used to support a thesis exactly opposite to the one advanced by him.

From his observations one contends that a picture is presented of a mesial presternum and metasternum, and a mesosternum continuous with both, but thicker on either side than in the mesial plane. The presternum is continuous with the shoulder-girdle (coracoid and clavicle) ; the metasternum projects into the abdominal wall. The ribs secondarily join the sternal anlage, and are distinctly cartilaginous when they fuse with a cellular sternum. After fusion, lines of separation occur at the junctions to produce the costo-sternal joints.

One would not venture to criticize in this way the results of so eminent an observer if one had not had opportunities of largely repeating the observations made by him, or if one were not convinced that MINOT'S criticism[43] is a suggestive one, and that a stage earlier than that at which RUGE commenced his observations must be examined before conclusions such as he advanced can be arrived at.

From an examination of embryos, both chick and mammalian, and from an examination of the observations of others on the development of the vertebrate sternum, one concludes that the preponderating weight of evidence is in favour of an independent sternum, associated in its early development with the shoulder-girdle and acquiring secondary and variable connexions with the ribs.

C. OSSIFICATION OF THE STERNUM

The process of ossification of the sternum occurs late in foetal life, and is characterized in man by deposits of endochondral bone. Such diverse statements and so many observations have, at different times, been made upon the occurrence of those centres, that it will be best to summarize one's personal observations first, and then to compare them with those of others.

If these centres of ossification possess a morphological value, and are, in any sense, indicative of a metameric formation of the sternum, it is of prime importance to demonstrate their segmental character.

It is to be noted that when ossification commences, the sternum is an exact cartilaginous model of the future bone ; the presternum may or may not be separated from the mesosternum by a transverse, fibrous lamina ; and the cartilaginous metasternum is continuous with the mesosternum.

The process is most conveniently studied in two stages—before and after birth.

(*a*) Ossification of the Human Sternum before Birth

The following facts have been derived from an examination of two hundred and thirty-six sterna of human embryos between the foetal ages of three and nine months.

Dates of Ossification.

The approximate periods of ossification in the component parts of the sternum are shown in the diagram (Pl. V, Fig. 35), which essentially corroborates the accepted account of the dates at which the several centres appear. The first nuclei appear, generally, in the sixth month for the presternum and the first piece of the mesosternum. In the seventh month centres appear for the second and third pieces of the mesosternum. No further addition to the number of centres occurs during the eighth and ninth months; and in full-time foetuses (of which one hundred and twenty-two examples were examined) the fourth piece of the mesosternum and the metasternum are usually cartilaginous (Table I).

Position and Number of Centres of Ossification.

In Table II, a summary is given of the situation and number of centres of ossification in the component parts of the sternum. A more intimate analysis did not appear necessary; and for the sake of brevity and clearness, reference has been omitted to the separation or fusion of double centres, and to obliquity in their position (such oblique double nodules being grouped as lateral). The results tabulated, it should be noted, are reached from an examination of specimens, of which the large majority are full-time foetuses. The cases of younger sterna are not only fewer in number, but are also less advanced in ossification.

While there is considerable variability, both in number and position, the centres of ossification are, as a general rule, single and median, and are five in number; one for the presternum, one each for the first three elements of the mesosternum, and one for the metasternum. Exceptions to this rule are found in all situations, except in the metasternum, which, in the few cases in which bone formation has begun, is invariably provided with a single median centre.

The *presternum* is generally formed by a single centre (79 per cent.) Where there are two centres, they are, generally, vertically placed. Three or more centres occur quite rarely (2·6 per cent.)

The first centre for the *mesosternum* is, as a rule, also single (78·5 per cent.); when there are two, they are usually laterally placed. The second and third centres of the mesosternum are less frequently single than the above-named centres (59·3 per cent.: 60·5 per cent.) When there are two centres, they are in most cases laterally placed. The fourth centre in the mesosternum is not generally present (26 per cent.) When it occurs it is nearly as often double as single; and when two centres are present, they are as often vertical as lateral in position. It is of course possible, as MARKOWSKI[44] infers, that the lower of two vertical centres represents the metameric centre of ossification for the fifth piece of the sternum; but, as it usually occurs in the interval between the attachments of the fifth and sixth pairs of costal cartilages, and not between the attachment of the sixth and seventh pairs, it has been looked upon as pertaining to that, and not to a lower segment of the bone.

The part of the sternum between the attachments of the sixth and seventh costal cartilages is cartilaginous at birth. It appears to be ossified, as a rule, by extension from the third or fourth piece, though there is reason for believing that in some rare cases it may possess a separate and independent centre (MARKOWSKI).

Fissures : Grooves : Foramina.

One remarkable negative feature characterizes the series of foetal sterna examined. In all there is a complete median plate of cartilage, grooved it may be on one or both sides, perforated in some instances by one or more holes, but in no single instance is there a *fissura sterni. A longitudinal groove* (Table III) is characteristic of the foetal mesosternum, occurring in one hundred and fifty-eight out of two hundred and twenty-two examples, or 70·1 per cent., a proportion which obtains generally for all ages. It may be faint or obvious; it may be found on one or both aspects of the mesosternum, and implicate it in the whole or part of its length, but it never appears in the presternum. This grooving of the mesosternum is probably associated with the method of early development of the cartilage, but it is at the same time plain that it is not necessarily coincident with a bilateral *ossification* of the mesosternum.

Sternal foramina (Table IV) occur only occasionally (in seventy-two out of two hundred and thirty-six cases, or 30·5 per cent.) The number and situation of the perforations are as follows :—

	Cases		Per cent.
One foramen in the metasternum . . .	54	...	22·8
Two foramina in the metasternum . . .	5	...	2·1
One foramen in the mesosternum . . .	8	...	3·3
Two or more foramina (in the mesosternum and metasternum)	5	...	2·1
	72	...	30·5

The great majority thus occur singly in the metasternum, and the presternum is never perforated. From an examination of a human embryonic sternum, 9 mm. in length (third month) (Pl. II, Fig. 19), one is led to believe that the perforation is due to the persistence of vessels, preventing the conversion of the embryonic connective tissue into cartilage in the middle line.

Like the grooves, these foramina are not improbably causally associated with the mode of early development of the sternum, and it is therefore noteworthy that neither grooves nor foramina occur in the presternum.

Union of Sternal Elements and Costal Cartilages.

An examination of the mode of union of the parts of the sternum with one another and with the costal cartilages brings out the fact that the connexions are much the same in the earlier and later months of foetal life (Table V).

The presternum and mesosternum are usually connected together by a fibrous lamina (76·4 per cent.) opposite the attachments of the second costal cartilages. More rarely they are fused together by cartilaginous union (23·6 per cent.). I have only met with one example (in a nine months foetus) of a case of alteration in position of the junction to the point opposite the attachments of the third costal cartilages.

The mesosternum and metasternum are usually (77·9 per cent.) united by cartilage, and only exceptionally (22·1 per cent.) by a fibrous lamina.

The costal cartilages in the centre of the series are generally fused with the lateral borders of the sternum, and are not united to it by a fibrous lamina. The first costal cartilage is also, as a rule (81·3 per cent.), continuous with the presternum. Occasionally on one side or both the union is fibrous.

The condition of the seventh and eighth costal cartilages has been particularly noted. It is not uncommon for the seventh pair of cartilages to articulate together in front of the sternum (thirty-four cases—14·4 per cent.) (In still fewer cases the same occurs with the sixth costal cartilage). In 8 per cent. of the cases the seventh cartilage fails to reach the sternum on one side or both. On the other hand, the eighth cartilage on one side or both is connected with the sternum in still fewer cases (4·8 per cent.) In rare cases, the fifth, sixth, or seventh cartilage reaches on one side to the middle line of the sternum, its distal end pushing its way forwards through the body of the sternum.

Shape of the Metasternum.

Out of one hundred and eighty-nine cases, the metasternum is present in one hundred and eighty-two (96·3 per cent.); absent in seven instances (3·7 per cent.) I have been as careful as possible to discard all examples in which there was the slightest indication that the metasternum had been accidentally lost in maceration.

While the shape is extremely variable, it is more often pointed and median than bifurcated. An undivided metasternum occurs in one hundred and seven cases (57·6 per cent.); a bifid metasternum in seventy-seven cases (42·3 per cent.)

Anomalies in Development.

One of the most striking features of the series of embryonic sterna examined is the absence of anomalous conditions, and the regularity and symmetry of development. No case of *fissura sterni* is recorded. One example occurs of transference of the pre-mesosternal junction to the level of the third costal cartilages. A few instances are found in which one or more costal cartilages (usually the fifth, sixth, or seventh) force their way through the cartilaginous sternum to the middle line. Absence of the metasternum, asymmetry in the attachment of costal cartilages, and fusion of contiguous costal cartilages together, also occur in a few examples.

Suprasternal Cartilages.

In two cases suprasternal cartilages have been found, situated at the cephalic border of the presternum, between the clavicular articular surfaces. In one case the cartilages are separated from the presternum and fused together; in the other case, they are separate from one another, but continuous with the cartilaginous presternum (Pl. VI, Figs. 43A, B).

(*b*) Ossification of the Human Sternum After Birth

1. *Growth of the Presternum after Birth.*

After the age of sixteen years the presternum is always a single median bone. Among younger sterna, between the first and sixteenth years inclusive, out of eighty-four examples, sixty-nine (82·1 per cent.) possess single median centres; eleven (13 per cent.) have double vertical centres (eight fused, three separate); two cases present double centres, lateral or oblique; and in two cases three and five centres, respectively, are present.

These statistics harmonize with the conditions obtaining in the foetal presternum, in which there is commonly a single median centre (79 per cent.), and more often a pair of median, vertical centres (13 per cent.) than lateral or oblique centres (2·3 per cent.) The larger percentage of single median centres in the presternum after birth is doubtless due to the previous fusion of two centres in some cases.

Completion of the Presternum.

After the age of sixteen years, there is a still further growth of the presternum by means of an ectochondral ossification around and along the first costal cartilage (Pl. V, Fig. 36). The ossification is at first independent of the presternum, but the bone produced soon completely fuses with it so as to form spurs or *sternal cornua*, which provide a more extensive surface for the articulation of the sternal end of the clavicle. These sternal horns are present in 71 per cent. of the sterna in my possession over the age of twenty-five years. Among those between twenty-five and thirty years there are twenty-five examples out of fifty-six sterna. Of sterna under twenty-five years, only three possess these projections—two at twenty-one, and one at nineteen years.

These sternal horns increase the width of the adult bone, and must be taken into account in the transverse measurements of young and adult bones, respectively.

There is no doubt that in some cases at least the first costal cartilage has a share in forming the articular surface for the sterno-clavicular joint—TESTUT,[67] MORRIS,[46] ANTHONY[1]—and these sternal horns are produced by ossification, which serves the purpose of extending the area of the sterno-costal articular surface.

The presternum is complete at sixteen, and is supplemented between twenty-five and thirty years by the addition of these cornua.

ALBRECHT[2] (quoted by ANTHONY[1]) contends that theoretically the human presternum contains sixteen centres of ossification—two 'hemi-sternebrae' in front of the first pair of thoracic ribs, two between the first and second pairs; two 'hemi-post-omosternums' (the omosternum of the batrachia); two 'pre-para-sternals' representing the sternal ends of the last pair of cervical ribs; two para-sternals representing the sternal ends of the first thoracic pair; two subclavicular epiphyseal points; two caudal hemi-epiphyses belonging to the second pair of hemi-sternebrae; and two hemi-epiphyses corresponding to the Lophosteon of birds.

RAMBAUD and RENAUT[58] describe a case of the occurrence of five centres of ossification in the presternum of a full-time foetus. In QUAIN's *Anatomy*[57] a presternum is figured with six centres. ANTHONY[1] found at most three centres in his cases, and more often two; one superimposed above the other. He agrees with the facts adduced by my observations, and by others (RAMBAUD and RENAUT, TESTUT,[67] and MARKOWSKI[44]) that the presternum is usually ossified from one centre and more rarely from two.

2. *Growth of the Mesosternum after Birth.*

After the age of twenty-one, the mesosternum is a single bone, and after sixteen years the fusion of its component parts makes it impossible to determine the precise number of the original elements.

Ridges on the Mesosternum.

In the adult bone the only evidence of the number of component parts of the mesosternum is derived from the presence of ridges across the bone; but these ridges are quite unreliable guides. They are variable in number and strength, and are not normally present except between the attachments of the third costal cartilages (69·2 per cent. of all sterna over twenty years).

Out of five hundred and twenty-four cases (Table VI) the ridges are absent altogether in one hundred and forty cases (26·7 per cent.) There are three hundred and sixty-three examples of a ridge opposite the third costal attachment (69·2 per cent.); two hundred and five examples of a ridge opposite the fourth (39·1 per cent.); twenty-one of a ridge opposite the fifth (4 per cent.); and two of a ridge opposite the sixth costal attachment (0·3 per cent.).

The only evidence which these ridges afford supports the facts of ossification; there are at least three elements engaged in the formation of the mesosternum. They are of no value in deciding upon the presence or absence of a fourth element; and there is no justification for the statement[57] that the mesosternum 'is marked on its anterior surface by three slight transverse elevations at the lines of junction of its four component parts.'

Ossification of the Mesosternum

Number of Elements.

An examination of one hundred and forty-one mesosterna between the ages of birth and sixteen years confirms the view adopted from an examination of foetal sterna (p. 18), that it is usual to find three centres of ossification, but only exceptionally four centres (Table VII).

Three centres of ossification are practically constant; and in two cases only was the third centre absent (at the ages of two and nine years, respectively). In thirty-eight cases (26·9 per cent.) there is a fourth centre for the ossification of the lowest part of the mesosternum, between the attachments of the fifth and seventh costal cartilages. This element receives laterally the attachment of the sixth costal cartilages.

The percentage of cases in which a fourth centre of ossification occurs is lower than in the foetal sterna examined (29 per cent.), probably on account of fusion in some cases of the two lower centres. There is, among the cases examined, no evidence of the occurrence of a distinctly segmental fifth centre for the ossification of the part of the mesosternum between the sixth and seventh costal cartilages.

Median and Bilateral Ossification of the Mesosternum.

In the case of each so-called segment of the mesosternum, it is much more common (Table VII) for ossification to occur by means of single, median centres, than by two or more lateral or vertical centres. When more than one centre of ossification are present, it is further much more common to find them lateral (or oblique) than vertical in position. The third piece of the mesosternum is the one most frequently bilateral, and the first is most often single and median (Pl. V, Figs. 38 and 39).

In this respect again confirmation is given to the conclusions drawn from the examination of foetal sterna. The proportion of single centres in sterna after birth is, doubtless, higher, on account of pre-natal fusion of certain additional centres.

Relation of Ossification of Mesosternal Elements to Asymmetry of the Sternum.

Many instances have been noted of obliquity in the lines of junction, irregularity in the form and shape, obliquity in position, of the ossifying elements of the mesosternum. These irregularities have doubtless some influence in causing curvature and asymmetry of the sternum, if only by the approximation or separation of adjacent costal cartilages.

Fusion of the parts of the Mesosternum.

The number of sterna examined gives sufficient data for the determination of the approximate order and time of the fusion of the component elements of the mesosternum. The series may be subdivided at the nineteenth year. Sterna of nineteen years and over usually possess mesosterna, in which the elements are fused together. In sterna of eighteen years or less the component elements of the mesosternum are usually separate. After the age of forty-one (in two hundred and ninety-nine sterna between forty-two and eighty-two years, inclusive) the mesosternum is always a single undivided mass.

Out of one hundred and sixty-one sterna between twenty-six and forty-one years, inclusive, the mesosternum is a single bone in one hundred and fifty-five cases (96·2 per cent.) The six exceptional mesosterna consist in every case of two pieces, separated in five examples between the first and second elements, and in one between the third and fourth.

(1)	F	*aet.*	30	
(2)	M	,,	34	
(3)	M	,,	39	1 2 + 3 + (?) 4
(4)	M	,,	39	
(5)	M	,,	41	
(6)	M	,,	32	1 + 2 + 3 4

Among forty-four sterna between the ages of twenty and twenty-five years, the mesosternum is a single piece in thirty-six cases (81·8 per cent.) There are nine exceptional cases, in eight of which the mesosternum is in two pieces ; in one it is in three pieces.

(1)	M	*aet.*	21	
(2)	M	,,	23	
(3)	M	,,	24	1 2 + 3 + (?) 4
(4)	F	,,	25	
(5)	M	,,	25	
(6)	F	,,	20	1 + 2 + 3 4
(7)	M	,,	21	
(8)	M	,,	20	1 + 2 3 + 4
(9)	M	,,	20	1 2 3 + 4

In five cases the cleavage is between the first and second elements ; in two cases between the third and fourth ; in one between the second and third ; and in one instance the second piece is separate from both first and third.

Among seventeen sterna at nineteen years, the mesosternum is a single bone in ten cases (58·8 per cent.) Of the remaining seven cases, in five the first piece is separate ; in one the first and second pieces are separate ; and in one case all the elements are separate.

Below the age of nineteen, as already stated, the mesosternal elements are more frequently separate than fused.

Of eleven sterna at the age of eighteen years, four possess mesosterna (36·3 per cent.) in the form of a single bone ; in one case all the elements are separate ; in six cases the first piece only is separate, and in one of the six it is fused with the presternum.

Among seven sterna at seventeen years, there are five in which the mesosternal pieces are all separate ; and two in which it consists of two pieces (1 · 2 + 3 + 4, and 1 + 2 · 3).

Of sixteen sterna at sixteen years, six have mesosterna, the elements of which are all separate ; five in which they are all fused (31·2 per cent.) ; and five in which the mesosternum is in two parts ; of the last-named series, four show a cleavage between the first and second, and one a cleavage between the second and third pieces of the bone.

Out of seven sterna at fifteen years, the mesosternal elements are all separate in three cases, all fused in two cases (28·5 per cent.) In two cases the mesosternum is composed of three separate pieces.

Of seven sterna at fourteen years, the mesosternal elements are all separate in three cases ; all fused in one case (14·2 per cent.) In two cases the first piece is separate ; and in one case the first and fourth pieces are separate, the second and third being fused together.

In a sternum of thirteen years of age, the parts of the mesosternum are all separate.

Of five sterna at twelve years, the elements of the mesosternum are all fused in one case (20 per cent.) ; and all separate in another. In two other cases, the first, and the first and second, respectively, are separate from the rest.

Among three mesosterna at eleven years, there are two pieces in two cases (1 · 2 + 3 : 1 · 2 + 3 + 4) ; and in one case three pieces (1 + 2 · 3 · 4).

Three sterna at ten years, and six at nine years, show all the mesosternal elements separate.

Of three cases at eight years, the mesosternal elements are all separate in one case ; in two cases the first two elements are separate (1 · 2 · 3 + 4).

Among five mesosterna at six years, different conditions are present in each case :—

(1) 1 · 2 · 3 · 4
(2) 1 · 2 · 3 + 4
(3) 1 · 2 + 3
(4) 1 + 2 · 3
(5) 1 + 2 + 3 + 4

Among five sterna at five years, all the mesosternal elements are separate in four cases ; in one case the second and third pieces are fused together.

Of three sterna at four years, one has all the mesosternal elements separate ; in two instances the third and fourth pieces are fused (1 · 2 · 3 + 4).

In eighteen sterna, aged 0—2 years, the mesosternal elements are separate in all.

This statement has been made at length to show that although there is wide variability, the examination of an extended series shows a considerable regularity in the mode of fusion of the parts of the mesosternum (see Table VIII). There is a tendency for the parts to unite together from below upwards, and only exceptionally in the opposite direction. Precise data are not possible about the fourth element, as it is so often absent; when present, it is usually the first to unite with the preceding portion.

Between the time of birth and the end of the tenth year (Table VIII) three or four pieces of the mesosternum remain separate. Between the eleventh and fifteenth years inclusive the third (or the fused third and fourth) segment begins to unite with the second. Between sixteen and twenty years inclusive the second, third, and fourth pieces have usually united, and the second is beginning to join the first. Between twenty-one and twenty-five years all the elements become fused, so as to form a single bone.

Eight anomalous cases have been noted, in which union occurred in different ways (Table VIII). These anomalies are all traceable to the behaviour of the second piece of the mesosternum, which fuses with the first or third piece or with both, leaving the other element or elements separate.

These observations confirm and amplify the statement of Dwight[12, 13] and others regarding the date of completion of ossification of the mesosternum. They indicate, in my opinion, a greater degree of precision than Dwight's cases admitted, in the process of union of the several elements (Pl. V, Fig. 37).

In examining the ossification of the mesosternum it is difficult in some cases to decide on the relation to particular ribs of a given centre of ossification, and one has to admit the general conclusion that the osseous deposit occurs with characteristic irregularity. It appears to be stretching the facts observed too far to assume that a given centre is actually associated with any given pair of ribs. At the same time, an important point is demonstrable, that even in the most regular and symmetrical cases there are only three, or at the most four, sets of centres for the mesosternum. No doubt five or more centres may occur, but I have searched in vain among the examples examined for the presence of a distinctly segmental fifth mesosternal element, such as has been figured and described by Otto.[50] One does not doubt its existence, but one fails to give it the morphological importance ascribed to it, and one explains its occurrence on the same grounds as that of other centres—mechanical causes. It is useless to quote the text-book statements on this point. They are copied from one to another, without verification, and all are more or less erroneous. The statement that is most approximate to the truth, as I have observed it, is DWIGHT'S[12]: 'Few examples occur over twenty years in which the mesosternum is not one piece.'

3. *Growth of the Metasternum*

The date of ossification of the metasternum is extremely variable. A centre is usually absent before five years, and present after eighteen years, and may appear at any date between five and eighteen (Table IX). It appears never to become completely ossified, being found tipped with cartilage even in extreme old age.

It is always ossified by a median centre, which is practically always single. Only three cases occur in my collection of additional ossifications. Two are examples of additional endochondral ossifications at the extremity of the main centre. The third case is peculiar: in this two small bilateral nodules are interpolated between the mesosternum and the metasternum.

(*c*) UNION OF THE MESOSTERNUM WITH THE PRESTERNUM AND METASTERNUM (TABLE X)

1. *Union of the Mesosternum with the Presternum.*

Fusion of the mesosternum with the presternum must be regarded as an abnormality. It occurs in 8·8 per cent. of the six hundred and forty-two sterna examined. Its frequency increases with age. Fusion occurs in 3·1 per cent. of sterna under thirty, in 10·5 per cent. between thirty and forty-nine, and in 15·6 per cent. between fifty and eighty-two. At the same time it is not altogether a senile condition. Among forty-six sterna between sixty-one and eighty-two years, union of the presternum and mesosternum only occurs four times (8·7 per cent.); and among twenty-two sterna between sixty-six and eighty-two it only occurs once.

On the other hand, there are grounds for believing that in some cases this condition is associated with the occurrence of an arthrodial joint between the presternum and first costal cartilage (Pl. VI, Fig. 40). A close scrutiny of fifty-three cases of fusion of presternum and mesosternum shows in twenty-one the existence of what appears to be an articular facet for the first costal cartilage, instead of the usual excavation. One hesitates to speak more confidently in regard to this point without further investigation upon sterna in a fresh condition. All my specimens were dry and macerated; but the conditions were striking enough to warrant the suggestion that just as separation of the presternum and mesosternum is associated with fusion of the first costal cartilage with the presternum, so in cases of fusion of these two elements of the sternum, an arthrodial articulation may coincidentally occur between the sternum and the first costal cartilage so as to permit free movement of the ribs and expansion of the chest.

Although MUSGROVE,[4f] among eighteen examples of costo-sternal joints, never found a single case of a diarthrodial joint between the first costal cartilage and the presternum, ANTHONY,[1] out of sixty-six cases, found such a joint in seven examples, of which five were bilateral. He quotes TCHAUSSOW as recording nineteen examples out of eighty cases.

Fusion of the First Piece of the Mesosternum only with the Presternum.

This rare condition illustrates the fact that fusion of the mesosternum with the presternum is not dependent upon age alone. As already stated (p. 20), in one foetal sternum the fibrous septum of separation of the cartilaginous presternum and mesosternum was situated opposite the attachment of the third costal cartilages. There is, therefore, a possibility at least that all cases of this sort may be congenital in origin. Among the sterna in my possession there are five in which the first piece of the mesosternum is separate from the other pieces, and fused with the presternum. The ages of the sterna were eighteen, nineteen, twenty-five, forty-four, and fifty-nine years* (Pl. VI, Fig. 41). DWIGHT[14] has described an example of this condition, and TURNER[72] has given a case occurring in the skeleton of an Andaman islander.

In the gibbon it is the normal condition, as described by DE BLAINVILLE,[8] KEITH, and others.

* Another example, not included above, occurs along with other skeletal peculiarities in the skeleton of an African negro, aged twenty years, in the anatomical museum of this University.[56]

2. *Union of the Mesosternum and Metasternum.*

This, though not normal, is a condition essentially associated with advancing age (Table X). It may occur at any time after the growth of the mesosternum is completed. After the age of twenty years, out of five hundred and twenty-one cases, 65·7 per cent. show the metasternum separate; 34 per cent. show fusion. Between fifty and eighty-two years separation occurs in 53·9 per cent; fusion in 45·3 per cent. After sixty years, union of the metasternum is more frequent than separation (thirty to twenty-five); and of thirteen sterna between the ages of seventy and eighty-two, nine show fusion and four show separation of the mesosternum and metasternum. This statement confirms the view that fusion of the metasternum is a senile change—occurring, as it does, after the age of sixty.

(*d*) *Summary.*

Reviewing the facts detailed above relating to the ossification of the sternum: the bone is laid down, primarily in association with the shoulder-girdle, as a median cartilaginous lamina, modelled in the form of the future bone, and connected in a definite and symmetrical way with the cartilages of a certain number of ribs. The conversion of the cartilaginous model into the osseous sternum is by endochondral ossification, as in the case of the vertebral bodies, basis cranii, and the epiphyses of the long bones. It is a slow process, and allows of expansion of the bone in all directions in relation to the growth of associated parts.

We need not discuss the question of the significance of the mode of ossification, or the value to be attached to it in a morphological sense. One does not attach any special morphological significance to the occurrence of 'special centres' in the cartilaginous sternum—or, indeed, in any cartilaginous mass in which this method of ossification occurs. In cases of endochondral ossification the deposition of bony 'centres' appears to be determined by mechanical causes, more or less obscure. One inclines to the belief that bone production may be excited by stress or strain affecting particular points in the cartilaginous mass, causing vascularization and ossification. Reference has already been made to the difference in ossification of the lower end of the femur and the lower end of the humerus. In the former only one epiphysial endochondral 'centre' appears; in the latter there are four. It is not impossible that the single centre in the femur is produced by the exercise of a single fundamental force—the direct relation of the femur to the tibia; while on the other hand, at the lower end of the humerus, causes of ossification may be found in the pressure of the radius and ulna, and the traction of the muscular masses attached to the epicondyles of the humerus.

So in the case of the sternum. Its cartilaginous condition may justifiably be taken as the basis of comparison in different groups of animals; and the endochondral centres of ossification may be regarded as altogether secondary, and devoid of any special morphological significance. As in the case of epiphyses, the centres of ossification in the sternum may be explained by the exercise of traction or pressure on the part of the ribs and costal cartilages.

This view appears, on the whole, more satisfactory than a nebulous, transcendental notion, of a hypothetical representation of sternebrae or sternal segments.

It affords an explanation of the *intercostal* and *median* deposit of bone in the cartilaginous sternum, which produces ultimately an apparent, and it may be permanent, segmentation of the sternum in such animals as the Edentata, possessing a mobile sternum. *Per contra*, it explains the condition found in man, cheiroptera, birds, etc., in which, along with well-developed clavicles and shoulder-girdles, the mesosternum remains a simple bone, and even becomes more consolidated than in the embryonic condition. Lastly, it explains the irregularity in the occurrence of the centres of ossification of the sternum. Even leaving out of account the ossification of the meta-sternum, the 'segments,' of which the mesosternum is composed, are not (except in certain mammals, to which reference will be made later) equal to or alternate with the number of costal cartilages associated with it.

In the human mesosternum there are, in my experience, never five segmental centres of ossification; at the most four, or still more commonly only three are present. There is very rarely a centre in the interval between the articulations of the sixth and seventh costal cartilages; and there is more often than not no centre in the space between the fifth and sixth. Their absence needs no explanation, but may be suggested as due to the close, but variable, approximation of the lower costal cartilages at their junction with the sternum; this approximation causes the traction of these costal cartilages to be exerted simultaneously in the growing sternum, and so prevents the formation of an osseous centre, which might make its appearance if the sternal attachments of these cartilages were further removed from one another.

If the terms 'sternebrae' and 'sternal segments' possess any real morphological significance, some more adequate explanation is required of the absence of these sternebrae between the sixth and seventh, and between the fifth and sixth costal attachments, than the bare and meaningless statement that 'they have been lost in the process of evolution.'

From this process of ossification one is led to a belief that morphologically the sternum is a simple cartilaginous structure (possibly bilateral in origin), median in position, associated with shoulder-girdle and ribs, and subserving the purposes (in different degrees in different animals) of shoulder-girdle movements and of respiration. Its ossification is conducted by a slow and plastic method, by means of which its form can be adapted to the needs of the animal, and which leads to the ultimate production of different types of sternum—on the one hand, the clavicular or human type; and on the other hand, the purely thoracic or respiratory type, as in the carnivora or ungulata.

This view appears further to explain those cases in which on one or both sides the distal end of a rib overlaps the sternum, and reaches the middle line; the sternum itself persisting or being absent at the same time; it accounts for the non occurrence of segmentation in the cartilaginous mesosternum; and for the variability in the matter of fusion or separation of the cartilaginous mesosternum in relation to the presternum and metasternum.

In dealing with the observations of previous observers, it would be a matter of great difficulty to summarize the extraordinarily discrepant accounts that are given of the ossification of the sternum. My task is lightened by reason of the appearance of an important memoir by MARKOWSKI,[44] in which these statements are given with some fulness. This author also deals exhaustively with some parts of the question under consideration. As, however, his statistics are compiled from an examination of the sterna of embryos and children after birth—*taken together*—it is not quite easy to harmonize them with those presented in my own personal observations. This is a matter for regret, as it appears that we have been simultaneously working along similar lines. Our results do not agree statistically, but as will be shown later there are certain broad generalisations which can be stated from a comparison of the two series of observations.

Dates of Ossification of parts of the Sternum

Presternum.

Whereas my observations show that a centre (or centres) for the ossification of the presternum usually occurs in the sixth month, Markowski states that it begins to appear at the fourth or fifth month. In regard to the number of centres, a general agreement exists between us. A single centre is most common (M., 68·4 per cent.; P., 79 per cent.); double centres are less common (M., 29 per cent. (vertical); P., 17·2 per cent. vertical, 1 per cent. horizontal); three centres (or more), 2·6 per cent. in both cases. He does not make any observations on the union of the presternum and mesosternum; and regards the presternum as morphologically associated with the first and second ribs.

Mesosternum.

There is general agreement in the two series of observations, in regard to the main facts observed, although statistically wide differences are apparent. The comparison between the two series of observations of the ossification of the mesosternum may be readily shown in a tabular form:—

Date of Union P. (whole)	Date of Union P.	Date of Union M.	Mesosternum	Date of Appearance M.	Date of Appearance P.
21—25 years complete	16—20 years (1st–2nd)	13th year (1st–2nd)	1st	5th month	6th month (66·6%)
	11—15 years (2nd–5th)	7—11 years 50% (2nd–3rd)	2nd	5th month	7th month (77·4%)
			3rd	7th & 8th month	7th month (54·8%)
		0—15 years (3rd–4th, 4th–5th)	4th	59% before birth, 15% after death, 26% absent	8th month (37·5%)
			5th	9th month (*once*)	*never*

Metasternum.

Markowski mentions one case in which the metasternum is absent altogether. He states that it begins to ossify just after birth, or in the first three years; and among his cases the latest date was in the sixth year. He states further that ossification occurs by two lateral or by one median centre. My observations agree more with those of previous observers, who lay stress upon the variability in the time but the stability in the mode of ossification of this part of the bone—from one median centre.

The general conclusions at which Markowski arrives, and upon which I would lay most stress, are (1) the agreement in our observations that the sternum is ossified from single median centres more often than from bilateral double centres, although he asserts that this is a higher and later mode of development; and (2) the obvious and striking irregularity in the mode of ossification of the mesosternum.

Although great stress is laid upon the metameric arrangement of the parts of the sternum, Markowski admits that this is secondary; and he fails to indicate—just as my specimens fail to indicate—a metameric relationship between the lower true ribs and parts of the mesosternum. And although he pins his faith on the association of the presternum with the first and second costal cartilages, he admits that a single median centre is much the commonest for this part of the bone (68·4 per cent.)

In my opinion, the great value of Markowski's researches is to show again how very variable is the deposition of the centres of ossification. He rightly lays stress upon the asymmetry of centres; and, more particularly, upon the occurrence of additional accessory centres round the main centres.

These points, to my mind, are supporting evidence in favour of the view that the centres of ossification are not of morphological value; but that the sternum is essentially a shield, in whose substance these osseous deposits occur as bosses to strengthen it, not through hereditary influence, but through causes which are mechanical, functional, and adventitious.

Markowski's memoir is a valuable and thoughtful contribution to the subject, and has been of great interest in the final preparation of the present work.

His main morphological thesis is diametrically opposed to the view at present advanced. He considers the sternum as made up of a series of intercostal segments corresponding to vertebral bodies ; and the absence of centres in the lower segments as indications of reductions (from below up). He does not, however, depend for his proof upon segmental *ossification.* This, he admits, cannot be maintained, but he relies on transient cleavages in the cartilaginous sternum (*Rippen linien*), which, he says, occur opposite the costal attachments. But one would submit that prior to these cleavages (which cannot be said to be, by any means, constant or obvious) the cartilaginous model is a longitudinal strip without, at an earlier period, any trace of a metameric structure, either in cartilage or before the formation of cartilage, that has yet been satisfactorily demonstrated. The segmental character appears to be introduced by the association of the ribs with this sternal *anlage.* The only obvious cleavage is at the manubrio-sternal junction ; and that in the foetal sternum is by no means constant in occurrence or definite in time.

II. THE FORM OF THE ADULT HUMAN STERNUM

A. Length and Breadth

The measurements of five hundred and four sterna are given in Table XI—three hundred and ten male, one hundred and twenty-six female, and sixty-eight unclassed. Among those whose ages where known, one hundred and eighty-three were under forty, and two hundred and fifty-three were over forty years of age. An analysis of the measurement shows distinct differences dependent upon age and sex.

(*a*) *Age Differences.*

In Table XI, the male and female sterna over twenty-one years of age have been grouped together in two series—under and over forty years of age. From a comparison of the measurements of the two groups, it appears that a certain increase, both in breadth and length, takes place after the age of forty. This increase is apparent, as to breadth, in all three parts of the sternum. On the other hand, while the total length of the bone is greater over forty years, the increase (in both sexes) is seen to be due to the greater length of the metasternum, and (in the male only) to the greater length of the mesosternum. The male presternum and the female mesosternum are actually shorter in the series over forty years of age than in the younger bones.

(*b*) *Sex Differences.*

While it is obvious (Table XI) that the male sternum is absolutely larger, in both length and breadth, and in all three parts, than the female sternum, there are several important differences in the relative size of the parts of the bone, in the two sexes, as shown already by Hyrtl,[26] Strauch,[62] Dwight,[13] and others.

1. *Presternum.*

Among the specimens in my collection, the average male presternum measures in length 52·0 mm., and in breadth 65·3 mm. (Table XII). The female presternum measures in length 47·3 mm., and in breadth 58·3 mm.

The *breadth index* $\left(\frac{100 \times B}{L}\right)$ of the male presternum is 125·5; of the female presternum is 123·2. The *length index* $\left(\frac{100 \times L}{B}\right)$ of the male presternum is 79·6; that of the female presternum, 81·1. The male presternum, is, therefore, wider and shorter; the female, longer and narrower.

2. *Mesosternum.*

The average measurements (Table XII) of the mesosternum are :—

	Length		Breath
Male	103·7 mm.	.	40·5 mm.
Female	91·0 mm.	.	36·8 mm.

The indices for the two sexes are :—

	Length index		Breadth index
Male	256	.	39
Female	247	.	40·4

The male mesosternum is, therefore, on the average, longer and narrower; the female shorter and broader.

The statistical method does not very clearly indicate a point that was often obvious in the examination of the series. In the female, the mesosternum is often extremely broad in the lower part (Pl. VI, Fig. 42A), so as to give rise to a 'type' of sternum which can be almost designated the 'female' type; although it must be admitted that this type is not unfrequently found in male sterna as well (Pl. VI, Fig. 42B).

3. *Metasternum*

The measurements of the metasternum are vitiated because of the dry and shrivelled condition of this part of the bone. However, as all measurements have been taken in the same way, they are included for what they may be worth. The measurements are :—

	Length		Breadth
Male	40·0	.	20·0
Female	33·5	.	16·0

The indices are :—

	Length index		Breadth index
Male	200·0	.	50·0
Female	209·3	.	47·7

The male metasternum, therefore, appears to be shorter and broader ; the female longer and narrower.

The male sternum thus differs from the female in having a longer and narrower mesosternum, and a presternum (and possibly a metasternum) which are shorter and broader.

Relative length of Presternum and Mesosternum in the Male and Female

The law propounded by HYRTL[26] is not obeyed by the series under examination (Table XIII), that '*the manubrium of the female sternum exceeds half the length of the body ; while the body in the male sternum is at least twice as long as the manubrium.*' This law was supported by STRAUCH,[62] quoted by DWIGHT ; but has been somewhat adversely criticized by the last-named author.[13] An analysis of the lengths of the presternum and mesosternum in the adult (22–82) shows that on the average the relative length of the two parts is the same in both sexes (1 : 1·9), and the *presternum is thus usually a little more than half the length of the mesosternum.*

When, however, the series of adult sterna is broken into two groups —those under and those over forty years of age—a difference in relative length comes to light, due probably to an increase in length in the *male mesosternum* in later years. Between the ages of twenty-two and thirty-nine (Table XIII), the relative length of the presternum and mesosternum is as stated above (1 : 1·9) ; but between forty and eighty-two years, there is a difference. The mesosternum of the male is twice the length of the presternum (1 : 2) ; that of the female is less than twice the length (1 : 1·8); so that the older group coincides with HYRTL's statement.

The measurements of one hundred and six young sterna (sixty-five male, forty-one female), between two and twenty-one years, have been added in Table XIII. The shrinkage of cartilage, and the consequent loss of length, more particularly of the mesosternum, probably renders these measurements fallacious ; but the series agrees with HYRTL's statement, the relative length of presternum and mesosternum being in the male 1 : 2, and in the female 1 : 1·9.

B. Variations in Form

(a) Suprasternal Ossifications

From an examination of two hundred and thirty-six foetal sterna between three and nine months (p. 20), only two examples were obtained of additional suprasternal cartilages (0·8 per cent.) In a female sternum of six months, two ovoid cartilages occur upon its upper border, fused together, but separate from the presternum. In another female sternum of nine months, two cartilages occur separate from each other, and fused with the upper border of the presternum (Pl. VI, Fig, 43A, B).

Since the above investigation was published the statement has been made[47] that such conditions are much more common than appeared from my observations. To verify or reverse my previous statement, Dr. W. H. Broad, Robert Gee Fellow of Anatomy in the University of Liverpool, has examined for me fifty-four foetuses, with, however, a completely negative result. None of the sterna presented suprasternal cartilages. The particulars of age and sex of the foetuses examined were :—

Age	Number	Sex	
		M.	F.
Months 3	1	1	0
„ 4	1	1	0
„ 5	3	2	1
„ 6	6	6	0
„ 7	12	5	7
„ 8	10	9	1
„ 9	21	10	11
	54		

With this controlling observation one appears to be justified in regarding the appearance of these additional cartilages as a rare and anomalous condition.

Out of five hundred and sixty-three sterna, young and adult, between the age of two and eighty-two years, four hundred and sixty-seven, or 83 per cent., present what may be styled a normal presternal notch. The notch in these cases varies considerably in width and depth. In one hundred and ninety-three cases it is a well-marked wide concavity (Pl. VII, Figs. 45, 46, 47); in one hundred and eighty-nine cases it is shallow (Figs. 45, 46); and in eighty-five cases it is narrow (Fig. 47).

In ninety-six cases (17 per cent.) there are deviations from the normal, accompanied by the absence of a presternal notch. The variations that occur are devisable into two main groups: (1) fifty-one cases (9·0 per cent.) in which the upper border of the presternum is flat, convex, or raised into a median projection; and (2) forty-five cases (7·9 per cent.) in which two lateral projections or separate ossicles occur.

In the first series sixteen examples occur in which the upper border of the presternum is a horizontal, straight, or irregular line. In twenty-three cases it is convex; in twelve cases it is raised up into a distinct median projection (Pl. VII, Figs. 48, 49).

In the second series the projections from the presternum are bilaterally placed. In one case only (0·17 per cent.) are there two separate suprasternal ossicles (Fig. 50). In another case there is a prominent tubercle on the left side fused with the presternum, and on the right side a sessile tubercle surmounted by an articular facet* (Pl. VII, Fig. 51).

The remaining cases, forty-three in number, are examples of the presence of lateral tubercles on the upper border of the presternum, which fall into four groups not clearly separated from each other. (1) There are eleven examples of prominent tubercles bilaterally placed upon the upper border of the presternum (Pl. VII, Figs. 52, 53); (2) there are ten cases in which the projections form ridges separated by grooves or notches from the clavicular facets (Fig. 52). Again, there are twenty-two cases in which there are distinct articular projections (Fig. 54) (3) separate from or (4) continuous with the clavicular articular surfaces.

Of the last-named series, probably not all are undoubted suprasternal ossifications. Some (in group 3) appear to be facets for the articulation of

* More recently I have obtained a third example (Pl. VII, Fig. 44) not included in the series, with an articulating separate ossicle on the left side, and an articular facet upon the right side.

ossicles which have been lost in maceration; and others (in groups 2 and 4) may be associated with variations in the mode of articulation of the clavicle or attachments of the sterno-clavicular ligaments.

Significance of Suprasternal Ossifications.

It is thus evident that these suprasternal ossifications are both rare and variable in their occurrence. The nodules may be separate or fused together; separate from the presternum or attached to it; bilateral or median in position.

They are vestigial structures, and several views have been formulated regarding their homologies. They have been regarded as representative of costal, shoulder-girdle, or sternal elements. BRESCHET,[6] who first described them, inclined to the belief that they represent the persistent distal ends of cervical ribs, the more proximal portions of which had not been developed. This notion does not bear investigation; in cases in which cervical ribs are fully developed, and reach to the sternum, their attachment to the presternum is by means of costal cartilages to the lateral borders of the bone below the articulation of the clavicles.[70]

There is more difficulty in deciding if the ossicles are homologous with shoulder-girdle or sternal elements. GEGENBAUR[19,20] and PARKER[53] both seem to agree that they represent structures which are not, strictly speaking, appertaining to the shoulder-girdle, but are median in position and placed in front of the sternum (interclavicle and omosternum).

PARKER lays great stress on the morphological distinction between 'membrane' bones and 'cartilage' bones in the lower vertebrates, and points out that the shoulder-girdle (scapula, coracoid, and prae-coracoid) and sternum (including omosternum) are cartilaginous in formation; whereas the clavicle and interclavicle are membrane bones.

There seems to be a general consensus of opinion regarding the fate and homologies of the elements of the shoulder-girdle. The reptilian coracoid appears to be represented in man by the coracoid process, and possibly also by the costo-coracoid ligament (along with the epicoracoid bone, present in certain mammals (Pl. X, Fig. 66), such as *Mus musculus*, *crocidura* (GEGENBAUR). The prae-coracoid, extending in reptiles from scapula to sternum, is rudimentary in man, being overlaid and replaced by the clavicle. Its extremities, however, are possibly persistent in the form of the sterno-clavicular meniscus, and the cartilaginous inner end of the clavicle on the one hand, and in the acromio-clavicular meniscus when present on the other hand.

The other elements present in the neighbourhood of the presternum are the interclavicular ligament and the supra-sternal ossicles, the former developing in membrane, representing probably the interclavicle, and the latter, developing in cartilage representing the occasional recurrence of the omosternum (Pl. VIII, Fig. 55).

It is not impossible, however, that the suprasternal ossicles may represent persistent and detached portions of the prae-coracoids,[63] which are responsible for the production of the menisci and inner portions of the clavicles.

In June of last year, in the Anatomische Gesellschaft at Heidelberg, Dr. H. EGGELING[15] read a paper on the subject of the suprasternal ossicles, fully confirming the foregoing observations. The chief differences in the two series of observations lie in the fewer number of cases and the higher proportions of ossicles or tubercles in Dr. EGGELING's experience.

(*b*) *Sternal Foramina* cannot be said to be uncommon. One hundred and thirty cases (20·2 per cent.) have been found among six hundred and thirty-one sterna. The proportion among foetal sterna was 30·5 per cent. They are always median and usually single. Occasionally two foramina occur in the metasternum ; and in three instances foramina are found coincidently in both mesosternum and metasternum. They are much more frequent (Table XIV) in the metasternum (16·4 per cent.) than in the mesosternum (3·8 per cent.) When in the mesosternum the foramen is always in the lower half of the bone ; most commonly opposite the attachment of the fifth costal cartilages : and more frequently above than below that position (Pl. VIII, Fig. 56).

It is noteworthy that nothing in the least approaching the condition of sternal fissure has been met with in this series. The foramina are small in all cases ; the largest admitting nothing larger than an ordinary pencil.

The explanation one has to offer for the occurrence of sternal foramina is that they are deficiencies in the primitive cartilaginous sternum, owing to the failure of the praechondral tissue to form cartilage on account of the presence or formation of a bunch of vessels with its surrounding envelope of connective tissue in some part of the tissue in which the cartilage is being laid down. This view is supported by the occurrence of such a condition in an early foetal sternum (p. 19). One cannot ascribe the formation of the foramina to the failure of the centres of ossification to unite together; nor can any special morphological significance be attached to their presence.

One rejects the idea of sternal foramina being associated with the occurrence of *fissura sterni*; the causes of the two conditions seem to be distinctly different.

(*c*) *Asymmetry of the Sternum* (Plate IX, Fig. 61).

This condition is not uncommon. It is shown in curvature of the long axis of the bone, obliquity in the pre-mesosternal junction, inequality in position and number of costal attachments, and in differences in the position and form of the clavicular facets.

The *foetal sternum* is itself usually straight, and is asymmetrical only by reason of occasional irregularities in the position and number of costal attachments. The causes of asymmetry appear to operate for the most part after birth; and the chief causes appear to be obliquity in the union of the ossifying centres, right-handedness (or the reverse); and the asymmetrical position of the thoracic and abdominal viscera.

1. *Irregularity and Obliquity in the Union of the Component Elements* of the sternum is one of the commonest causes of curvature, and of asymmetry in the costal attachments. The most notable illustration of this condition is found at the junction of the presternum with the mesosternum (Table XVI). This occurs in 30·3 per cent. of all sterna examined. The obliquity of junction is most often downwards and to the left (left, 17·0 per cent.; right, 13·2 per cent.), so as to produce a convexity to the right, and a downward displacement of the second left costal cartilage. It is more frequent with advancing age (Table XVI), showing that it is caused not merely by the shape of the sternal elements, but by influences such as right-handedness, operating after completion of the individual elements.

This statement does not coincide with that of BIRMINGHAM,[7] who states that among thirty sterna examined by him, twelve were symmetrical in this particular; while in the remaining eighteen, ten showed an obliquity downwards and to the right; eight showed an obliquity downwards and to the left.

2. *Lateral Curvature of the Sternum* (Table XV). In 35·6 per cent. of the sterna examined, the long axis of the sternum presents a convexity slight or well marked to the right or left. The convexity is more often to the right (23·2 per cent.) than to the left (12·3 per cent.), and the curvature occurs more often in adult (38·9 per cent.) than in young sterna (32·3 per cent.)

This agrees with BIRMINGHAM's conclusion. He found out of forty-six cases examined, a curvature to the right in fifteen examples (32·6 per cent.), a curvature to the left in twelve cases (26·0 per cent.)

3. *Asymmetry in Attachment of the Costal Cartilages* (Tables XVII–XIX). The young sternum is naturally straight and symmetrical. The alteration in costal attachments appear to be caused by (i) alterations in the form of the thorax brought about by movements, curvature of the spine, and conditions affecting the viscera, (ii) obliquity in the osseous union of the sternal elements, (iii) differences in the depth of the first pair of costal cartilages, and (iv) alterations in the relative position of the sixth, seventh, and eighth costal cartilages.

Some degree of costal asymmetry is common, and is found in the majority of adult sterna.

It is more frequent in the adult (69·9 per cent.) than in the young sternum (41·2 per cent.) It is rather more common to find downward displacement of the costal attachments on the left (57·4 per cent.) than on the right side (42·5 per cent.); and in some cases there is asymmetry of the costal cartilages in two directions in the same sternum. The cartilages in or near the middle of the series are most frequently asymmetrical in position; and most rarely the seventh and first. The following is the order of frequency :—

Adult : 3rd, 2nd, 4th, 5th, 6th, 7th, 1st.
Young : 4th, 5th, 3rd, 6th, 2nd, 7th, 1st.

The first costal cartilage is occasionally asymmetrical by reason of increased depth and more extensive junction than usual with the presternum. This occurs much more frequently on the right than on the left side (28 : 5) (Table XVIII).

The sixth costal cartilage and its attachment to the sternum are interesting on account of occasional asymmetry, and also because of the light thrown upon the possible existence of a fifth element in the mesosternum. It is normally attached to the third or fourth piece of the mesosternum (72·6 per cent.), and it is never displaced to a higher point. It is displaced downwards in 27·3 per cent. of cases; and more frequently articulates between the mesosternum and the metasternum than with the metasternum only. Asymmetry in attachment occurs forty-seven times out of one hundred and forty-eight cases (31·7 per cent.) It is much oftener displaced downwards on the left (thirty-nine cases = 82·9 per cent.) than on the right side (nine cases = 17·0 per cent.)

The seventh costal cartilage has its normal attachment between the mesosternum and metasternum in 68·1 per cent. of cases (Table XIX). It is not commonly raised to articulate with the mesosternum alone (9·3 per cent.), and when this does occur it is more frequent on the right than on the left side (8 : 3). It is attached to the metasternum only in 15·7 per cent. of cases; and when asymmetry occurs, the left cartilage is more often displaced downwards than the right (44 : 12). It may fail altogether to articulate with the sternum on one or both sides (6·6 per cent.); and the left is more frequently absent than the right (4 : 30). This corroborates the idea derived from an examination of higher cartilages: that a shifting downwards of the costal cartilages in relation to the sternum is more common on the left side than on the right, and, similarly, that there is a firmer and closer attachment of the right costal cartilages than of the left.

The eighth costal cartilage has an occasional attachment to the sternum, on one or both sides; and more often on the right than the left side. The results of observations made upon young sterna are given in Table XXI.

As the adult sterna in my collection were mostly dry, and in many cases lacked costal cartilages, one was unable, from their examination, to arrive at conclusions which would be reliable. I have, therefore, specially examined another series of fifty-six sterna with the costal attachments intact, with the result that forty-five sterna (80·3 per cent.) were found to be normal; eleven sterna (19·5 per cent.) were abnormal (Table XXII). Of the eleven abnormal cases, two (3·5 per cent.) are examples of failure of the seventh costal cartilage to reach the sternum, in one case on both sides, in the other case on the left side. The nine remaining cases (16 per cent.) are examples of a junction of the eighth costal cartilage with the sternum on one side or both. In two cases there is a junction with the sternum on both sides; in two cases the junction is on the left side only; and in five cases the eighth costal cartilage is attached to the sternum on the right side only. Coupled with the larger series of younger sterna these examples confirm the conclusions of CUNNINGHAM[11] and others, and showing that the eighth costal cartilage has a greater tendency to become attached to the sternum on the right side than on the left.

Examination of the attachment of costal cartilages to the sternum indicates (1) an individual variability in the connexion of the ribs with the sternum unrelated to any essential change in the structure of the latter, (2) a greater tendency to detachment and downward displacement on the left side, and (3) a firmer and more extensive attachment on the right side, particularly at the ends of the series.

4. *Asymmetry of Clavicular Facets.*

There are slight differences in the size and concavity of the pre-sternal facets for articulation of the clavicles (Table XX). A more important difference, however, which is to be associated with asymmetry of the sternum, occurs on the *level* of the two facets. It was found unequal in one hundred and ninety-nine cases (38·9 per cent.), and the left facet is much oftener in a higher position than the right one (left, 145 = 28·5 per cent.; right, 54 = 10·3 per cent.)

This agrees with BIRMINGHAM'S[7] conclusion on this point. He found the right facet more often lower in position than the left, and he associates rightly the vertical depth of the interval between the first two costal cartilages with this condition. On the other hand, it is possible to regard the occurrence of a higher clavicular facet as compensatory for curvature caused, it may be, by the costal attachments.

These somewhat minute differences in the form of the bone, and its relations to the costal cartilages and the clavicles—differences that appear for the most part to be caused by influences operating after birth—by their very minuteness serve to emphasize the essential character of the sternum as a bone of a fixed and determined type not subject to large variations or much affected by changes in correlated structures. It particularly impresses one with the idea of the secondary relation of the ribs to the sternum, the former being subject to very considerable variations without producing any appreciable alteration in the sternum.

(*d*) *Shape of the Metasternum.*

The shape of the metasternum is extremely variable. Without describing in detail these variations, it is enough to point out that it is normally median in position, and is usually not bifurcated at the extremity (four hundred and twenty-nine cases = 57·8 per cent.) It is bifid in a minority of cases (three hundred and thirty-four cases = 42 per cent.) The constancy of its median position, and the constant occurrence of a single median centre of ossification, lend support to the idea of the formation of the sternum in the middle line, rather than by fusion of lateral structures derived from costal cartilages.

Summary

Surveying the foregoing facts, one has a clear picture of a series of conditions caused by various influences (of which right-handedness is probably the most important), and giving rise, in many cases, to a slightly asymmetrical form of sternum. The right costal catilarges have a firmer adhesion to the sternum than the left. At the ends of the series this is most obvious: the first right costal cartilage has oftener a larger and deeper connexion with the presternum than that on the left side; the left seventh costal cartilage is more often detached from the sternum than the right; and the right eighth costal cartilage is more often adherent than the left. Coincidently there is a greater tendency on the left than on the right side for a downward displacement of the costal attachments. These conditions are, probably, the cause of lateral curvature of the sternum, with

which two other asymmetrical features are associated (probably compensatory in character)—obliquity of junction of the presternum and mesosternum, and a higher level of the left sterno-clavicular articulation.

The development, ossification, and form of the human sternum taken together present a picture of which the essential feature is median position. If the human sternum were bilateral in origin, more frequent examples might be expected of cleavage of its lateral parts. Sternal foramina are not indications of fissure ; the presternum is always median and imperforate ; the mesosternum in its cartilaginous form is median, and its ossification is more often median than bilateral. The metasternum is always median and ossified by a single median centre ; and is more often pointed or rounded than bifid at its extremity.

The connexion of the sternum with the costal cartilages is variable, but without producing variations in its own intrinsic form ; the development and ossification of the bone give no indication of any essential metameric dependence upon the association with rib elements, except what may be due to mechanical influences.

Neither the cartilaginous sternum nor the centres of ossification agree or vary with the number of associated ribs.

III. THE COMPARATIVE ANATOMY AND MORPHOLOGY OF THE STERNUM

A study of the characters of the sternum and associated parts in vertebrate animals lends support to the notion that the bone is axial in position, and primarily connected with the shoulder-girdle, and secondarily with the ribs ; that the human sternum is more primitive in type than the quadrupedal sternum usually regarded as typical of the mammalia ; and that the so-called segmentation of the sternum is a specialization associated with the adoption of the quadrupedal position and the needs of locomotion. Too much stress has in my opinion been laid by many anatomists upon the similarities in structure of the fore and hind limbs. Even among quadrupeds there are as many essential differences between them as likenesses, both in structure and functions. And the sternum is in my view fundamentally associated with the fore limbs.

In the following pages a summary only is necessary of the comparative anatomy of the sternum. The elaborate memoir of PARKER[53] may be consulted for the requisite detail.

A. FISHES

The sternum is absent among fishes as a rule. Instead, the elements of the shoulder-girdle meet on the ventral surface of the body and form a shield for the protection of the heart and branchial chamber. Fishes are characterized by the great variety in the arrangements of the parts of the shoulder-girdle. The simple type is found among cartilaginous fishes, such as *Acanthias vulgaris*, in which the lateral halves of the shoulder-girdle are confluent, and a continuous cartilaginous bar extends across the middle line. Among chondrostean fishes, such as *Acipenser sturio*, the coracoid elements fail to meet, and clavicles and interclavicle are interposed between them. In *Protopterus annectens* there is present a median element, separate from the coracoids and receiving the ends of the clavicles. In bony fishes clavicles are present, and there is a variable development of the coracoid element.

The only fish which is known to possess a sternum is *Notidanus indicus*, the Perlon shark. This is described by Professor T. J. PARKER[55] in *Nature*. It had previously been described by HASWELL.[22] It is present in the middle ventral line as a distinct, four-sided, lozenge-shaped cartilage, 'let into the arch as it were in front.' Two elements are distinguishable in it—anterior and posterior. Its remarkable feature from our present point of view is its intimate association with the shoulder-girdle, and the entire absence of connexion with the ribs. This sternum is an addition to the shoulder-girdle, and is added without the intervention of the ribs at all.

Attention may be directed in this place to an interesting and remarkable paper by Professor T. J. PARKER[54] on the origin of the sternum. Enquiring if there is any genetic connexion between the 'omosternum' of Notidanus and of Amphibia and the 'costal' sternum of Amniota, he inclines to the belief that the latter is derived from the former. He thinks it possible that in early Amniota a 'post-omosternum' existed, joined late in development by the first pair of ribs. Later on the succeeding ribs would join it. In *Apteryx* he found that in the earliest stage in which a sternum was present, it extends back to the level of the third rib; the first and second pair are attached to it by articulation, the third by fibrous tissue. In the next stage, the first three pairs are attached by joints, the fourth pair by fibrous tissue, from which he concludes that the sternum undergoes a backward growth. Retardation of chondrification of the sternum would lead to the development of a sternum of indifferent tissue, subsequently chondrified from the ribs.

He states certain hypothetical stages in the phylogeny of the sternum, tracing it by gradual differentiation from an association with the shoulder-girdle (probably bilateral), a secondary union with the ribs, a delay in chondrification, and a subsequent extension of cartilage from the ribs.

These views are valuable. The facts I have adduced regarding the early development of the sternum give support to the hypothesis of PARKER, and indicate that a view different from that of RUGE and his followers is at least tenable.

The essential feature of the parts under consideration in fishes is the union of the elements of the shoulder-girdle in the mid ventral line, for the construction of the girdle itself and for the protection of the heart.

B. Amphibia

Among Amphibia wide variations exist in the shoulder-girdle and sternum. In some examples, as in *Proteus anguinus*, a fish-like character persists. Praecoracoids and coracoids are present, but no sternum. In others, as in *Bufo*, a leaf-like sternum is present between the ventral ends of the shoulder-girdles. In other cases again, as in *Rana* (Pl. VIII, Fig. 57), an additional element, the omosternum, makes its appearance, separated from the sternum proper by the praecoracoids, epicoracoids, and coracoids. Neither omosternum nor sternum have any connexion with the ribs: but as shown already are derived from the shoulder-girdle, and are in intimate association with it.

C. Reptiles

Among reptiles there are many differences in the condition of shoulder-girdle, sternum, and ribs, and in their relations to one another. There is, however, a distinct gradation as we proceed from lower to higher forms.

Among *Ophidia*, in which the limbs and their girdles are absent, the sternum is absent too; and at the same time the ribs are highly developed and of great importance.

In *Chirotes canaliculatus*, 'the only annulate saurian with anterior limbs,' there is together with a shoulder-girdle, a sternum which is differentiated into presternum, mesosternum, and metasternum (Pl. VIII, Fig. 58). 'The ribs do not appear to be connected with the relatively extremely small bone' (Parker).

In *Anguis fragilis*, clavicles, interclavicle, and articulating coracoids are present, together with a presternum, connected by fibrous tissue with one pair of ribs (Pl. X, Fig. 65).

In such reptiles as *Iguana tuberculata* and *Lemanctus longipes*, clavicles, interclavicle, precoracoid, and coracoid, are closely associated with a broad shield-like sternum. In *Lemanctus longipes* (Pl. VIII, Fig. 59), there are eight cervical vertebrae, of which the last four carry ribs. Beyond these there are four sternal ribs, *i.e.*, vertebral ribs, articulating by synovial joints with the lateral borders of the sternum. There is no differentiation of presternum and mesosternum, but the hinder end of the sternum is bifurcated, and each bifurcation is again subdivided into long, narrow cartilaginous processes. This condition is directly comparable with the arrangement of the parts in the Ornithodelphia (*Ornithorhynchus* and *Echidna*), which cannot but be said to have developed upon parallel lines.

In the *Crocodiles* (Pl. VIII, Fig. 60) there is a further modification of the parts by a simplification of the connexion of the sternum and shoulder-girdle, and its closer association with the ribs. The elements forming the shoulder-girdle are more rudimentary. There are no clavicles. There is a rudimentary interclavicle : and a simple coracoid, articulating with the sternum. The sternum itself is more highly developed. There is an indication of differentiation of presternum, mesosternum, and metasternum, but no separation of the several parts has occurred, and the mesosternum is unsegmented. The metasternum is bifid, and may articulate with one or two ribs. The costal connexions of the sternum are much closer than in other reptiles. There are two pairs of cervical ribs, and six, seven, or eight sternal ribs, articulating in pairs with the borders of the sternum.

The above examples indicate the primary and essential association of the sternum with the shoulder-girdle, and its secondary connexion with the ribs.

D. Birds

In birds the sternum is broad and simple in character, its chief variability being in the development of the keel. It is characterized by its close and intimate association with the parts of the shoulder-girdle—in which coracoid, precoracoid, clavicles, and interclavicles, are usually present—and by the variability in the number of sternal ribs. Cervical ribs also are commonly present.

In *Rhea Americana* there are only three pairs of sternal ribs, crowded together in their articulation with the anterior part of the lateral border of the sternum.

E. Mammalia

The mammalian sternum is usually divisible into the three parts, presternum, mesosternum, and metasternum; but there are considerable variations in the form and disposition of the three elements, to a large extent dependent upon and correlated with the arrangement of the shoulder-girdle and ribs.

Ornithodelphia. At the outset it is to be noted that *Ornithorhynchus* and *Echidna* present a sharp contrast to the rest of mammals in the possession of a shoulder-girdle, of a complex, reptilian type, associated with a mammalian form of sternum. For several reasons I propose first to describe and contrast these two forms separately (*Echidna* (Pl. X, Fig. 68), from a specimen in the Zoological Museum of the University of Liverpool; *Ornithorhynchus* (Pl. X, Fig. 69), also from the University Museum). From a comparison of Parker's figure[53] with the Liverpool specimens, I conclude that his example of *Echidna* was immature and imperfect.

The shoulder-girdles are very similar in *Ornithorhynchus* and *Echidna.* The coracoids laterally and the interclavicular portion of the clavicles in the median line articulate with the anterior margin of the presternum. The presternum is also much alike in the two cases; in all cases it is separate from the mesosternum. The mesosternum in two examples of *Echidna* consists of two pieces. In *Ornithorhynchus* in one instance it is composed of two pieces, in another of three. The metasternum is an oval bone imbedded in cartilage in *Echidna.* It is absent in both examples of *Ornithorhynchus.*

One would direct particular attention to the mode of attachment of the ribs. In *Echidna* the presternum carries the first two ribs. In *Ornithorhynchus* the first rib articulates with the presternum; the second with the interval between the presternum and mesosternum. In both *Echidna* and *Ornithorhynchus* the first piece of the mesosternum carries the third pair of ribs. The fourth and fifth pairs of ribs articulate with the second piece of the mesosternum (or, in one example of *Ornithorhynchus*, with the second and third pieces respectively). The sixth pair in *Echidna* articulates between mesosternum and metasternum; in *Ornithorhynchus*, with the lower end of the mesosternum. One noticeable feature of these sterna is that, although the mesosternum is segmented, there is no metameric co-ordination between it and the ribs.

The mammalian presternum.

The presternum is the one element of the mammalian sternum which is constantly present. It is sometimes the sole representative of the bone, as in some Cetacea (*Balaenoptera*, *Balaena*), and in the *Manatee*. In *Balaena* (Turner) only one pair of ribs reaches the sternum. In the Manatee (Pl. X, Fig. 67), two ribs articulate with it on each side ; and it possesses a bi-lobed projection in front of the articulation and a pointed process behind it.

Usually the presternum articulates with the first and half the second pair of ribs. Besides the *Manatee*, exceptions to this rule are *Tamandua*, *Beaver*, *Coypu*, and *Hylobates* (two and a half ribs), and *Echidna* and *Tamandua bivittata* (two ribs).

The presternum is usually composed of a single bony element. A remarkable exception is found in *Hylobates*, in which it is normally made up of two elements, one in front of the other, and receiving two and a half pairs of ribs (corresponding to a condition which occurs occasionally in man, as observed already, by inclusion in the presternum of the first piece of the mesosternum).

The form of the presternum varies considerably. That characteristic of the human sternum occurs among Primates, but only exceptionally in other orders, as among some Rodents (*Pteromys volucella*, *Arvicola amphibia*, and in *Centetes* among Insectivora.

In those orders where the shoulder-girdle is deficient and the clavicle is absent (as in Ungulata), the presternum becomes considerably reduced in size : in contrast to the mesosternum, which is greatly increased in width, particularly in its posterior portion. On the other hand, in exceptional cases, the presternum is keeled on its ventral surface in a more or less marked degree. This character has been noted in the lesser *Rat Kangaroo* (*Hypsiprymnus minor*), *Tree Kangaroo* (*Dendrolagus inustus*), *Vulpine Phalanger* (*Trichosurus vulpinus*), *Hystrix cristata*, Cheroptera, *Mole*, *and Aye aye*.

Special attention has been given to the form of the anterior end of the presternum. It appears to be much commoner for it to project forwards in front of the first rib than not: and this forward projection may be a single median spine, or may be bi-lobed. There is no forward projection in Ungulata as a rule (except in the *Peccary*, *Gazelle*, *Chamois* (Pl. IX, Fig. 62), and *Ox*, in which there is a slight median projection); nor in sterna of the human type (*Primates*, *Tamandua*, *Myrmecophaga jubata* (Pl. IX, Fig. 63), *Centetes*, and *flying Squirrel*).

The process in most mammals is single and median, and gives attachment to the clavicles (when present). It occurred in a characteristic form in all the Carnivora examined (Pl. IX, Fig. 64), and, usually, also in Rodents. It was found in most Marsupials (*Dasyurus mangoei*, *Wombat*, *Kangaroo*, *Hypsiprymnus minor*, *tree Kangaroo*, *vulpine Phalanger*, and *Koala*); among Edentata in the *climbing Ant-eater*, *three-toed Sloth*, and *giant Armadillo*; among Ungulates in the *Gazelle*, *Peccary*, *Chamois*, and *Ox*; in the *Mole* and *Elephant*; and in *Hyrax*, in which case it is tri-lobed.

A bilateral projection in front of the presternum is less common. It was present in *Petaurus*, *Bandicoot*, *Porpoise*, *Manatee* (Pl. X, Fig. 67), *Tatusia*, *Armadillo*, *two-toed Sloth*, *Water Rat*, and *Java Loris*.

The mammalian mesosternum.

The mesosternum may be absent or indistinguishable from the presternum (*e.g.*, *Manatee* (Pl. X. Fig. 67), *Balaena*). In Mammalia it is the portion of the sternum in which the most striking differences occur. In the embryo it is at first a simple bar of cartilage in which ossification (endo-chondral or periosteal) occurs, so as to produce in the adult of different orders two extreme types—the segmented and the unsegmented. The simple unsegmented type of sternum is associated with a powerful development of pectoral muscles, and with a specialization of structure of the shoulder-girdle. It occurs in *Man*, *Orang-outan*, and *Gibbon* (I have not met with an example of an unsegmented mesosternum in the gorilla or chimpanzee); in *Cetacea* (in the *Porpoise* the mesosternum is fused with the presternum and metasternum), Cheroptera, and in the *Mole*.

The segmented type of mesosternum is characteristic of animals in which the shoulder-girdle is reduced to its simplest form, the clavicle is absent or deficient, and the fore limb is adapted to quadrupedal locomotion. This type of sternum, therefore, is associated with the need of pliancy and elasticity in lateral movement of the trunk.

The mesosternum is comprised of a number of 'segments,' usually median and intercostal, and separated from one another by plates of cartilage or by fibrous laminae. The extreme example of this form of mesosternum occurs in the polymorphous Edentata, in which, as a rule, the mesosternal segments regularly alternate with costal attachments (Pl. IX, Fig. 63). Even here, however, exceptions may occur (*Manis longicauda*) in which there are five mesosternal segments giving attachment to seven and a half sternal ribs (PARKER).

This regular alternation of mesosternal segmentation and costal articulation I have found only exceptionally in other orders, *e.g.*, in *Cercoleptes caudivolvulus*, *Nasua narica*, and *Mustela vulgaris*, among Carnivora; in *Paca*, *Dasyprocta*, *Atherura africana*, among Rodents; in an exceptional example of *Bos indicus* among Ungulata; in an example of *Ateles Goeffroyi*; and in a Chimpanzee with only six sternal ribs.

In most orders the number of mesosternal segments is less than the number of associated ribs, although at the same time there is undoubtedly a general correlation between the two, and an increase in the number of sternal ribs is co-incident with an increase in the number of mesosternal segments. In the rat, for example, there are four mesosternal segments and seven sternal ribs: in the rabbit, five mesosternal segments and eight sternal ribs. I have notes of three examples in the *Orang-outan*, possessing three mesosternal segments and six pairs of sternal ribs; and of five examples in which there are four mesosternal segments and seven pairs of sternal ribs.

While Mammals exhibit considerable variability in the relative number of mesosternal segments and ribs, there is one important point of general agreement. There is usually one mesosternal rib in excess of the number of mesosternal segments (Pl. IX, Fig. 64). The penultimate sternal rib is attached to the side of the last mesosternal segment, or along with the last sternal rib to the junction of mesosternum and metasternum. The last sternal rib articulates either with the junction of mesosternum and metasternum, or more rarely with the metasternum alone. The so-called metameric arrangement fails through the mode of attachment of the penultimate rib and the presence of a rib in excess of the number of mesosternal 'segments.'

It has been shown that only in exceptional cases (*e.g.*, Edentata) does a true alternation of mesosternal segments and costal articulation occur. There are, on the other hand, orders in which specialization of the sternum occurs in the opposite direction, leading to equally exceptional conditions. Such examples occur among Ornithodelphia, Sirenia, and Cetacea. The arrangement of the ribs and mesosternum in *Ornithorhynchus* and *Echidna* has already been discussed. In Sirenia, PARKER[53] describes the sternum of the Manatee as representing the presternum alone, and receiving the attachments of only the second pair of ribs. In two examples in the Liverpool Museum, a sternum of a simple type occurs, with a pair of bilateral forward projections and a pointed posterior extremity. The first ribs are cervical, and the sternum receives the second and third pairs (Pl. X, Fig. 67). From PARKER's description of the *Dugong's* sternum, which I have not had an opportunity of examining personally, it is evident that there is a complete sternum, comprising presternum, mesosternum (of three segments), and metasternum. Yet there appear to be only two or three pairs of sternal ribs.

Among Cetacea, in the *Dolphin* there is no metasternum. The presternum receives one-and-a-half pairs of ribs, and the mesosternum, composed of two elements, articulates with two-and-a-half pairs of ribs. There are, in two examples, thirteen and fifteen pairs of ribs respectively altogether, and in both cases four pairs of sternal ribs. In *Balaena mysticetus* a simple sternum occurs (PARKER) with a pointed posterior extremity, and only one pair of ribs articulating with it.

Examples such as these are as much at variance with the notion of a metameric sternum with a costal origin as the Edentate sternum is in harmony with it. Reviewing the whole series, and bearing in mind the general mammalian arrangement and the exceptional conditions of an opposite character which occur, one is forced to the conclusion that, while the differences in costal attachments are probably responsible for differences in the form of the sternum, by affecting its mode of ossification and influencing the conversion of the embryonic structure into a homogenous or a segmented bone, these differences do not affect its essential structure, as a longitudinal, ventral, thoracic axis.

The mammalian metasternum.

The metasternum is not constantly present in mammalia. It is absent in *Ornithorhynchus*, present in *Echidna*. It is generally present in Edentata but is absent in *Unau* (Parker), and in the *three-toed* and *two-toed Sloths*. In Sirenia it is present in the *Dugong* (Parker), but it is not differentiated —if present—in the *Manatee*. It is generally present in Ungulata, but is absent in the *Tapir*. Among Cetacea, it is not present in the *Dolphin*, and is absent or undifferentiated in *Balaena* and *Balaenoptera*.

The mammalian metasternum is always median in position, elongated as a rule, and either broadened out and capped with cartilage at its free end (Rodentia, Chiroptera, Carnivora, Marsupials) or pointed and angular (Echidna, Ungulata). The occasional bifurcation of the metasternum met with in man does not appear to occur in other mammals.

The position, form, ossification, and occasional absence or want of differentiation of the metasternum, make it difficult to accept the view of its metameric origin from the ventral ends of the ribs. It is essentially median, and a backward prolongation of the ventral thoracic axis.

Summary

A survey of the differences in the character of the sternum in the different classes of vertebrates enables one to form a clearer opinion of its morphological position. Its peculiarities appear to be associated, to a certain extent, with differences in the mechanism of respiration, but to a much greater degree with differences in the functions of the fore limb.

In simple types of Fishes (such as Elasmobranchs) the place of the sternum is occupied by the ventral elements of the shoulder-girdle, which may, as in the dog-fish or skate, form a continuous bar extending across the middle line beneath the heart. With one exception (*Notidanus*), however, no fish possesses a sternum proper, and the heart is protected and supported by the shoulder-girdle.

In air-breathing vertebrates the sternum is not always present; nor is its most primitive form to be looked for in animals like *Ophidia*, without limbs, and with a high development of the ribs.

Among Reptiles the sternum is found in several different forms. In its most primitive form (Batrachia, Lacertilia) it is a median structure, not connected with the ribs, but associated with the two halves of the shoulder-girdle.

Chirotes canaliculatus presents a remarkably complete sternum, without costal connexions, and associated with a rudimentary shoulder-girdle.

Among the higher Reptiles (Crocodilia) the sternum acquires costal connexions in addition to its attachments to the shoulder-girdle, and assumes a character directly comparable with that characteristic of the most primitive Mammals (*Ornithorhynchus*, *Echnida*) but at the same time it is a simpler structure, as shewn in the want of differentiation of the several elements.

The study of the sternum in Reptiles encourages the idea that the association of sternum and shoulder-girdle is a primary and fundamental relation; and that the connexions with the ribs is a secondary event.

In still higher vertebrates—Birds and Mammals—the modifications of the sternum which occur are directly associated with alterations in the construction and uses of the shoulder-girdle. Costal connexions are always present, but with wide variations in different groups. The differences in the type of shoulder-girdle appear to determine the constitution of the sternum.

In bipedal animals, or animals whose fore limbs are used for flight, burrowing, etc., in which the coracoid and clavicle (Aves, Ornithodelphia), or clavicle (cat, mole, man) are powerfully developed, the sternum is of a simple type, forming a broad, flat bone, keeled, it may be, for the attachment of powerful pectoral muscles. In such cases the presternum is broad and strong, and the mesosternum is in the form of a single bone.

Among quadrupeds, on the other hand, and Mammals in which the fore limb is more assimilated in type to the hind limb than in birds and bipedal mammals, and is used for supporting weight and for locomotion, mainly or solely, the shoulder-girdle is more rudimentary, the clavicle is absent or defective, and the sternum, at the same time, is modified in a different direction. The presternum is more rudimentary, and the mesosternum may be throughout life in a quasi-segmented condition.*

In the case of the biped, fusion of the sternal elements is a necessity, in order to obtain the proper use of the fore limb. In the quadruped, segmentation and pliancy of the sternum are equally a necessity to ensure ease and readiness in lateral movement of the trunk. In both the respiratory necessities are the same, and are equally provided for by the bony and muscular mechanism.

The mammalian sternum is essentially characterized by the possession of presternum, mesosternum (simple or compound), and metasternum. The only element constantly present, however, is the presternum, the other elements being in different cases either absent or undifferentiated. Lastly, the most variable features of the sternum are produced by the variations in the connexions of the ribs (Tables XXIII, XXIV).

* In the ox the mesosternal 'segments' are united by cartilaginous laminae; and one finds, in old examples, a gradual fusion of the segments by osseous union, beginning in the hinder part of the mesosternum. In one case in my collection, the mesosternum is in one piece, and has the metasternum fused with it.

IV. TERATOLOGY OF THE STERNUM

I have had no opportunities of making personal observations on this aspect of the subject. ANTHONY devotes a chapter to the subject in his valuable memoir,[1] from which the following summary is taken :—

Absence of the Sternum.

The metasternum is occasionally wanting in the human subject, and in rare cases the mesosternum and metasternum are both absent together, the presternum alone being present. It is doubtful if the presternum alone is ever absent : such conditions as have been described being possibly cases of fissure. One case is recorded of absence of the presternum and mesosternum together, the metasternum alone being present. In this case the thorax was enclosed by a fibrous membrane.

Defective or Excessive Attachment of the Sternal Ribs.

The first or the seventh pair of ribs may fail to reach the sternum. The former is the rarer condition, and is found most commonly in anencephalic monsters. It may or may not be associated with *fissura sterni.*

On the other hand, the last cervical vertebra may carry sternal ribs (TURNER[70, 74]). This is a very rare occurrence. It is much more common to find the eighth pair of ribs associated with the sternum (TREDGOLD,[69] CUNNINGHAM[11]). It is commoner in the male than in the female, and on the right side than on the left.

Perforations in the metasternum are regarded by ANTHONY as indications of the primitive lateral separation of the parts. Perforations never occur in the presternum.

Fissures may be partial or complete ; the former occurring in the presternum or metasternum, separately or together ; the latter occurring so as to produce two lateral plates, each associated with its corresponding ribs. Many cases occur in anencephalic foetuses. The two hemi-sterna are in such cases (TURNER[73]) united across the middle line by a fibrous membrane.

GENERAL CONCLUSIONS

The conclusions at which one has arrived from the foregoing considerations may be summarized here.

Surveying the whole field, the sternum is to be regarded as evolved, developed, and constructed rather in relation to the shoulder-girdle than to the thorax. It primarily subserves the functions of the fore-limb, and is secondarily utilized for purposes of respiration. It therefore receives the attachment of a variable number of ribs.

In those animals in which the fore-limbs are limited in functions and serve solely for quadrupedal movement, the limitation is associated with (1) a failure in development of the shoulder-girdle, and (2) a coincident modification of the sternum, which in such cases is connected only with the ribs, and assumes a quasi-segmental character.

If the quadrupedal mammal is to be regarded as the type, then it might be fairly assumed that its sternum is also typical. But can this be asserted? The mass of evidence seems to point to the conclusion that the fore-limb is primarily developed as a prehensile organ; that its more primitive type is to be looked for in animals with a strongly developed shoulder-girdle: and that the fore-limb of quadrupedal mammals is a modification from this primitive type, associated with defects in the formation of the shoulder-girdle and modifications in the form of the sternum.

In other words, segmentation of the sternum is not a primitive condition. It is a secondary event, in two senses—both ontogenetically and phylogenetically. It is an architectural device adopted to suit the particular needs of a modified type, utilized for a particular end in one case and abandoned in another; just as in the formation of the dorsal axial skeleton, segmentation is made use of in the formation of the vertebral column, but is discarded in the construction of the basis cranii, and is modified in the formation of the sacrum.

In advancing a view which is opposed to orthodox belief, one has to face the essential foundations of current opinion. In this light, I venture to express the view that there is no solid evidence of the ontogenetic or phylogenetic origin of the sternum from the ribs. In my opinion and by positive observations the weight of evidence is all on the side of the primary association of the sternum with the shoulder-girdle, and its secondary connexion with the ribs. And I venture, further, to submit that my view is borne out and supported by the evidence of comparative anatomy.

In favour of the view put forward are the following arguments :—

1. The early development of the sternum shows it closely related to the shoulder-girdle and independent of the ribs.

2. The ossification of the several parts, whether median or lateral, is not truly segmental, and is not dependent upon costal connexions, except in the mesosternum.

3. The so-called 'segments' of the mesosternum are not truly metameric. As a rule they are not the same in number as the ribs which articulate with the mesosternum, but fewer. They are not costal but inter-costal. And the formation of segments is due to the deposition of bony masses, whose separation from one another—like their origin—is associated with the mechanical effects produced by the costal attachments to the borders of the sternum.

4. Individual variations are common in the arrangement of the ribs in relation to the sternum. But they occur without producing any fundamental differences in the morphology of the bone itself.

5. A study of the comparative anatomy of the sternum demonstrates that the bone may exist without any connexion with the ribs ; and that the ribs may be highly developed and of great functional importance in cases of absence of the sternum (and shoulder-girdle). Moreover, modifications in the form of the sternum are more dependent upon modifications in the shoulder-girdle than upon differences in its rib-connexions.

In opposition to the views submitted, the following are the chief arguments :—

1. The accounts given by previous observers—notably Ruge—of the early development of the sternum. In previous pages the memoir of this distinguished observer has been referred to, and it need only be re-stated here that, admirable as Ruge's observations are, and valuable as a demonstration of fact, there is really nothing in the observations made that prevents one

from coming to a conclusion diametrically opposed to the view which he takes, and which has become crystallized into dogmatic assertion by succeeding writers. As MINOT suggests, an earlier stage in development must be observed in order to ascertain whether a sternal *anlage* exists or not before the elementary growth of the ribs is completed. This I believe has been demonstrated as a cellular strand projecting from the shoulder-girdle, and secondarily connected with the rib elements.

2. The 'segmental' ossification of the sternum and the bilateral ossification of the mesosternum (in certain of its segments and in certain animals) have been cited as arguments in favour of its costal origin. It has already been conclusively demonstrated (1) that the centres of ossification are not costal but inter-costal, (2) that they do not agree as a rule with the number of associated ribs, and (3) that they are more usually, both in individuals and in species, median than bilateral.

3. The type of sternum characteristic of mammals (quadrupeds) is segmented (*e.g.*, Edentata). It has been already shewn that this form of sternum may be regarded rather as a modification than as the primitive elemental type.

4. Teratological conditions lend absolutely no support to the idea of the costal origin of the bone. From abnormal conditions only tentative conclusions can be arrived at as to what the procedure should be in normal conditions. But in most cases either excess or arrest of development is the cause of an abnormality. The most remarkable form of arrest of development of the sternum is *fissura sterni*, in which an absence of the bone altogether or its longitudinal fissure into two lateral halves may occur. There is no doubt that the normal mode of development of the bone in many lower forms is in two lateral strips separated by the heart. But there is no instance of the occurrence of 'segments' of the sternum isolated from one another, and connected with the ventral ends of the ribs, as one would expect if the various parts of which the bone consists were originally derived from the ribs. In other words, obvious proof of the existence of a sternum without rib connexions has been adduced, but no evidence exists of the persistent association of elements of costal origin arrested in the process of development into a composite sternum.

In conclusion, one may point out that there still remains a great deal that is uncertain and problematic in regard to this question. One has only succeeded in partially covering the ground in the foregoing pages; and the teratological aspect of the subject has not been personally investigated at all. The observations recorded and the general interest arising out of the study of the various problems associated with them appear to me to be enough to warrant the attention they have received, and to justify my taking advantage of this opportunity to formulate my views on a subject which has occupied my attention for several years.

TABLES

TABLE I.—*Ossification of the Sternum (percentages)*

			Centre Present						Centre Absent					
				Mesosternum						Mesosternum				
Months	Number of cases	Average Length	Presternum	1st	2nd	3rd	4th	Metasternum	Presternum	1st	2nd	3rd	4th	Metasternum
		mm.												
IX	122	64·4	96·7	99·2	99·2	83·3	29	8·1	3·3	·8	·8	16·6	71	91·8
VIII	21	52·3	81	81	76·2	47·6	9·5	14·3	19	19	23·8	52·3	90·5	85·7
VII	16	49·1	93·3	87·5	87·5	62·5	37·5	12·5	6·6	12·5	12·5	37·5	62·5	87·5
VI	31	40·7	80·6	83·8	77·4	54·8	6·4	0	19·3	16·1	22·5	45·1	93·5	100
V	24	36·5	62·5	66·6	41·6	12·5	4·1	0	37·5	33·3	58·3	87·5	95·8	100
IV	13	29·6	15·3	23	15·3	7·7	7·7	0	84·6	77	84·6	92·3	92·3	100
III	9	23·9	2·2	2·2	2·2	1·1	0	0	77·7	77·7	77·7	88·8	100	100

TABLE II.—*Median and Lateral Ossification*

	Months	IX	VIII	VII	VI	V	IV	III	Total	Percentages	
Presternum	Centre Single	84	14	9	24	12	2	2	147	...	79
	,, Double Vertical	21	3	4	1	3	0	0	32	17·2	
	,, Double Lateral	2 } 23	0 } 3	0 } 4	0 } 1	0 } 3	0 } 0	0	2 } 34	1·0 } 18·2	20·9
	,, Three or more	4 } 27	0 } 3	1 } 5	0 } 1	0 } 3	0 } 0	0	5 } 39	2·6	
	Total Ossified	111	17	14	25	15	2	2	186	...	...
Mesosternum First Piece	Centre Single	80	15	12	23	12	3	2	147	...	78·5
	,, Double Vertical	1	1	0	1	2	0	0	5	2·6	
	,, Double Lateral	25 } 26	1 } 2	1 } 1	2 } 3	1 } 3	0	0	30 } 35	16·0 } 18·6	21·3
	,, Three or more	4 } 30	0 } 2	1 } 2	0 } 3	0 } 3	0	0	5 } 40	2·6	
	Total Ossified	110	17	14	26	15	3	2	187	...	...
Second Piece	Centre Single	59	12	9	19	5	2	2	108	...	59·3
	,, Double Vertical	5	0	1	1	0	0	0	7	3·8	
	,, Double Lateral	47 } 52	4 } 4	3 } 4	4 } 5	1 } 1	1 } 1	0	60 } 67	33 } 36·8	40·6
	,, Three or more	6 } 58	0 } 4	1 } 5	0 } 5	0 } 1	0 } 1	0	7 } 74	3·8	
	Total Ossified	117	16	14	24	6	3	2	182	...	...
Third Piece	Centre Single	59	7	4	14	1	0	1	86	...	60·5
	,, Double Vertical	3	0	1	0	1	0	0	5	3·5	
	,, Double Lateral	30 } 33	3 } 3	4 } 5	3 } 3	0 } 1	2 } 2	0	42 } 47	29·5 } 33	39·3
	,, Three or more	8 } 41	0 } 3	1 } 6	0 } 3	0 } 1	0 } 2	0	9 } 56	6·3	
	Total Ossified	100	10	10	17	2	2	1	142	...	...
Fourth Piece	Centre Single	18	1	3	0	0	3	0	25	...	53
	,, Double Vertical	7	0	2	0	1	0	0	10	21·3	
	,, Double Lateral	7 } 14	1 } 1	1 } 3	1 } 1	0 } 1	2 } 2	0	12 } 22	25·5	46·8
	,, Three or more	0 } 14	0 } 1	0 } 3	0 } 1	0 } 1	0 } 2	0	0 } 22		
	Total Ossified	32	2	6	1	1	5	0	47	...	...
Metasternum	Single Centre	10	3	2	1	1	0	0	17	...	100

TABLE III.—*Grooves*

Months	Cases	Present	Absent	Per cent.	
				Present	Absent
IX	113	75	38	66·3	33·6
VIII	17	6	11	35·2	64·7
VII	16	13	3	81·2	18·7
VI	30	24	6	80·0	20·0
V	24	19	5	79·1	20·8
IV	13	13	0	100	...
III	9	8	1	88·8	11·1
Total	222	158	64	70·1	29·0

TABLE IV.—*Sternal Foramina*

Months	No. of Cases	Absent		Present								Total
				One in Metasternum		Two in Metasternum		One in Mesosternum		Two or more in Mesosternum and Metasternum		
		No.	Per cent.	No.	Per cent.	No.	Per cent.	No.	Per cent.	No.	Per cent.	
IX	120	81	67·5	28	...	4	...	6	...	1	...	
VIII	20	14	70	4	...	0	...	1	...	1	...	
VII	16	10	62·5	6	...	0	...	0	...	0	...	
VI	30	20	66·6	9	...	1	...	0	...	0	...	
V	28	25	89·3	2	...	0	...	0	...	1	...	
IV	13	7	53·9	3	...	0	...	1	...	2	...	
III	9	7	77·7	2	...	0	...	0	...	0	...	
	236	164	69·4	54	22·87	5	2·14	8	3·38	5	2·14	

Total:

Absent . . . 164 = 69·4 per cent.

Present :—
- 1 in metasternum = 54
- 2 in metasternum = 5
- 1 in mesosternum = 8
- 2 or more in mesosternum and metasternum = 5

Total present 72 = 30·5 per cent.

TABLE V.—*Union of Sternal Elements and Costal Cartilages*

Months		IX	VIII	VII	VI	V	IV	III	Per cent.
Union of Presternum and Mesosternum	Fibrous	75·1	78·9	99·9	87	58·3	69·2	66·6	=76·4
	Cartilaginous	24.7	21	0	12·9	41·6	30·7	33·3	=23·6
Union of Mesosternum and Metasternum	Fibrous	31	31·5	31·2	40	9	0	11·1	=22·1
	Cartilaginous	68·9	68·4	68·7	60	90·9	100	88·8	=77·9
First Costal Cartilage	Fibrous	14	25	6·6	0	0	15·3	11·1	...
	Cartilaginous	76	68·7	80	100	78·2	76·9	88·8	=81·3
	Dissimilar	9·9	18·7	13·3	0	21·6	7·6	0	...
Seventh Costal Cartilage	Separate from sternum	6·6	5·8	18·7	15·3	0	9	0	= 8
	United	93·4	94·2	81·3	84·7	100	91	100	=92
Eighth Costal Cartilage	Separate from sternum	90	100	100	96·7	100	90·9	88·8	=95·2
	United	9·9	0	0	3·5	0	9	11·1	= 4·8

TABLE VI.—*Ridges on the Mesosternum*

No. of cases	Years	Absent	Present opposite			
			3rd C.C.	4th C.C.	5th C.C.	6th C.C.
44	20-25	21	20	4	1	0
34	26-29	9	9	16	0	0
127	30-39	26	97	51	7	2
110	40-49	30	72	41	4	0
141	50-82	41	97	51	7	0
68	Unclassed	13	53	37	2	0
524		140	363	205	21	2
	Per cent.	26·7	69·2	39·1	4·0	0·3

TABLE VII.—*Ossification of the Mesosternum; 141 cases, 0—16 years inclusive*

Segments	No. of cases	Per cent.	Centres			Double centres	
			Single	Double	Three	Vertical	Lateral
First	141	100	136	4	1	0	5
			96·4 per cent.	5 — 3·5 per cent.			
Second	141	100	115	23	3	3	23
			81·5 per cent.	26 — 18·4 per cent.			
Third	139	98·5	91	42	6	4	44
			65·4 per cent.	48 — 34·5 per cent.			
Fourth	38	26·9	29	9	0	0	9
			76·3 per cent.	23·6 per cent.			

TABLE VIII.—*Fusion of Mesosternal Elements together. Percentages*

Age	No. of cases	Normal process				Abnormal process				Usual condition
		1·2·3 or 1·2·3·4	1·2·3+4	1·2+3 or 1·2+3+4	1+2+3 or 1+2+3 +4	1·2+3·4	1+2·3+4 or 1+2·3	1+2·3+4	1+2+3·4	
1-5	29	82·7	6·9	3·4	6·9	...	...	...	...	All separate
6-10	17	64·7	17·6	5·8	5·8	...	5·8	...	...	3 or 4 pieces: first three separate.
		82·3								
11-15	23	34·7	13·0	26·0	17·3	4·3	4·3	...	...	1-4 pieces: first two separate.
		47·7		43·3						
16-20	59	22·0	5·0	25·4	40·6	...	1·6	3·3	1.6	1-4 pieces: first separate.
		27·0		66·0						
21-25	36	...	...	13·8	83·3	...	...	...	2·7	1-2 pieces: all fused.
				97·1						

TABLE IX.—*Ossification of the Metasternum*

Age	No. of cases	Centre absent	Centre present
0-4	24	19	5
5-9	18	5	13
10-14	17 } 64	9 } 29	8 } 35
15-18	29	15	14
	88	48 : 54·5 per cent.	40 : 45·4 per cent.
19-25	55	6 : 9·0 per cent.	49 : 89·0 per cent.
26-82	428	6 : 1·4 per cent.	422 : 98·6 per cent.

TABLE X.—*Union of the Mesosternum with Presternum and Metasternum*

A. WITH PRESTERNUM

Age	No. of cases		Per cent. separate		Per cent. fused	
0-14	62	198	98·2	96·8	1·7	3·1
15-19	58		98·2		1·7	
20-25	44		90·9		9·0	
26-29	34		100·0		0·0	
30-49	234	375	89·3	86·4	10·5	13
50-82	141		83·6		15·6	
Unclassed	68		89·7		10·3	
	642		90·9 per cent.		8·8 per cent.	

B. WITH METASTERNUM

Age	No. of cases	Per cent. separate		Per cent. fused	
0-14	62	100		0	
15-19	58	96·5		3·4	
20-29	72	80·6	65·7	19·3	34
30-49	240	60·9		39·1	
50-82	141	53·9		45·3	
Unclassed	68	67·6		32·3	

Table XI.—*Length and Breadth of the Adult Sternum*

Sex	Age	Breadth			Length			Total length
		Pre-sternum	Meso-sternum	Meta-sternum	Pre-sternum	Meso-sternum	Meta-sternum	
Male (123)	22-39	62·5	39·4	19·0	52·2	102·8	36·3	191·3
„ (187)	40-82	68·1	41·6	21·0	51·8	104·7	43·7	202·5
Total Male (310) ...	22-82	65·3	40·5	20·0	52·0	103·7	40·0	196·9
Female (60)	22-39	57·3	35·8	15·0	47·1	92·0	31·8	173·9
„ (66)	40-82	59·4	37·8	17·0	47·5	90·0	35·2	172·8
Total Female (126) ...	22-82	58·3	36·8	16·0	47·3	91	33·5	173·3
Unclassed	?	63·3	39·7	19·2	49·1	102·8	36·4	189·5
Average Male and Female (183) ...	22-39	57·8	38·4	17·9	50·4	98·8	35·2	185·4
Average Male and Female (253) ...	40-82	63·7	39·7	19·0	49·6	97·3	39·4	187·6
Total average (504) ...	22-82 and unclassed	61·6	39·2	18·7	49·7	99·6	37·0	187·5

TABLE XII.—*Sterna Indices (Adult, over twenty-one)*

A. BREADTH

	Male			Female			Unclassed	Total average
Age :—	22-39	40-82	Average	22-39	40-82	Average	Average	
Presternum ...	119·7	131·4	125·5	121·6	125·0	123·2	128·9	125·8
Mesosternum .	38·3	39·7	39·0	38·4	42·0	40·4	38·6	39·3
Metasternum .	52·3	48·0	50·0	47·1	48·2	47·7	52·7	50·1

B. LENGTH

	Male			Female			Unclassed	Total average
Age :—	22-39	40-82	Average	22-39	40-82	Average	Average	
Presternum ...	83·5	76·0	79·6	82·1	79·9	81·1	77·5	79·4
Mesosternum .	260·9	251·6	256·0	256·9	238·0	247·0	258·9	254·0
Metasternum .	191·0	208·0	200·0	212·0	207·0	209·3	189·2	199·5

TABLE XIII

Relative Length of Presternum and Mesosternum in the Male and Female

No. of cases		Age	Presternum	Mesosternum	Proportion
106	65 M.	2-21	M. 37·9	76·9	1 : 2
	41 F.		F. 37·3	73·0	1 : 1·9
183	123 M.	22-39	M. 52·2	108·8	1 : 1·9
	60 F.		F. 47·1	92·0	1 : 1·9
253	187 M.	40-82	M. 51·8	104·7	1 : 2
	66 F.		F. 47·5	90·0	1 : 1·8
Total 436	310 M.	22-82	M. 52·0	103·7	1 : 1·9
	126 F.		F. 47·3	91·0	1 : 1·9

TABLE XIV.—*Sternal Foramina*

Age :—	0-24	25-82	Total per cent.
No. of cases ...	152	479	631
Absent	80·2 per cent.	79·1 per cent.	79·6 per cent.
Present :—			
Metasternum ...	15·1 ,,	17·7 ,,	16·4
(1) ...	12·5 ,,	15·8 ,,	14·1 }
(2) ...	2·6 ,,	1·8 ,,	2·2 } 20·2 per cent.
Mesosternum ...	4·6 ,,	3·1 ,,	3·8 }
Situation :—			
C.C. 4	1	1	13·0 per cent.
C.C. 4-5 ...	2	5	30·4 ,,
C.C. 5	3	7	43·4 ,,
C.C. 5-6 ...	0	1	8·7 ,,
Junction ...	1	0	4·3 ,,
In both Meso- and Metasternum ...	...	...	3 per cent.

TABLE XV.—*Lateral Curvature of the Sternum*

No. of cases	Straight	Curved		Total per cent. curved
		Right	Left	
Young 139	94—67·6 per cent.	27—19·4 per cent.	18—12·9 per cent.	32·3 per cent.
Adult 490	299—61·0 ,,	133—27 ,,	58—11·8 ,,	38·9 ,,
Total 629	393—64·3 ,,	160—23·2 ,,	76—12·3 ,,	35·6 ,,

TABLE XVI.—*Obliquity of Junction of Presternum and Mesosternum*

Age	No. of cases	Straight per cent.	Oblique (per cent.)		
			Down to right	Down to left	Total
0-19	115	89·5	6·0	4·3	10·3
20-29	70	67·1	18·5	14·2	32·7
30-39	130	66·1	16·1	17·6	33·7
40-49	110	60·9	15·4	23·6	39·0
50-82	140	53·5	18·5	27·8	46·3
Unclassed	68	70·5	11·8	17·6	29·4
Total	633	69·5	13·2	17·0	30·3

TABLE XVII.—*Asymmetry of the Costal Cartilages*

	Adult		Young	
	Number	Per cent.	Number	Per cent.
Symmetrical	156	32·0	94	58·7
Asymmetrical	355	67·9	68	41·2
Down to Right	151	42·5	36	54·5
Down to Left	204	57·4	32	45·4
Both Directions ...	24	6·7	2	2·9

TABLE XVIII.—*Asymmetry of the First Costal Cartilages*

	Number			Per cent.	
Adult	R.	20	22	90·9	5·1
	L.	2		9·0	
Young	R.	8	11	72·7	7·1
	L.	3		27·2	
Total	R.	28	33	81·9	6·1
	L.	5		18·1	

TABLE XIX.—*Attachments of Seventh Costal Cartilages*

Attachment	Numbers			Per cent.		
To mesosternum—both ...	55		66	83·3		9·3
Right only ...	8	11		72·7	16·6	
Left only ...	3			27·2		
To junction of mesosternum and metasternum—both ...	407		479	84·9		68·1
Right only ...	64	72		88·8	15·0	
Left only ...	8			11·1		
To metasternum—both ...	55		111	49·5		15·7
Right only ...	12	56		21·4	50·4	
Left only ...	44			78·5		
Absent—both	13		47	27·6		6·6
Right only ...	4	34		11·7	72·3	
Left only ...	30			88·2		

Table XX.—*Asymmetry of Clavicular Facets*

1. Size

Number of Cases	Equal	Unequal	
		R. larger	L. larger
486	410 : 87·2 per cent.	35 : 5·4 per cent.	20 : 3·9 per cent
		54 : 9·4 per cent.	

2. Concavity

Number of Cases	Equal	Unequal	
		R. greater	L. greater
486	464 : 95·6 per cent.	12 : 1·9 per cent.	10 : 1·3 per cent.
		22 : 3·2 per cent.	

3. Level

Number of Cases	Equal	Unequal	
		R. higher	L. higher
506	307 : 61 per cent.	54 : 10·3 per cent.	145 : 28·5 per ct.
		199 : 38·9 per cent.	

Table XXI.—*Attachments of the Eighth Costal Cartilages in Young Sterna (under 21)*

Condition	Number		Per cent.	
Absent	123		91·1	
Present—Both	6	12	50	8·8
Right only	4	6	66·6	50
Left only	2		33·3	
Attachment—Junction	2	10 ...	20·0	
Metasternum ...	8		80·0	

Table XXII.—*Eleven Cases out of fifty-six Sterna of Variation in Attachment of Seventh and Eighth Costal Cartilages (adult)*

Sex	Age	Failure of 7th C.C.			8th C.C. reaches Sternum		
		R.	L.	Both	R.	L.	Both
F.	40	...	...	1	...	...	...
M.	44.	...	1	...	...	...	...
F.	32.36	...	...	...	...	...	2
M.	12.25.50	...	...	...	3	...	...
M.	39.44.	...	...	...	2 (almost)	...	...
?	? ?	...	...	...	...	2	...
		...	1	1	5	2	2

TABLE XXIII.—*Connexions of Mesosternum with the Ribs in some Mammalia*

(COMPILED FROM PERSONAL OBSERVATIONS AND OTHER AUTHORS)

Name	Total ribs	Sternal ribs	Ribs attached to mesosternum	Number of segments of mesosternum	Attachment of hinder ribs to mesosternum
Ornithorhynchus ...	16	6	4½	2	Peculiar
Echidna	16	6	4½	2	Peculiar
MARSUPIALS	13	7	5½	4	6 meso., 7 junct.
WOMBAT	14	6	4½	3	5, 6 junct.
EDENTATA	10-21	5-11	3½-9½	3-9	Last junct.
Tatusia septemcinctus ...	10	5	3½	3	" "
Tatusia peba	11	6	4½	4	" "
Armadillo	11	7	5½	5	" "
Giant Armadillo ...	12	8	6½	6	" "
Three-toed sloth ...	14	L. 8, R. 9	6½-7½	6	" "
Myrmecophaga jubata ...	18	11	9½	7	" "
Cyclothurus didactylus (1)	16	9	6½	7	" "
" " (2)	16	10	7½	8	" "
Tamandua	15	10	8	8	" "
Tamandua bivittata ...	17	10	8	8	" "
Two-toed sloth ...	21	L. 10, R. 11	R. 9½, L. 8½	9	" "
CARNIVORA :—Jackal ...	13	9	7½	6	8, 9 junct.
Nasua rufa	14	9	7½	6	8 meso., 9 junct.
Luwack...	13	9	7½	6	8, 9 junct.
Lioness...	13	9	7½	6	" "
Dog	13	9	7½	6	" "
Puma	13	9	7½	6	" "
Otter	14	10	8½	7	9, 10 junct.
Cercoleptes caudivolvulus	15	10	8½	8	Last junct. alternate

TABLE XXIII.—*Continued*

Name	Total ribs	Sternal ribs	Ribs attached to mesosternum	Number of segments of mesosternum	Attachment of hinder ribs to mesosternum
Nasua narica	13	9	7½	8	Last junct. alternate
Mustela vulgaris ...	14	10	8½	9	" "
RODENTIA :—Beaver ...	14	8	5½	3	6, 7 meso., 8 junct.
Water rat	13	8	6½	4	7 junct., 8 meta.
Coypu	13	8	5½	4	" "
Jumping hare	12	7	5½	4	6 meso., 7 meta.
Flying squirrel	12	7	5½	4	6, 7 junct.
Hystrix cristata ...	15 L., 14 R.	8	6½	5	7, 8 junct.
Spalax typhlas	13	8	6½	5	6 meso., 7 junct.
Paca	13	7	5½	5	7 junct. alternate
Dasyprocta	13	7	5½	5	" "
Atherura afr.	14	7	5½	5	" "
CHEIROPTERA	11	6	4½	1	6 junct.
UNGULATA :—Peccary ...	14	7	5½	4	6 meso., 7 junct.
Ox	13	7	5½	4	7 junct.
Bos indicus (1)... ...	13	7	5½	4	"
" (2)... ...	13	6	4½	4	6 junct. alternate
Chamois	13	8	6½	4	7 meso., 8 junct.
Bison	14	R. 7, L. 8	5½-6½	5	7, 8 L. junct.
Gazelle	13	8	6½	5	7 meso., 8 junct.
Antelope	13	8	6½	5	" "
Reindeer	?	8	6½	5	" "
INSECTIVORA :—Mole ...	13	7	5½	3	½ 4, 5, 6½, 7 3rd piece meso., 7 junct.
Centetes	15	7	5½	4	6 meso., 7 junct.

TABLE XXIII.—*Continued*

Name	Total ribs	Sternal ribs	Ribs attached to mesosternum	Number of segments of mesosternum	Attachment of hinder ribs to mesosternum
HYRACOIDEA	18	6	4½	4	5, 6 junct.
SIRENIA :—Manatee (2) .	17	2	2	1	Sternum simple
CETACEA :—Porpoise ...	12	4	2	1	Fused with pre- and metasternum
PRIMATES :—Tarsier ...	13	7	5½	3	{5, 3rd piece meso. 6, 7 junct.
Lemur	12	11	9½	4	{10 junct., 11 in front of meta. and with each other
Aye aye	12	9	7½	6	8 meso., 9 meta.
Nycticebus tardigradus...	15	11	9½	8	10, 11 junct.
Ateles geoffroyi... ...	14	8	6½	6	8 junct. alternate
Colobus vellerosus ...	12	R. 7, L. 8	5½-6½	5	7 junct., 8 L. meta.
Cynocephalus anubis ...	R. 12, L. 13	8	6½	5	7 junct., 8 meta.
Macacus inuus... ...	12	9	7½	6	8 junct., 9 meta.

Table XXIV

Anthropoids

	Total Number of Ribs	Number of Sternal Ribs	Ribs attached to meso-sternum	Segments of Mesosternum	Attachment of hinder Ribs
I. Hylobates—					
R.C.S. 58 ...	13	7	$4\frac{1}{2}$	?	?
61 (young).	13	7	$4\frac{1}{2}$	?	?
63 ...	13	7	$4\frac{1}{2}$	1	6 meso., 7 junct.
65 ...	13	R.8, L.7	R.$4\frac{1}{2}$ L.$3\frac{1}{2}$	2 (median)	6, 7 meso., R. 8 junct.
66 ..	13	7	$5\frac{1}{2}$	1	7 lower end meso.
67 ...	14	8	$5\frac{1}{2}$	2 (median)	7 meso., 8 junct.
L'pool 1 ...	14	7	$4\frac{1}{2}$	1	6 meso., 7 junct.
2 ...	13	7	$4\frac{1}{2}$	3 (median)	6 meso., 7 junct.
II. Chimpanzee—					
R.C.S. 1 ...	13	7	$5\frac{1}{2}$	2 (All median)	6 meso., 7 junct.
2 ...	13	6	$4\frac{1}{2}$	3	6 meso.
3 ...	12	?	?	4	?
4 ...	12	7	$5\frac{1}{2}$	3	6 meso., 7 junct.
5 ...	12	?	?	4	?
13 (young).	13	7	$5\frac{1}{2}$	4	6 meso., 7 junct.
14 ,,	13	7	$4\frac{1}{2}$	3	6 meso., 7 junct.
15 ,,	13	7	$5\frac{1}{2}$	4	6 meso., 7 junct.
16 ,,	14	8	$5\frac{1}{2}$	4	7, 8 junct.
L'pool (2) ...	13	6	$4\frac{1}{2}$	4	6 junct.—alternate.

TABLE XXIV.—*Continued*

ANTHROPOIDS.—*Continued*

	Total Number of Ribs	Number of Sternal Ribs	Ribs attached to Meso-sternum	Segments of Mesosternum	Attachment of hinder Ribs
III. GORILLA—					
R.C.S. 20 ...	13	7	5½	4 (median)	6 meso., 7 junct.
21 (young)	13	?	?	3 (1 and 2 bilateral) ...	?
21a „ ...	13	?	?	3 (bilateral)	?
23 ...	13	7	5½	2 (median)	5, 6 meso., 7 junct.
24 ...	13	?	?	2 (median)	?
29 (young).	14	7	5½	4 (bilateral)	6 meso., 7 junct.
30 „	13	7	5½	3 (bilateral)	7 junct.
L'pool (1) ...	13	7	5½	3 (median)	6 meso., 7 junct.
(2) ...	13	6	4½	3 (median)	5 meso., 6 junct.
IV. ORANG—					
R.C.S. 37 ...	12	R.7, L.6	5½, 4½	3 (median)	R. 7, L. 6, meso.
38 ...	12	6	5½	3 (median)	5 meso., 6 junct.
38a ...	12	6	5½	3 (median fused)... ...	5 meso., 6 junct.
40 ...	12	7	4½	3 (median)	6 meso., 7 junct.
40a ...	12	7	5½	3 (median fused)... ...	6 meso., 7 junct.
40b (young)	12	R.7, L.6	5½, 4½	3 (1 and 2 bilateral ...	R. 7, L. 6, junct.
40c „	12	7	5½	3 (bilateral)	6 meso., 7 junct.
47 „	12	7	5½	4 (median, exc. 2 bilateral)	7 junct.
48 „	12	7	5½	4 (1, 2, 3 bilateral) ...	6 meso., 7 junct.
50 „	12	R.7, L.6	5½, 4½	4 (2, 3, 4 bilateral) ...	6 meso., 7 junct.
51 „	12	7	5½	4 (bilateral probably) ...	6 meso., 7 junct.
52 „	12	?	?	4 (bilateral possibly) ...	?
56a „	?	6	4½	3 (2 bilateral)	5, 6 junct.
56b „	?	7	5½	4 (bilateral probably ...	6 meso., 7 junct.
L'pool (1) „	13	7	5½	4 (3 bilateral)	6 meso., 7 junct.
(2) „	12	8	6½	4 (median)	R. 7, 8 junct.; L. 7 meso.; L. 8 junct.

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EXPLANATION OF FIGURES

EXPLANATION OF FIGURES

PLATE I

Fig. 1. Human embryo (sagittal section).

Fig. 2. Rat 9 mm. Section across bottom of praecervical sinus.

Fig. 3. ,, ,, Sagittal section through chest wall.

Fig. 4. ,, ,, Transverse section through middle of chest wall, showing ossifying ribs and absence of sternum.

Fig. 5. Rat 10 mm.
Fig. 6. ,, ,,
Fig. 7. ,, ,,
Fig. 8. ,, ,,
} Magnified seven times, showing clavicles, presternum, mesosternum, and costal cartilages.

Fig. 9. Rat 10 mm.
Fig. 10. ,, ,,
} Magnified twenty-eight times, to show characteristic features of presternum and mesosternum.

Fig. 11. Rat 10 mm. Higher magnification, to show differentiation of tissue in sternum and costal cartilages.

PLATE II

Fig. 12. Rat 10 mm. Higher magnification, to show differentiation of tissue in sternum and costal cartilages.

Fig. 13. Rat 13 mm.
Fig. 14. ,, ,,
Fig. 15. ,, ,,
} Magnified seven times, to show structure and connexions of sternal elements.

Fig. 16. Rat 13 mm. { Magnified twenty-eight times, to show general structure of sternum and connexions of costal cartilages.

Fig. 17. Human sternum, third month. 8 mm. long, magnified twenty-eight times.

Fig. 18. ,, ,, 10 ,, ,, twenty-one ,,

Fig. 19. ,, ,, 9 ,, possessing sternal foramen, and eight costal cartilages—magnified eighteen times.

PLATE III

Fig. 20. Rat embryo. Coronal section of cartilaginous sternum, showing primary areolae—magnified seven times.

Fig. 21. Coronal section of older rat's sternum, showing primary areolae and absence of ossification in last piece of mesosternum—magnified seven times.

Fig. 22. Coronal section of older rat's sternum, showing primary areolae, thickened perichondrium, and absence of bone formation between sixth and seventh costal cartilages.

Fig. 23. Coronal section of sternum of mouse a few days after birth, showing bone formation and cartilages.

PLATE III—*Continued*

Fig. 24. Sternum (lower end) of rat nine days old, showing ossification.

Fig. 25. Section through shoulder-girdle, and sternum of an embryo of *Acanthias vulgaris* (advanced), showing the continuous cartilaginous structure.

Fig. 26. Section through early embryo of *Acanthias vulgaris*, showing the undifferentiated tissue of shoulder-girdle and sternum.

Fig. 27. Section of chick embryo (six days eighteen hours), showing the formation of the sternum on one side (St.) and the ribs (RR).

Fig. 28. The half-sternum (St.) of the same embryo more highly magnified, showing the difference in the tissue of the sternum and the rib cartilages (CC).

PLATE IV

Figs. 29-34. Sections of Rat embryos, showing the differentiation of sternum and clavicles. P.st., praesternum ; V, vein ; I.H.mm., infrahyoid muscles ; S.S., synovial sac.

PLATE V

Fig. 35. Diagram of human sternum at birth, showing the average dates of appearance of centres of ossification, and the percentage of centres present and absent at the time of birth.

Fig. 36. Sternal cornua. Ossification of the first costal cartilages, in the sternum of a male aged fifty-four years. (Reduced two-thirds).

Fig. 37. Diagram to illustrate the process of fusion of the several parts of the sternum, with the average dates of coalescence.

Fig. 38. (A—C)
Fig. 39. (D, E) } Varieties in the number and arrangement of the centres of ossification of the sternum. A, B, male sterna, *aet.* four years. C, female, four years. D, male, E, female sternum, *aet.* five years.

PLATE VI

Fig. 40. Sternum of a female, *aet.* fifty-four, showing fusion of presternum and mesosternum with an arthrodial surface, for the first costal cartilage (half natural size).

Fig. 41. Sternum of a male, *aet.* fifty-nine, showing fusion of first piece of mesosternum with presternum, pre-mesosternal articulation opposite third pair of costal cartilages, and two-and-a-half pairs of costal cartilages articulating with presternum (half natural size).

Fig. 42A. Sternum of a male, *aet.* forty-six. Male type (half natural size).

Fig. 42B. „ „ female, *aet.* thirty-eight. Female type (half natural size).

Fig. 43A. „ „ female foetus in the seventh month, showing supra-sternal cartilages, fused together, but separate from the presternum (natural size).

Fig. 43B. Sternum of a female foetus at full time, showing two supra-sternal cartilages, separated from one another, but each fused with the presternum. The metasternum is absent, and there are only six sternal ribs on the right side (natural size).

Fig. 44. Presternum of an adult, viewed from behind, showing a supra-sternal ossicle articulating with the supra-sternal notch on the left side, and an articular surface on the right side (natural size).

PLATE VII

Fig. 45. Supra-sternal notch, normal, broad, and shallow.

Fig. 46. „ „ „ „ „

Fig. 47. „ „ „ deep, and narrow.

Fig. 48. Male sternum (*aet.* nine years). Supra-sternal border raised into a median projection.

Fig. 49. Male sternum (*aet.* forty-six years). Supra-sternal border raised into a median projection.

Fig. 50. Example of supra-sternal ossicles.

Fig. 51. Supra-sternal ossicles (from behind). A fused ossicle on the left side ; a raised articular facet on the right side.

Figs. 52, 53. Examples of two fused tubercles on the supra-sternal border.

Fig. 54. Example of tubercles on the supra-sternal border, with articular facets.

PLATE VIII

Fig. 55. Scheme of the homologies of the shoulder-girdle and sternum.

Fig. 56. Sternum of a male (*aet.* thirty-five), with sternal foramina (half natural size).

Fig. 57. The shoulder-girdle and sternum of the frog (*Rana temporaria*), from Parker.

Fig. 58. The sternum of *Chirotes canaliculatus*, from Parker (× 9).

Fig. 59. Sternum and shoulder-girdle of *Lemanctus longipes*, from Parker.

Fig. 60. „ „ „ the Crocodile (young), from Parker.

PLATE IX

Fig. 61. Scheme of prevalent variations of the sternum, affecting (i) clavicular facets ; (ii) pre-mesosternal junction ; (iii) thickness of first costal cartilage ; (iv) displacement downwards of left cartilages (2-7) ; (v) detachment of left seventh costal cartilage ; (vi) attachment of right eighth costal cartilage ; (vii) sternal foramen ; and (viii) bifurcation of metasternum.

Fig. 62. Presternum of chamois (natural size).

Fig. 63. Sternum of ant-eater (*Myrmecophaga jubata*) (two-thirds natural size).

Fig. 64. „ jackal (two-thirds natural size).

PLATE X

Fig. 65. Shoulder-girdle, etc., of *Anguis fragilis* (× 6), from Parker.

Fig, 66. Presternum and supra-sternal ossicles in *Mus musculus*, from Parker.

Fig. 67. Sternum of *Manatee* (one-quarter natural size).

Fig. 68. Sternum, etc., of *Echidna*.

Fig. 69. „ „ *Ornithorhynchus*.

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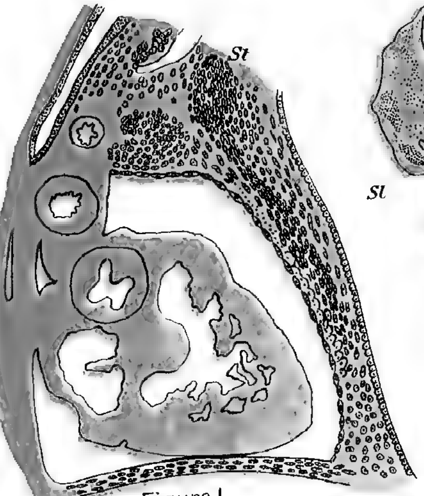
PLATE I.



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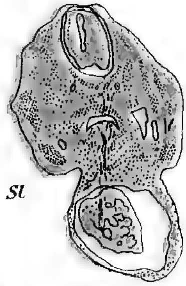

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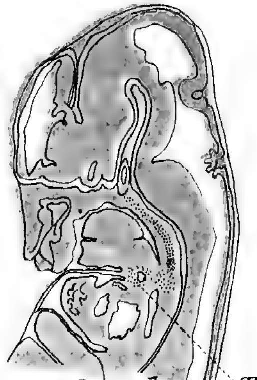

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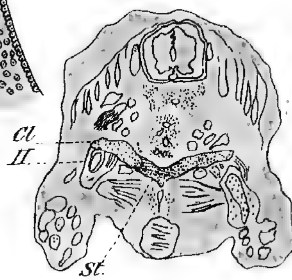

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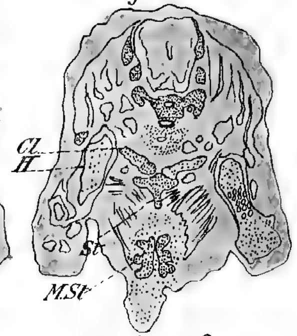

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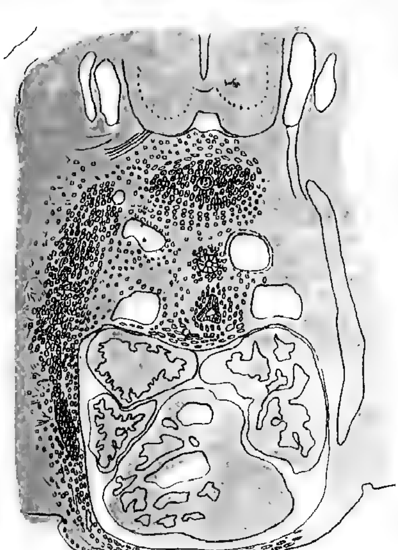

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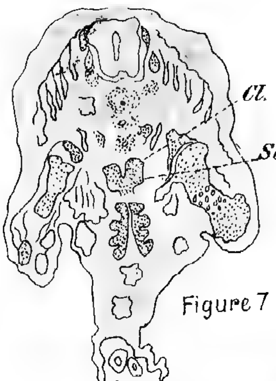

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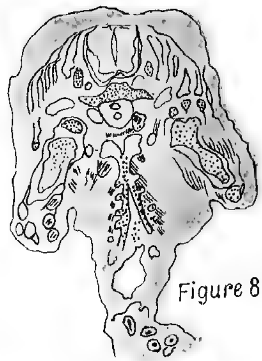

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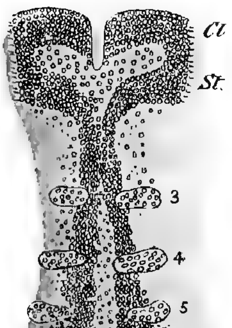

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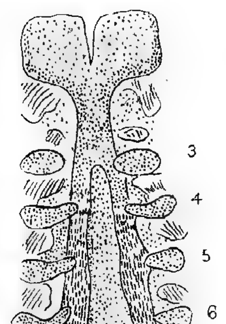

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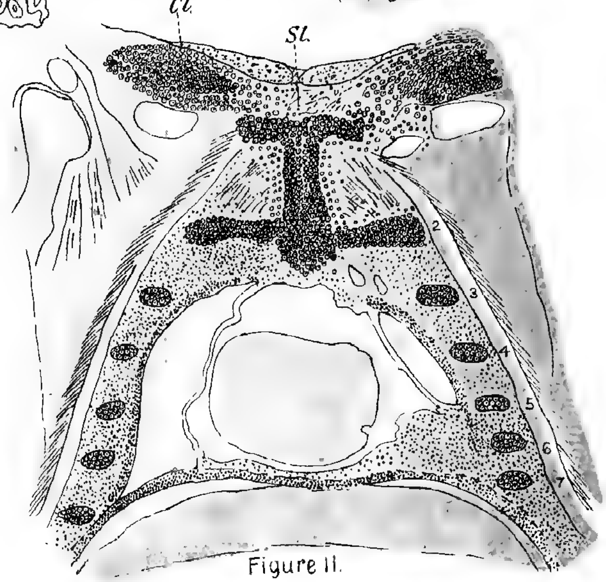


Figure 11.

PLATE 2.

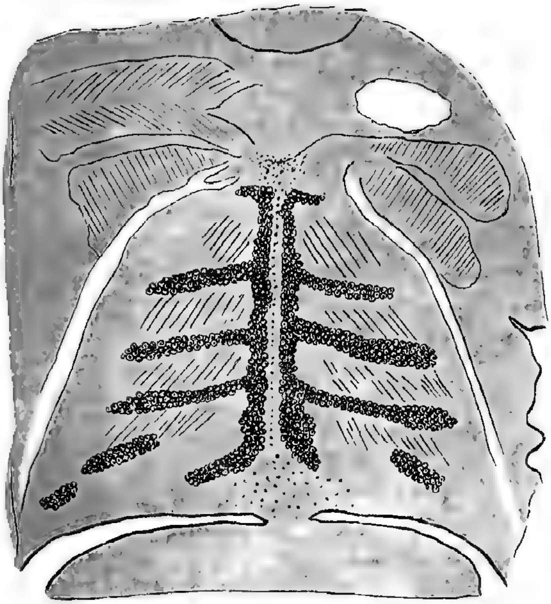


Figure 12.

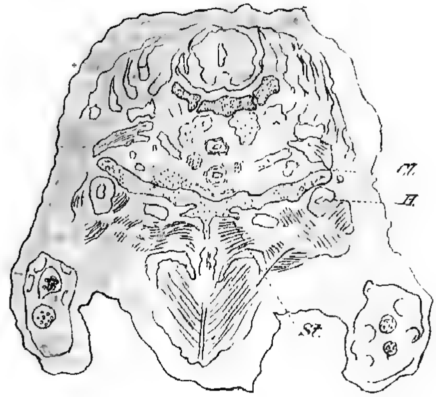
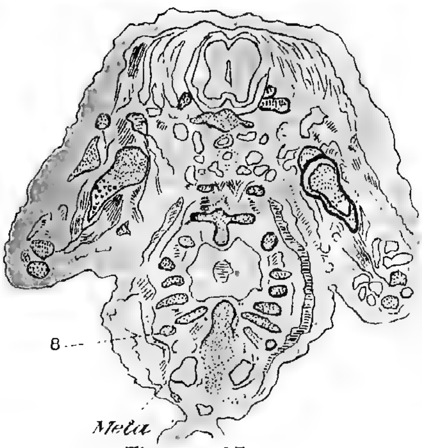


Figure 13.



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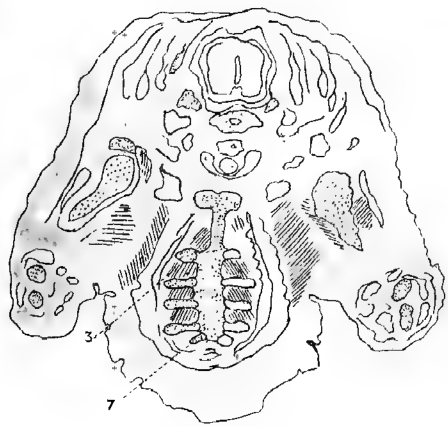

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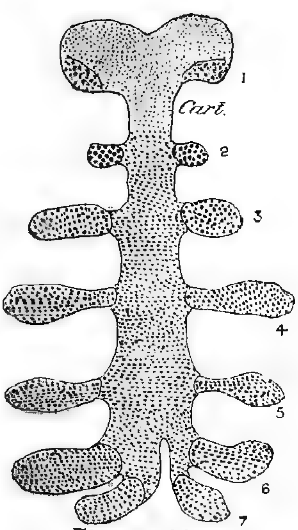


Figure 16

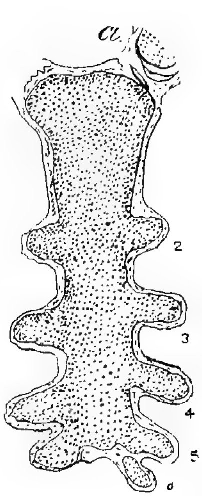
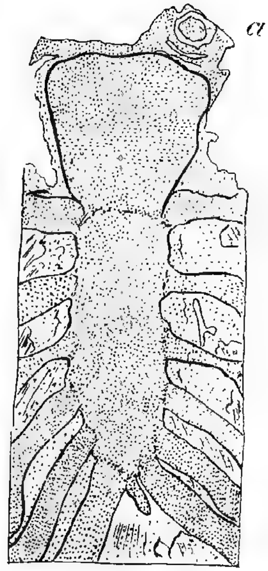


Figure 17



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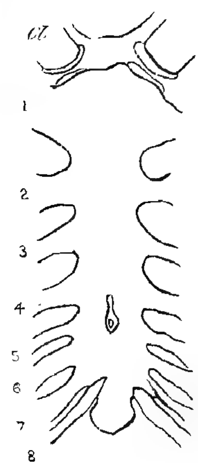
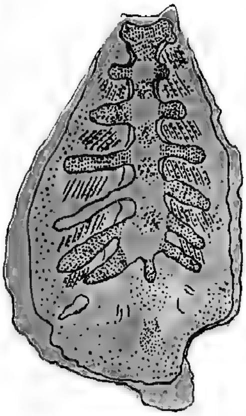


Figure 19.

PLATE 3.



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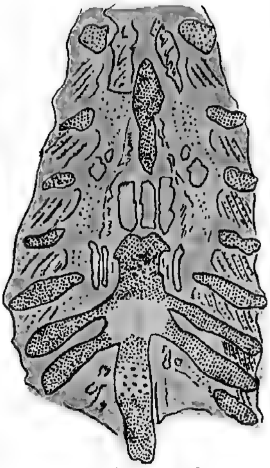

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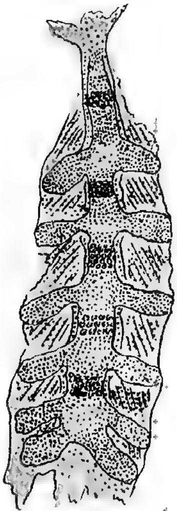

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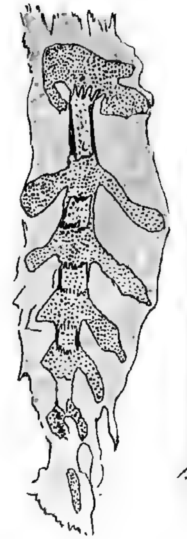

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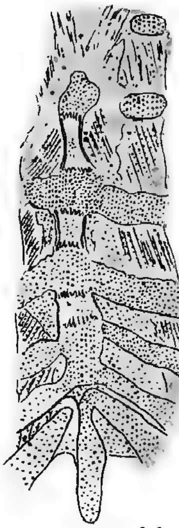
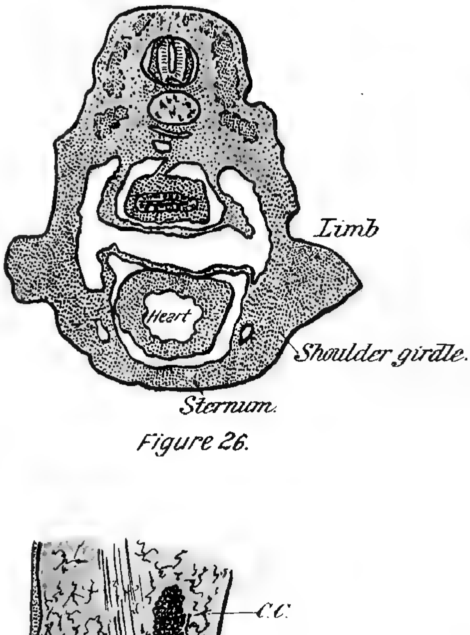


Figure 24

Acanthias Vulgaris



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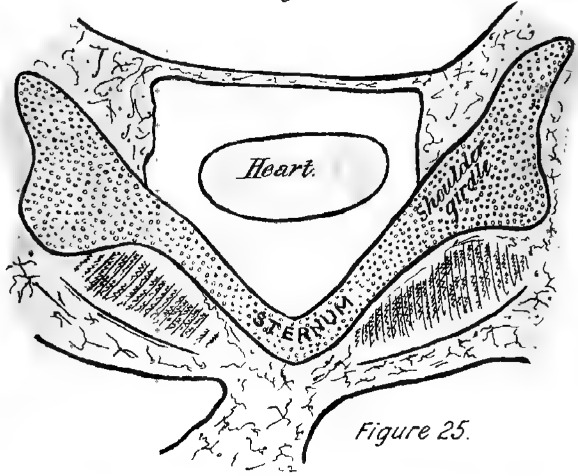

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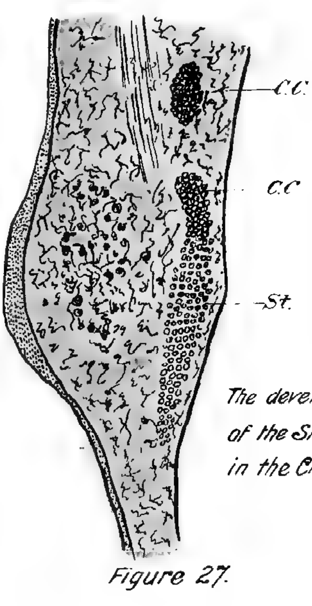


Figure 27.

The development of the Sternum in the Chick. (6 days 18 hours.)

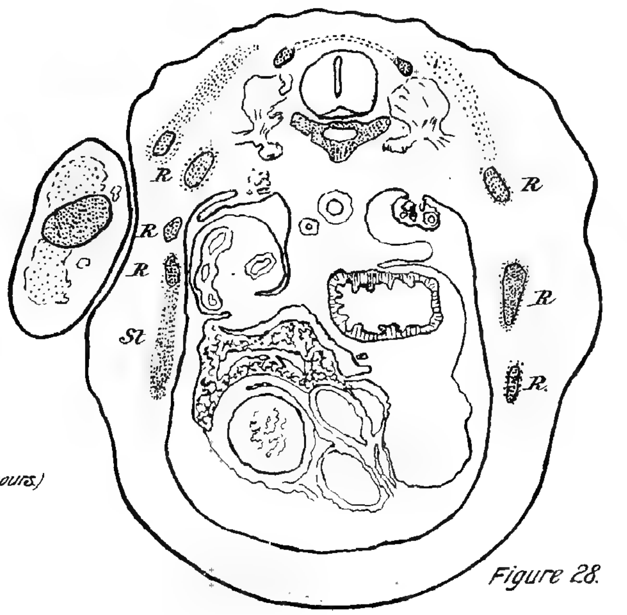
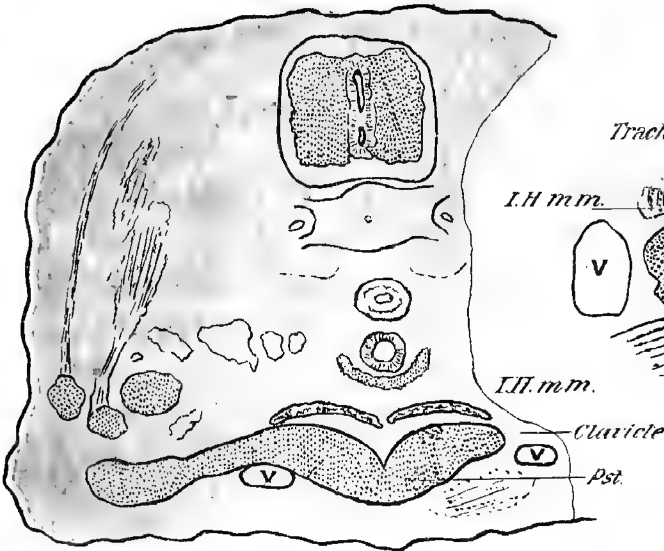


Figure 28.

Plate 4.



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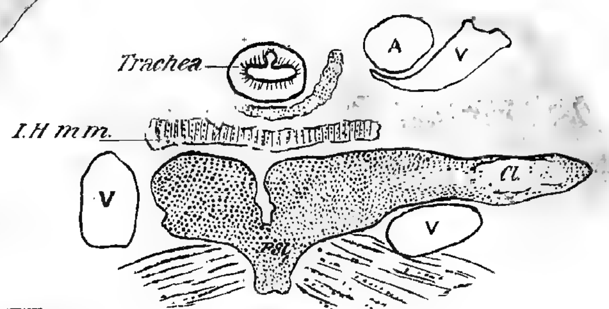

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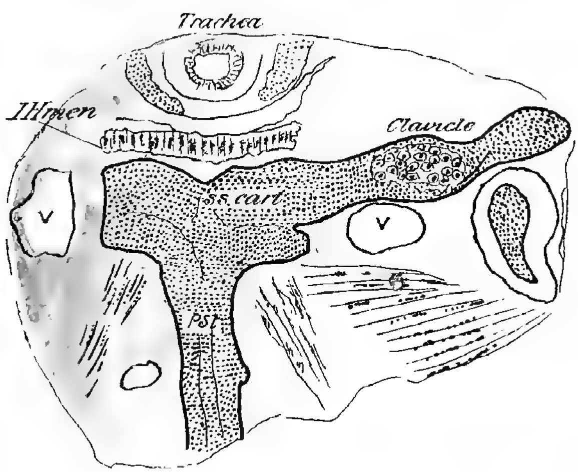


Figure 31

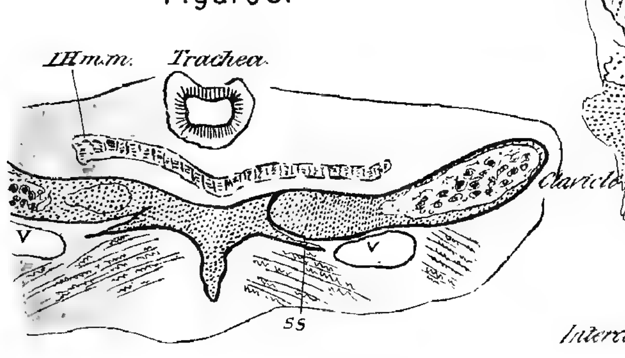
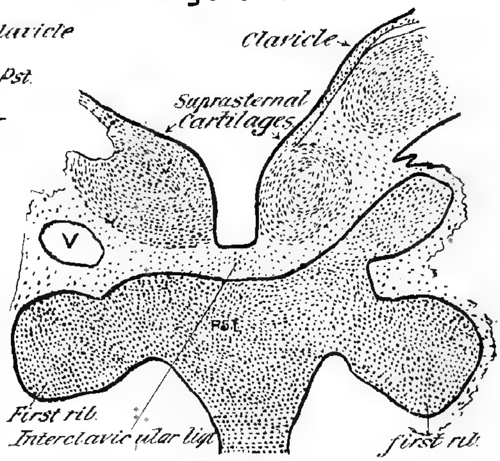


Figure 32



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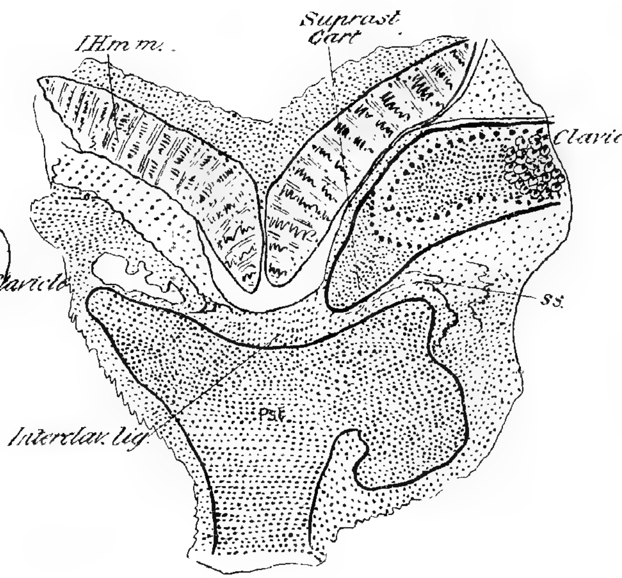


Figure 34.

Plate 5.

CONDITION AT BIRTH.

Centres present.	Centres absent.
96·7%	3·3%
99·2	0·8
99·2	0·8
83·3	16·7
71·0	29·0
91·9	8·1

DATE OF APPEARANCE

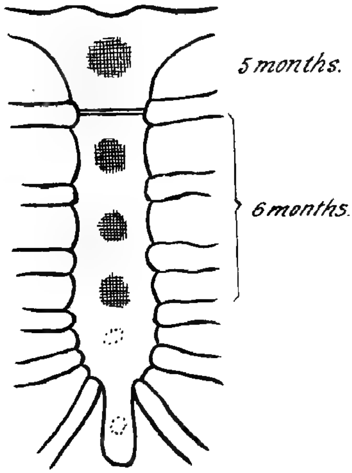
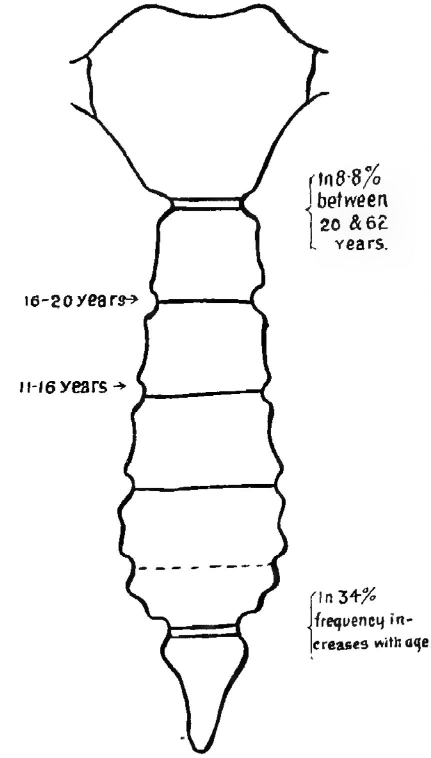


Figure 35.



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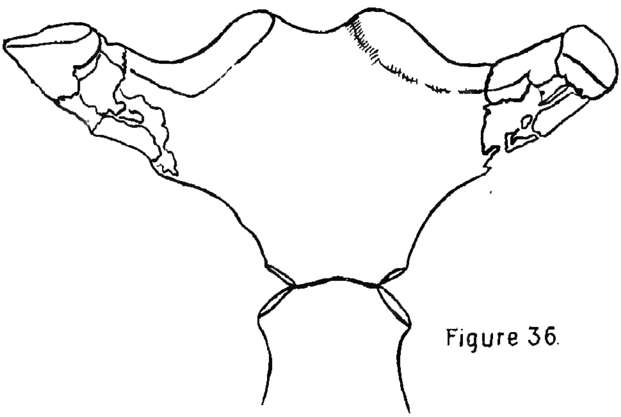

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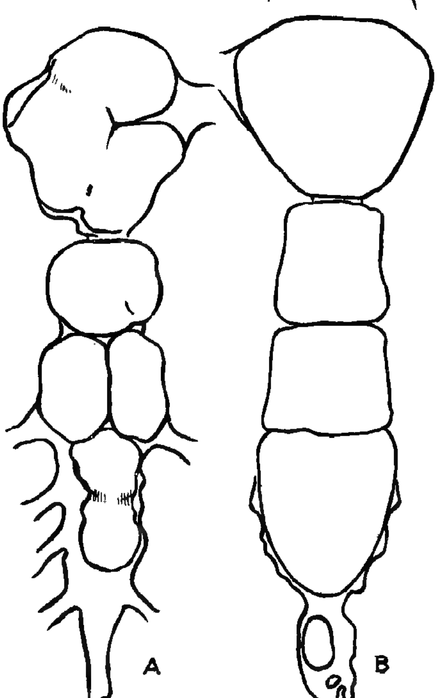

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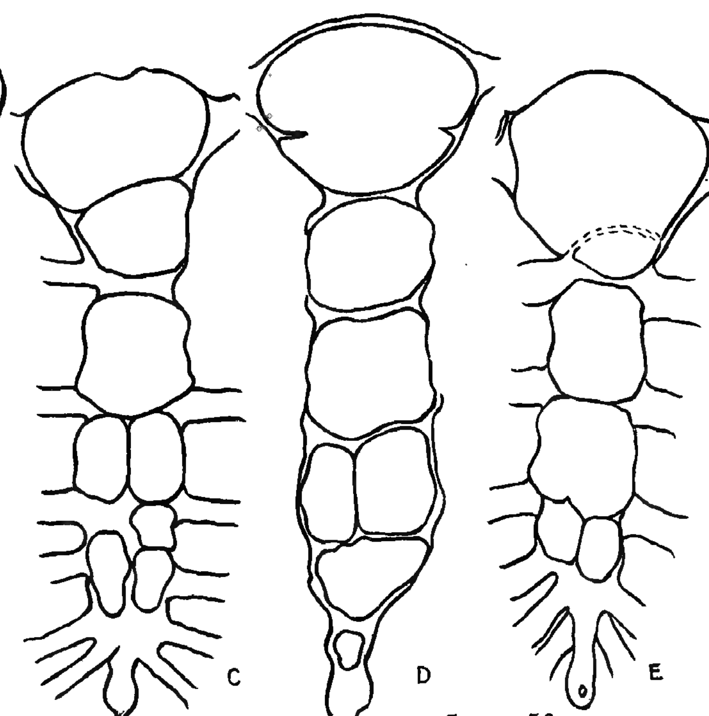
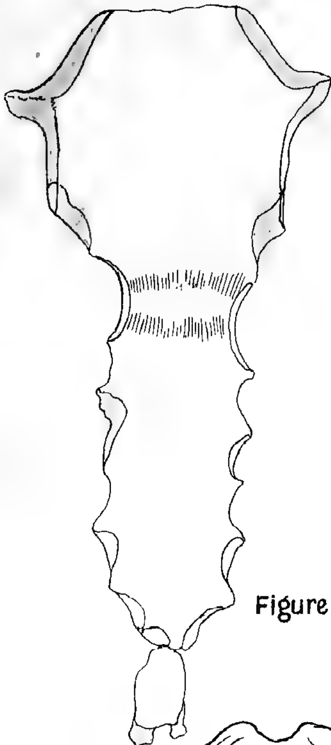


Figure 39.

PLATE 6.



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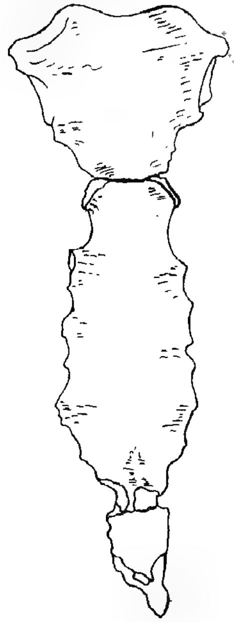
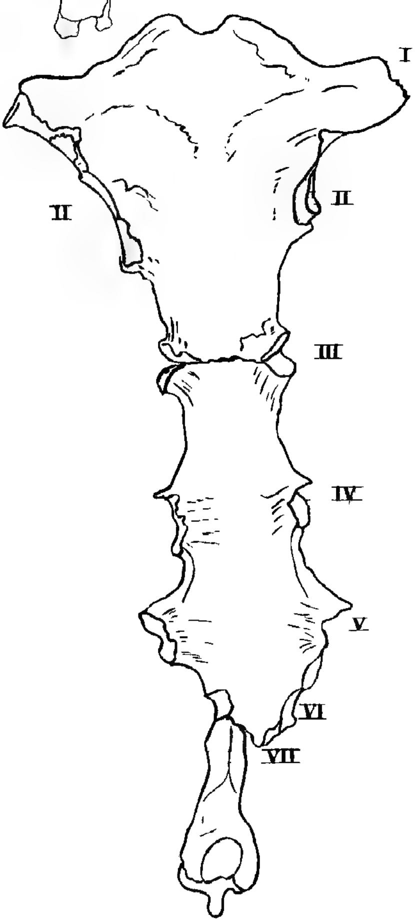


Figure 42 A.

Figure 42 B.



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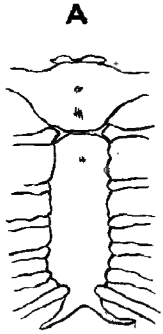

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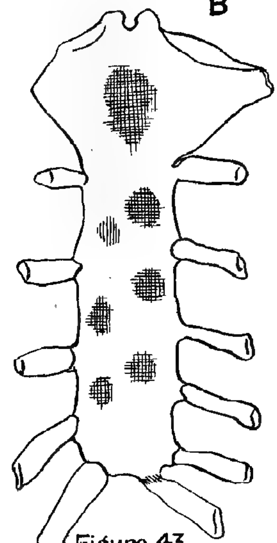

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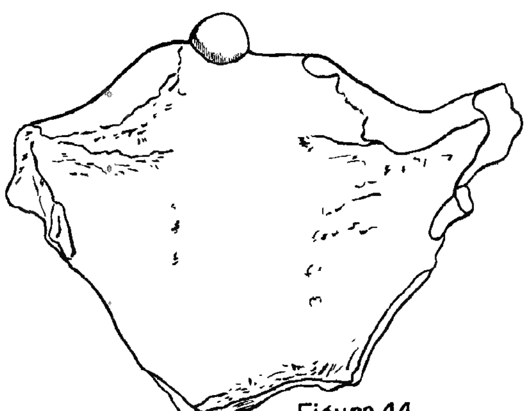
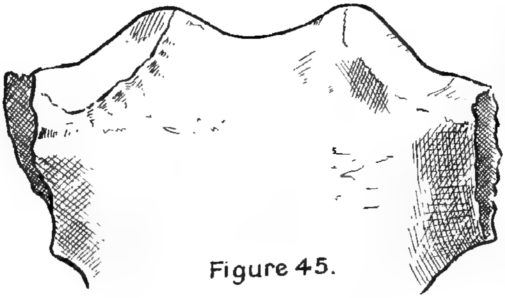


Figure 44.

Plate 7.



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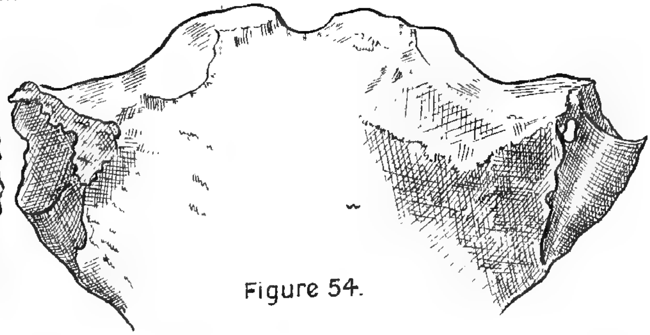

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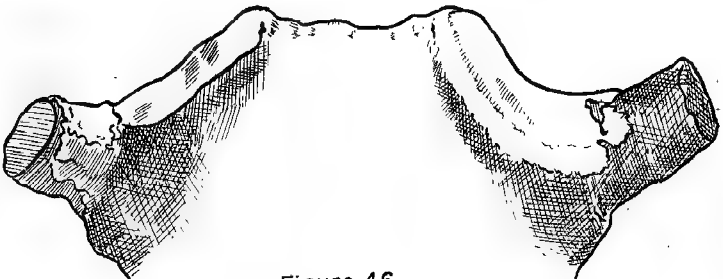

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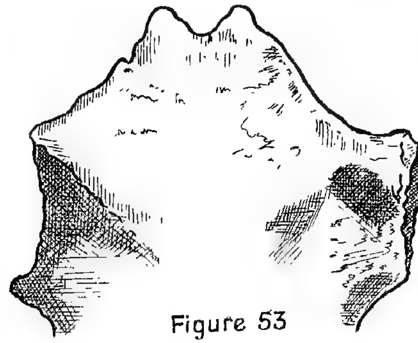
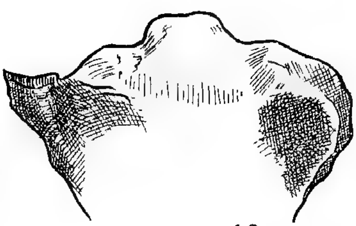


Figure 53

Figure 47.

Figure 52



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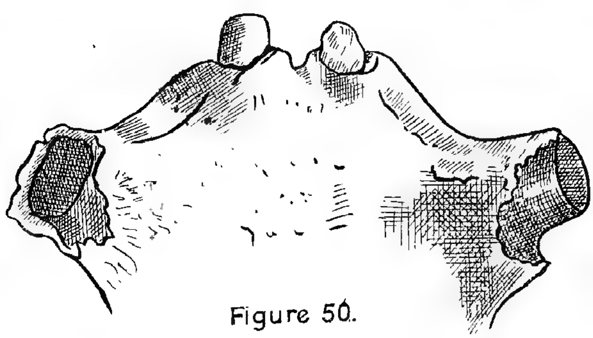

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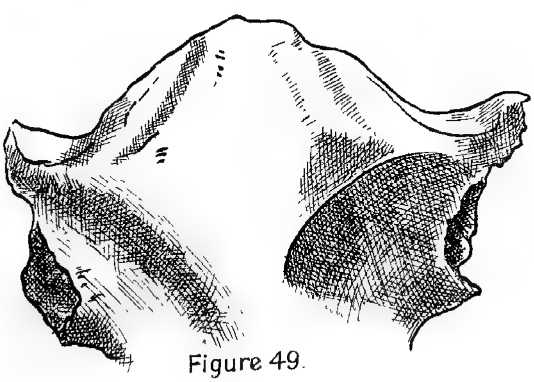

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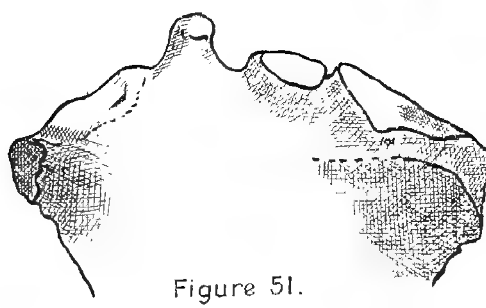
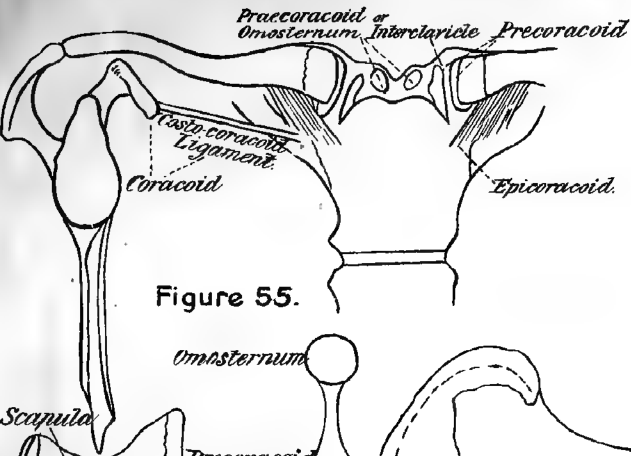


Figure 51.

PLATE 8.



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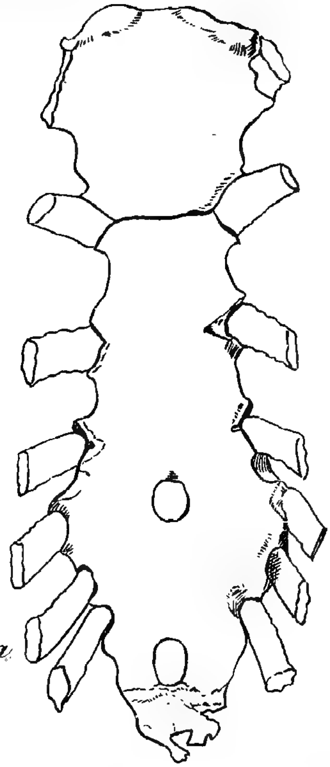

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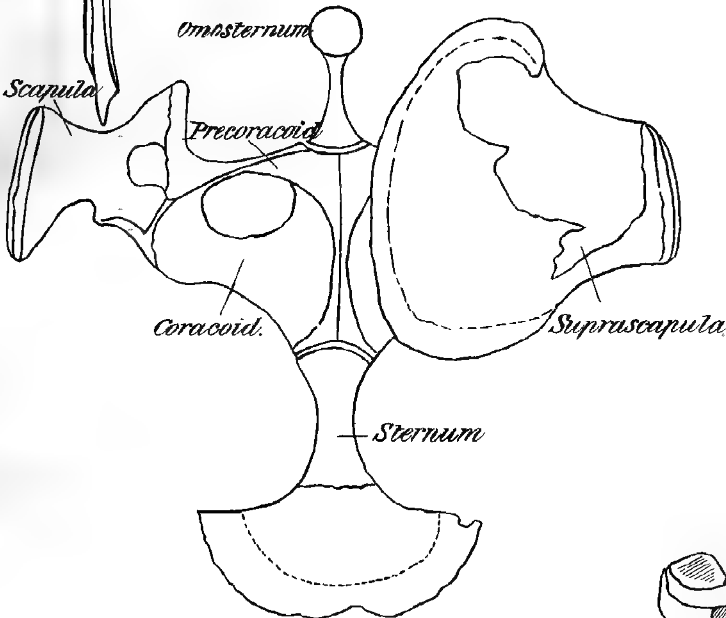

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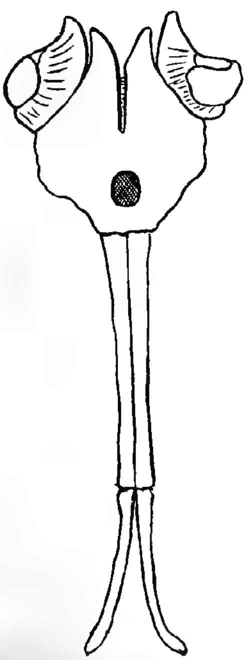

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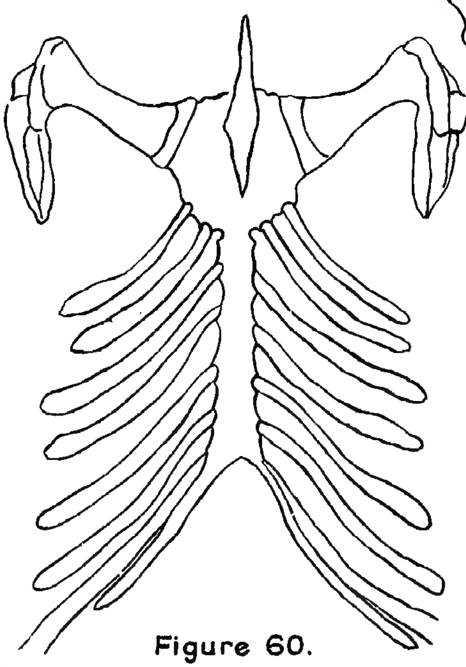

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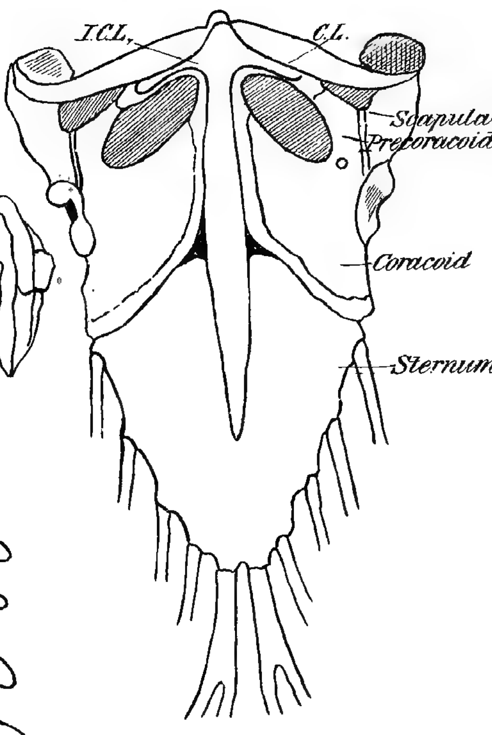

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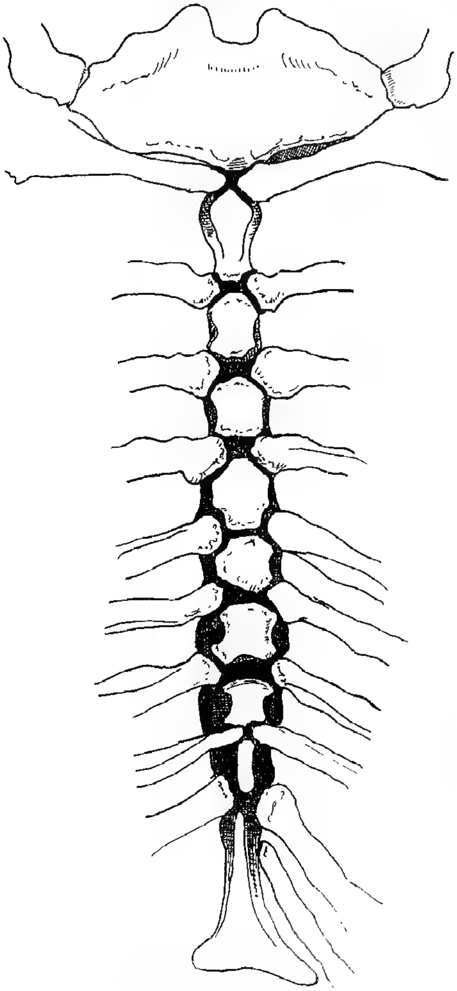

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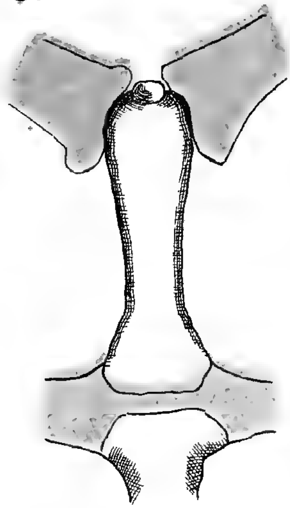

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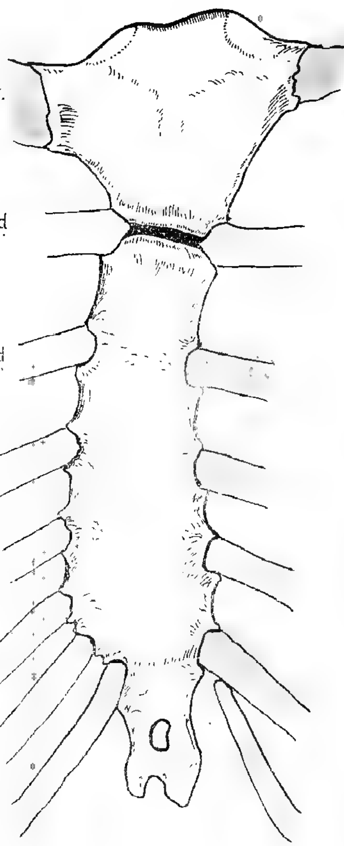

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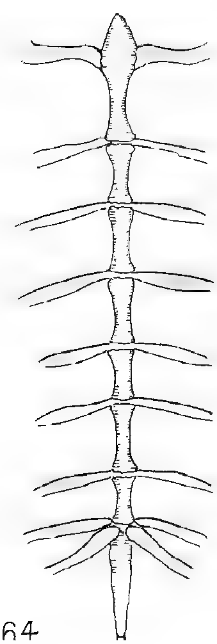
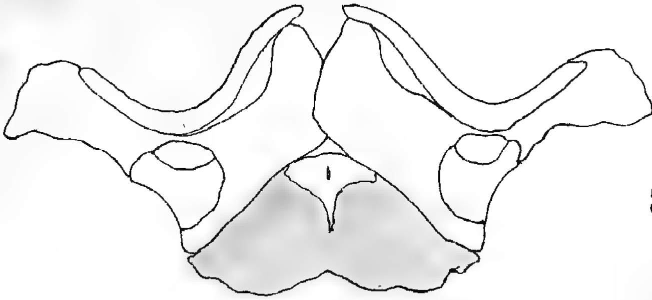


Figure 64

PLATE 10.



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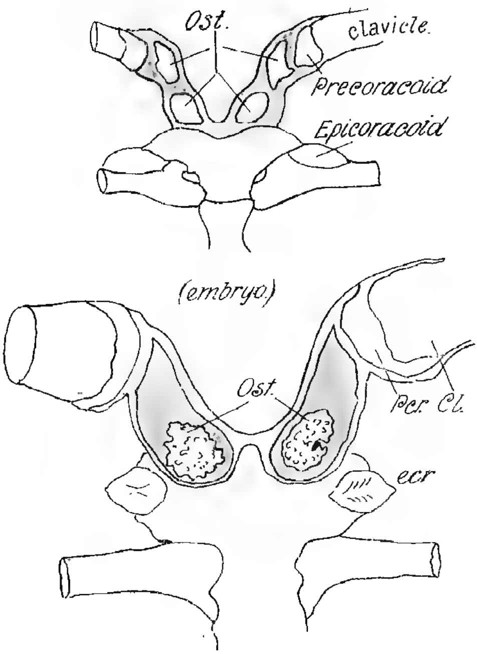

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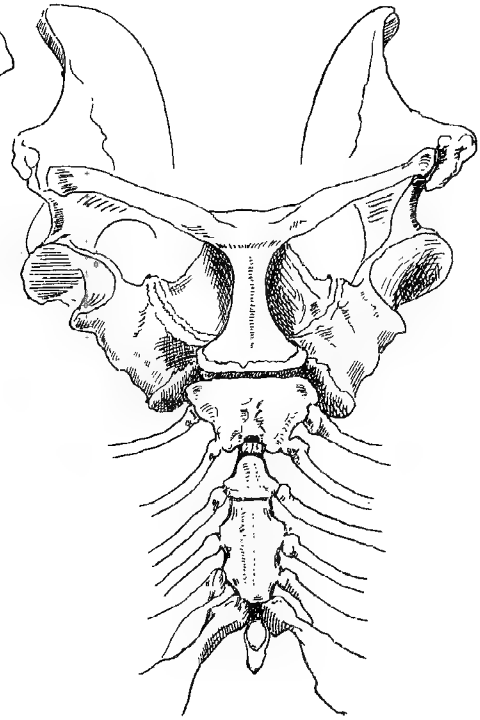

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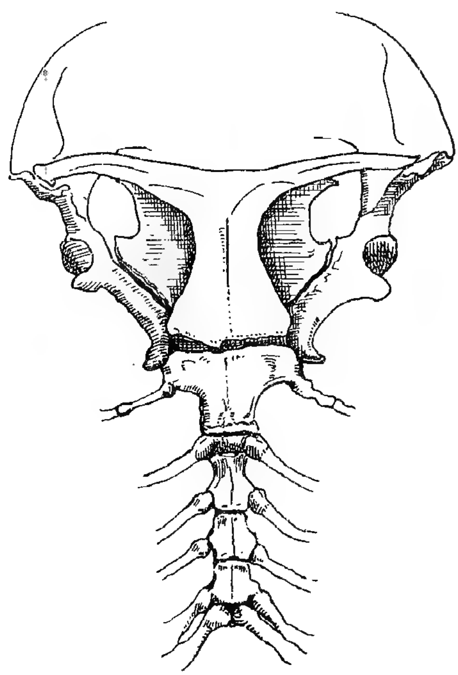

Figure 69.