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THE HUMAN STERNUM.

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by

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INTRODUCTION.

The thesis to be sustained in this monograph is that the human Sternum is in great part a costal derivative. Until recently this was the accepted view of the origin of the sternum, but lately Professor Cleland and Professor Paterson have opposed this hypothesis. The work connected with this paper was begun before the publication of Professor Paterson's preliminary communication in 1901 and the results obtained have been somewhat rearranged to meet his criticism as elaborated in his latest work published in June of this year.(1904)

It was originally intended to present a complete monograph on the Human Sternum but in view of the publication of Paterson's exhaustive work this has been deemed inadvisable as it would have entailed merely a considerable amount of unnecessary repetition.

No attempt therefore has been made to give an extended dissertation on the variations or comparative anatomy of the Sternum. Emphasis has been laid only on such points as were considered to have an essential bearing on the general question of the morphology of the human Sternum.

In the preparation of the paper I am greatly indebted to Principal Mackay of Dundee, Dr. Jas. F. Gemmell of Glasgow and Professor Young of Manchester for supplies of embryos.

I have also to acknowledge the kindness of Professor Young in painting the diagrams which are appended.

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PART I.

1. THE HUMAN STERNUM.

The sternum in the human adult subject is a plate of bone flattened from before backwards, placed longitudinally in the ventral mesial line of the thorax. On each side it is connected with the vertebral column by means of a series of more or less ossified bars (ribs), and with the scapula by the clavicle which articulates with its upper extremity. In its natural position an anterior surface looks forwards and upwards - a posterior backwards and downwards.

It is divided into three portions which are more or less distinct from one another.

a. Presternum or manubrium

b. Mesosternum, gladiolus or corpus sterni.

c. Metasternum xiphisternum or xiphoid or ensiform) Cartilage

These three portions may usually be recognised as separate parts up to middle life when, as a rule, the metasternum becomes ankylosed to the mesosternum. The ~~manubrium~~ presternum generally remains as a distinct bone up to advanced life.

In early life the ~~gladiolus~~ mesosternum consists of 4 segments which unite with one another between the 15th. and 30th - 35th years, so that on superficial examination the sternum would seem to consist of 6 segments. In a few rare cases two additional small separate bony nodules (supra-sternal bones) have been found lying above the ~~manubrium~~ presternum between the surfaces with which the clavicles articulate/

articulate.

PRESTERNUM. The presternum is quadrilateral in outline, but, from the fact that the superior border is considerably greater than the inferior, the bone assumes a somewhat triangular shape. It is the thickest and broadest part of the sternum.

ANTERIOR SURFACE The anterior surface is convex transversly and concave in the vertical direction. It presents in well marked bones a V shaped ridge representing the limits of origin of the Pectorales Majores.

POSTERIOR SURFACE. The posterior surface is smooth and somewhat concave in the vertical direction, plane in the transverse.

SUPERIOR BORDER. The superior border is the thickest of the four borders. It is marked by three notches - two lateral and one median. The two lateral notches - the clavicular - carry articular surfaces which are somewhat oval in shape, concave from side to side, convex from before backwards and directed upwards backwards and outwards.

The median notch is known under the various names - suprasternal notch or depression, episternal notch, presternal notch, incisura semilunaris, interclavicular notch, furcula, incisura jugularis, fourchette, etc., and is for the greater part subcutaneous.

INFERIOR BORDER. The inferior border is straight, and articulates by a rough oval surface with the mesosternum.

LATERAL BORDERS. Each lateral border presents at its upper part a rough elongated triangular surface for the attachment of /

of the costal cartilage of the 1st. rib - and at the inferior extremity a demifacet for the costal cartilage of the 2nd. rib.

Between the two the border slopes downwards and inwards and forms a boundary of the 1st. intercostal space.

MESOSTERNUM. The mesosternum is a long narrow bone which is broader below than above.

ANTERIOR SURFACE. The anterior surface is directed upwards and forwards and is nearly flat. It is crossed however by three transverse ridges, the surfaces between which are slightly concave from above downwards and flat or slightly convex from side to side. At the junction of the 3rd and 4th pieces (the widest part of the mesosternum) a foramen - the foramen sternale - is sometimes present.

POSTERIOR SURFACE. The posterior surface is concave both longitudinally and transversly, and is comparatively smooth. It is crossed by three faint ridges corresponding to those on the anterior surface.

LATERAL BORDERS. Each lateral margin is marked by 4 complete and 2 demifacets for articulation with costal cartilages. The upper demifacet joins with that on the presternum to form a single articular surface for the 2nd costal cartilage. The lower demifacet, with a corresponding demifacet on the metasternum, forms the articular surface for the 7th costal cartilage.

The intervals between the costal articular surfaces decrease in size from above downwards.

Interval between	2nd.	and	3rd.	about 1"
"	"	5th.	and 6th.	" $\frac{1}{8}$"
"	"	6th.	and 7th.	" $\frac{1}{4}$" to $\frac{1}{8}$"

The/

The non-articular portions of the lateral margins form a series of curved notches which bound the corresponding intercostal spaces.

The transverse ridges crossing the mesosternum are associated with the articular facets for the 3rd. 4th and 5th costal cartilages - each ridge extending from the centre of one facet to the centre of the corresponding facet on the opposite side.

SUPERIOR BORDER. The superior border presents an oval rough surface for articulation with the presternum.

INFERIOR BORDER. The inferior border is narrower and articulates or is fused with the metasternum.

METASTERNUM. The metasternum is a thin, spatula like process, which lies at the bottom of an infrasternal depression formed by the approach of the 7th costal cartilages.

Its posterior surface is continuous with that of the mesosternum, but, in the majority of cases, its anterior surface is in a deeper plane than the anterior surface of the mesosternum. In form the metasternum presents many variations. It may be entirely cartilaginous, entirely osseous, or partly cartilaginous, partly osseous. It may be bent backwards or forwards, deflected to one or other side, perforated or bifid. It is connected above to the mesosternum, below to the linea alba.

STRUCTURE of STERNUM. The sternum is composed of delicate cancellated tissue, covered by a layer of compact bone which is thickest at the superior border of the presternum.

2. STERNAL ARTICULATIONS.

The sternum articulates on each side with the clavicle, and, in the majority of cases, with the first seven costal cartilages. In addition the three pieces of the sternum in early life present distinct inter-articulations.

STERNO-CLAVICULAR ARTICULATION.

Ligaments :- Anterior Sterno-Clavicular
Posterior Sterno-Clavicular
Interclavicular
Costo Clavicular
Interarticular fibro plate.

Anterior Sterno-Clavicular ligament. This ligament constitutes a broad fibrous band running downwards and inwards - attached above to the anterior border of the articular surface on the sternal end of the clavicle, and below to the upper part of the anterior surface of the presternum.

Posterior Sterno-Clavicular ligament. This band runs downwards and inwards from the posterior border of the articular surface on the sternal end of the clavicle to the posterior surface of the upper portion of the presternum.

Interclavicular ligament. The inter-clavicular ligament extends between the apices of the articular surfaces on the sternal ends of the clavicles - crossing the interclavicular notch on the upper border of the presternum. It is attached by some fibres to this notch, and the manner of its attachment varies somewhat. In some cases the fibres of attachment form a continuous sheet

passing/

passing down to the anterior aspect of the presternum. In other cases this sheet is replaced by two separate bands each of which passes down on the anterior aspect of the presternum. In a third form, the fibres of attachment are confined to a single median band also passing down to an attachment on the anterior surface of the presternum.

Costo-Clavicular ligament. This ligament is attached below to the upper and inner portion of the cartilage of the 1st. rib and passes obliquely upwards, outwards and backwards to be attached to the rhomboid impression on the lower surface of the sternal end of the clavicle.

Interarticular Fibro-plate. In outline the inter fibro plate is somewhat circular. It is not of uniform thickness, being thickest behind and above, thinning gradually from this to its centre and expanding again slightly to its anterior inferior aspect. It is attached above to the apex and posterior border of the articular surface on the clavicle - and below to the sternum at the angle of junction of the first costal cartilage with the presternum. It has also an attachment by its circumference to the ligaments encircling the joint - the most important being a definite attachment to the inter-clavicular ligament.

CHONDRO-STERNAL ARTICULATIONS. The costal cartilage of the 1st rib, in practically all cases, is directly continuous with the presternum forming a synarthrodial articulation.

The articulations of the remaining 6 cartilages are of an arthrodial/

arthrodial type.

The following ligaments are similar in all:-

Anterior Chondrosternal.

Posterior do.

Capsular

Anterior Chondro-Sternal ligament. The fibres of this ligament radiate inwards in a fan shaped manner from the anterior surface of the inner end of the costal cartilage to the anterior surface of the sternum. Each ligament forms a broad thin membranous sheet which interlaces with its fellow of the opposite side, with the corresponding ligaments above and below, and with the tendinous fibres of origin of the Pectoralis Major.

Posterior Chondro Sternal ligament. This ligament is similar in appearance to the anterior, but is less distinct. It passes inwards from the posterior surface of the inner end of the costal cartilage to radiate on the posterior surface of the sternum where it is associated with the periosteum.

Capsular ligament. The capsular ligament, when separated from the anterior and posterior chondrosternal ligaments, is an exceedingly thin membrane surrounding the joint. It is usually however, slightly strengthened above and below exhibiting in these situations a structure more distinctly fibrous than elsewhere. The inferior band is usually the better developed.

In the articulations of the costal cartilages of the 2nd and 3rd ribs with the sternum, an additional ligament - the inter-articular/

interarticular - is developed.

Interarticular ligament. In the case of the 2nd. costal cartilage, the interarticular ligament is attached by one extremity to the middle of the articular surface of the rib cartilage, and by the other to the band of tissue - a continuation of that uniting the presternum with the mesosternum, - intervening between the demifacets.

The interarticular ligament associated with the 3rd. costal cartilage is attached to the line of junction between the 1st and 2nd pieces of the mesosternum. Occasionally in some of the other articulations an interarticular ligament is present.

CHONDRO-XIPHOID ARTICULATION.

Ligaments :- Anterior Chondro Xiphoid

Posterior Chondro - Xiphoid.

Anterior Chondro Xiphoid ligament. This ligament passes between the 7th costal cartilage and the metasternum in front. It has usually associated with it ligamentous fibres from the 6th costal cartilage and occasionally also from the 8th. The ligaments of opposite sides interlace with one another as they pass to their attachments on the metasternum.

Posterior Chondro Xiphoid ligament. This has a similar attachment on the posterior surfaces of these parts, but is usually feebly developed in comparison with the other.

INTER-STERNAL ARTICULATIONS.

1. The presternum may articulate with the mesosternum either/

either by an amphiarthrodial or by a true diarthrodial joint. The ligaments of the joint are anterior and posterior premesosternal ligaments, thin fibrous bands extending between the two bones.

2. The mesosternum sometimes articulates with the metasternum by an amphiarthrodial joint, in relation to which are anterior and posterior ligaments intimately associated with the periosteum.

3. OSSIFICATION of the STERNUM.

1. Development of Centres:-

Presternum. The presternum usually ossifies by a single centre which appears before birth, at about the 6th month. The number of ossific centres is however subject to considerable variation, but the arrangement of the accessory centres will be fully considered in dealing with the morphology of this part.

Mesosternum. The mesosternum is ossified generally from 7 or 8 centres. The first of these appears above the 3rd rib usually between the 7th and 8th months of foetal life, although a centre has been noted in the 6th month. Following this centre three pairs appear between the attachments of the lower true ribs. The upper pair make their appearance from the 6th to the 8th months, while the middle pair appear about the 9th month. The lowest pair are not developed till the 8th or 10 th month after birth.

Metasternum. The metasternum ossifies from a single centre which is exceedingly variable in the time of its appearance. Professor Cleland[12] has recorded a case in which it was present at the 2nd year, but it may occasionally not appear until the 18th year or later.

2. Completion after birth. The further development of the mesosternum is associated with a fusion of the various centres. The two lateral nuclei of each segment unite in the median line but their times of union are subject to so much variation that it is impossible to assign to them, with any degree of accuracy, definite dates of union. In a large majority of cases the ossific nuclei/

nuclei are single from the outset. At an early period then, the mesosternum consists of 4 separate bony segments. The gradual fusion of these with one another to form the single bony mesosternum is effected from below upwards. The lowest piece joins the 3rd about the 2nd or 3rd year, while the junction of the 1st and 2nd pieces is not effected until the age of 20 to 25 years.

In those cases where the metasternum presents, in early life, an articulation with the mesosternum a complete ankylosis usually takes place after middle life (40 - 50 years). The mesosternum rarely unites completely with the presternum although in old age (65 to 75 years) the fibrocartilage between them may become partially calcified or ossified. Two forms of joint are found connecting the pre - with the meso-sternum, viz. a diarthrodial and an amphiarthrodial form, the latter being the more common. According to Gray[25] the diarthrodial joint has no tendency to ossify at any age while the amphiarthrodial may ossify as early as the 34th year.

See plates XXXI, XXXII, XXXIII & XXXIV.

PART II.

1. VARIATIONS with SEX and AGE.

According to Hyrtl's[30] observations the presternum of the female exceeds half the length of the mesosternum, while, in the male, the mesosternum is at least twice as long as the presternum. From an examination of 200 sterna, Strauch[59] has confirmed this for the average of his series of measurements, but has found important exceptions. In the complete series, the presternum of the male was .007 cms. shorter than in the female, but, on the other hand, the mesosternum was 2 cms. longer - the measurements being 11 cms. (male) and 9 cms. (female).

In general he has found that the different parts of the male sternum are absolutely thicker and broader, but relatively thinner and narrower than in the female. When male and female sterna of equal lengths were taken it was observed that the male presternum was narrower than that of the female, and also, that the female mesosternum was broader in its lower part than that of the male.

Dwight[17], from observations made on 228 sterna, found that Hyrtl's[30] statement applied to the average measurements but as applied to individual cases it did not hold for 2 persons out of 5. The variations of the different parts were greater amongst men than women.

Various attempts have been made to establish a constant relationship between the length of the bone and the height of the individual. Korber[35], indeed, stated that such a constant relation-

relationship does exist, but Strauch[59] and Dwight[17] both disagree with this statement. Strauch[59], while giving the average relationship as $\frac{1}{7.78}$ in men and $\frac{1}{8.04}$ in women, admits that the individual variations were too pronounced to enable him to formulate any reliable law, and Dwight[17] in corroboration of this opinion, states that, in a series of cases examined, while the female sternum was shorter in proportion to the body height than that of the male, it proved at the same time to be relatively smaller in the shorter than the taller women.

The changes which take place in age have already been noticed in association with the ossification of the sternum but to these may be added the observation of Dwight[17] that the several parts of the mesosternum unite later in the lower than in the higher races.

2. ASYMMETRY of the STERNUM.

Excluding simple cases of asymmetry due to curvature an asymmetrical condition of the sternum as a whole is of comparatively rare occurrence and is due, when present, usually to irregular ossification. A recent case published by Buchanan[6] may be quoted as an example of this condition. In this case - the sternum from a girl of 4½ years - the presternum was completely ossified, while the metasternum which measured 2" was cartilaginous, and had a small perforation. The mesosternum was composed of 3 transverse segments - the uppermost being single whilst the other two were double. On the posterior aspect, in the interval between the 1st and 2nd transverse segments of the mesosternum, two distinct osseous nuclei were developed. An interesting point was that the metasternum carried two facets placed close to one another. Asymmetry of the metasternum is the rule rather than the exception. A few of the peculiar forms met with are shown in the accompanying diagrams. (Plate I Figs 1 & 6)

3. ASYMMETRY of the COSTAL ATTACHMENTS.

a. Bifid ribs. The simplest form of variation in connection with the costal attachments is that associated with the presence of a bifid rib. The following cases from the dissecting rooms will indicate the forms of this variation.

Case 1. (fig 7) 7th rib from left side. From the upper border of the rib at a distance of $2\frac{1}{2}$" from the costo-chondral junction, a small flat plate of bone ($\frac{1}{2}$" long and $\frac{1}{2}$" broad at its base) projects upwards and inwards and terminates in a small bulbous extremity $\frac{1}{4}$" broad.

Case II. A small cartilaginous spike about 1" long was found projecting outwards from the left side of the mesosternum in the interval between the 3rd and 4th chondro sternal junctions.

Case III. (fig 8) 7th? rib from right side. The head neck and posterior third of the shaft of the rib are apparently normal. At the junction of the posterior with the middle third the rib widens out and at the junction of the middle and anterior thirds bifurcates. One limb (the upper) has a rounded extremity, the other is cupped apparently for the costal cartilage.

Case IV. (fig 9) 4th? rib of right side. The rib is single from the head to the angle but at the angle it rapidly widens out presenting the appearance of two distinct rib shafts joined by a thin lamella of bone. At a distance of 4" from the costo-chondral junction this lamella ceases and the separate rib shafts run forwards to the sternum. The extremities of both limbs are cupped apparently for costal cartilages.

Case V. (fig 10) 5th rib from left side. The rib begins to widen from the junction of its posterior and middle thirds, the appearance being that of an expansion from its upper border. At a distance of 2½" from the costo chondral junction a distinct bifurcation is effected and each of the limbs is provided with a costal cartilage. The two costal cartilages, however, are separate for a small distance only. They rapidly approach and fuse, so that a single cartilage unites the bifurcated rib with the mesosternum.

Case VI. (fig 11) This specimen - 1st rib from right side - presents a bifidity at its vertebral attachment. It is a museum specimen and from its appearance seems to be the result of fusion of a 7th cervical with a 1st thoracic rib - but there is no history of the original connections of the rib.

Case VII. (fig 12) 5th. left rib. Close to and involving the costo-chondral junction the rib shaft widens, and its vertical diameter is increased to almost twice the size of the other portions by the addition of an extra portion at the upper border of the shaft. The supero-external angle of this additional part is prolonged into a bony spike projecting outwards along the thoracic wall. From the tip of the spike a fibrous band stretches to be attached in the vicinity of a small projection from the upper border of the rib shaft. The upper border of the rib, the bony spike and the fibrous band form the boundaries of an oval space the long diameter of which measures about 2". This space is filled by a fibrous membrane on the anterior surface of which are some muscular fibres, derived from the intercostals, and extending across between the superior and inferior boundaries of the/

the space.

b. Articulation of the ribs with the presternum. In a communication to the Academy of Science Bologna (April 26, 1899) D'Ajutolo described 8 cases of true diarthrodial joints in the cartilage of the 1st. rib. These joints, which were complete with well developed articular cavities containing synovial fluid, occurred chiefly in the centre of the cartilage. As there was no history of fracture or other injury, D'Ajutolo has suggested that in some cases the costal cartilage may be formed in two parts which may fail to unite with one another leaving an articular cavity between them, or that in other cases the costal cartilage may fail to unite with the rib cartilage on the one hand or the cartilage of the sternum on the other. Anthony[3] found this joint present in 7 cases out of 66 while Tchaussow[62] recorded 19 examples from 80 cases. A variation which is comparatively rare is that in which the lateral border of the presternum is associated on each side with the complete ends of the 1st and 2nd costal cartilages and partly with the end of the costal cartilage of the 3rd rib. Dwight[18] has described a case showing a variety of this nature and has found two other recorded cases reported separately by Meckel[43] and by Turner.[65] Dwight[18] has related this variation to the arrangement which occurs with considerable regularity in Gibbons - notably in Hylobates lar and Hylobates leuciscus, the details of which are sufficiently shown in the accompanying diagrams (figs. 15 and 16).

In Dwight's[18] case the manubrium was apparently continued to the level of the 3rd costal cartilage. It narrowed down to that level at which it presented a strong transverse prominence.

At/

At the level of the 2nd. costal cartilages any inequality of the surface of the front of the presternum was only to be detected by careful inspection. An almost imperceptible thickening of bone could be detected by the finger but there was no other sign of suture. 8 sternal ribs were present on the right side, the 8th rib on the left side just failed to reach the sternum. The apparent manubrium formed nearly half the length of the bone.

In two cases of my series a somewhat similar variety was present and also in a foetal sternum of the 9th month. In the first of the two adult cases the appearance was so similar to that reported by Dwight as to require no special description.

The other specimen (fig 13) was obtained from the post mortem room and unfortunately no record was kept of the exact arrangement of the ribs, so that it is impossible to say definitely whether it should be referred to this variety, or whether to another type of variation in which a 7th cervical rib is present. The conditions were as follows:- On the left side 6 true ribs were present - on the right side 7. The tips of the 7th. left and the 8th right ribs just failed to reach the sternum although they were intimately bound to it by ligamentous tissue. The whole sternum including the metasternum measured $7\frac{1}{2}$". The presternum alone measured $2\frac{3}{8}$" a length which is considerably greater absolutely than that in any other sternum of the series, while the meso-sternum is correspondingly absolutely smaller ($2\frac{3}{8}$"). On the right side two complete cartilages and one half cartilage articulated with the lateral border of the presternum - on the left side one complete/

complete and one half cartilage. The complete cartilage on the left side was considerably broader than either of the two complete cartilages on the right side and gave the impression of a fusion of two cartilages. The 2nd right costal cartilage was fused with the presternum - no joint cavity intervening. A distinct articulation existed between the presternum and mesosternum. Judging from the great length of the presternum it seems probable that in this case the costal cartilages on the right side are those of the 1st, 2nd and 3rd thoracic ribs and that there has been a fusion of the presternum proper with the first segment of the mesosternum. In the case of the foetal sternum (fig 14) 7 ribs are attached on each side. There is no indication of any joint formation at the level of attachment of the 2nd ribs but at the level of the 3rd ribs the continuity of the sternal cartilage is broken by a fibrous septum involving the whole thickness of the cartilage and extending across between the ends of the 3rd ribs.

A third variation is that in which a 7th cervical rib is present wholly or in part, unilateral or bilateral. This condition has been reported frequently but has been most fully described by Albrecht[2] who found a 7th cervical rib complete on the right side and partially represented on the left side.

The main features in Albrecht's[2] case are these:- The 7th cervical rib on the right side ends ventrally in a well developed cartilage which in turn is attached by its ventral end to a well defined nodule of bone. This nodule articulates with a facet on the presternum between the clavicular articular surface and the surface of insertion of the first thoracic rib. The cervical rib

on/

on the left side is represented only by a dorsal and ventral portion - the intermediate portion being wanting. The ventral portion which is bony articulates, as in the case of the bony nodule on the right side, with the side of the presternum between the clavicular articular surface and the insertion of the 1st. thoracic rib.

c. Articulation of ribs with meso and meta-sternum. The following observations were made chiefly on material obtained in the dissecting room of University College, Dundee, supplemented by a large number of fresh specimens obtained through the kindness of Prof. Sutherland from the postmortem room of the Dundee Royal Infirmary.

In all 51 sterna were available for examination. The attachment of the ribs to the whole sternum in these was found to be as follows:-

	Right.	Left.
Six in	2	1
Seven in	43	43
Eight in	6	7

A considerable amount of attention has already been given to the occasional presence of an 8th true rib in man. The results obtained by recent authors may be tabulated for comparison:-

Number of cases	Number of sternal ribs expressed in percentages. Six R	Six L	Seven R	Seven L	Eight R	Eight L	Author.
30		-	90		10		HYRTL.[30]
70	1,4	1,4	78,6	91,5	20	7,1	CUNNINGHAM[14]
106	1,9	1,9	88,7	92,4	9,4	5,7	Collective Invest. Committee 1895-96[13]
24 (light skin)		-	90	90	10	10	TREDGOLD[64]
5 (dark skin)		-	40	40	60	60	
236		8	87,2		4,8		PATERSON[48]
51	4	2	84,3	84,3	11,7	13,7	LICKLEY.

Reasoning from their individual statistics, some authors have advanced theories to account for the position of the 8th sternal rib. The most important of these are the theories of Cunningham,[14] and Tredgold.[64] Cunningham,[14] from the fact that in his series the condition was most frequent in males and on the right side put forward the view that it was associated with right handedness in man. Tredgold[64] again was of opinion that the predominance of the condition on the right side was related to the greater development of the organs on that side - the additional sternal rib being of a protective nature.

In the extended series (522 cases) however it is apparent that the difference between the two sides is too slight to be explained on such general hypotheses and certainly the figures afford little evidence in support of either of the preceding theories.

The condition is interesting chiefly in view of the generally accepted opinion that a degeneration at the caudal end of the thorax is in progression. The number of sternal ribs varies greatly in the different mammalian orders but if we confine our attention/

attention to the order Primates we find that a diminution in the number of the sternal ribs takes place in fairly regular order from the lowest to the highest forms. Tredgold[64] and Keith[32] have each carefully investigated the arrangement of the ribs in monkeys and their results generally are in accordance.

STERNAL RIBS (THORACIC)

TREDGOLD:-[64]	General number	Eight present in
Lemuridae & Platyrhini	8 or more	
Cercopitheci and Macaci	8	
Chimpanzees	7 or more	54%
Gorillas	7	28%
Gibbons	7	18%
KEITH:-[32]		
Lemuridae, Platyrrhini and Cynocephali	8 or more	
Macaci	8	
Semnopitheci	7 or more	
Chimpanzees	7 or more	46%
Gibbons	7	14%
Gorillas	7	10%

In the Orang an 8th. sternal rib is present only in very rare cases. The 7th rib in man normally reaches the sternum but its mode of attachment is subject to considerable variation. The following are the conditions observed in the 51 cases examined:-

	Right	Left
7th rib has a lateral attachment to the metasternum	21	24
7th rib is attached in front of the metasternum	15	13
7th ribs are articulated with one another in front	12	12
7th ribs are fused with one another in front	1	1
7th ribs fail to reach the sternum	2	1
	51	51

From these figures it will be seen that in a large percentage of cases (56% right, 52% left) the 7th costal cartilages have an attachment distinctly anterior to the plane of the metasternum.

Further, in many cases, while there was a distinct articulation with the side of the metasternum, the greater part of the cartilaginous extremity of the rib was found in front of the metasternum, the articulation with the lateral facets being effected by a small dorsal projection. The articulationof the 7th rib with the side of the metasternum was, as a rule, most nearly perfect in those cases where 8 sternal ribs were present.

Two of the cases present important variations which are worthy of somewhat fuller description.

In the first case (fig 33) the 6th costal cartilages articulated above with the lower end of the mesosternum and in front with one another. The 7th cartilages articulated with the lower borders of the 6th cartilages and by their extremities with one another. The metasternum was not continuous with the mesosternum but was attached by ligaments to the dorsal surfaces of the 7th cartilages.

In the second case (fig 34) that of a badly developed girl of 18 - the mesosternum terminated at the level of insertion of the 5th ribs. The extremities of the 6th and 7th cartilages on/

on the left side were fused together; those on the right side were closely united by fibrous tissue.

The upper margins of the extremities of the 6th ribs on each side articulated above with the lower end of the mesosternum. The two secondary bars - one fibrous, the other cartilaginous, formed in the manner described, between the ends of the 6th and 7th ribs, were in apposition in the middle line across which they were joined by fibrous tissue. The metasternum in this case also, failed to join the mesosternum, and was attached by ligamentous tissue to the dorsal surfaces of the secondary bars formed by the ends of the 6th and 7th ribs.

These cases may be compared with one reported by Dwight[7] where the condition is thus described. "The body (of the sternum) as seen from the front, ends at the level of the insertion of the 4th pair of costal cartilages. The 5th pair are attached to its lower end. The 5th, 6th and 7th pairs of cartilages meet one another and their fellows of the opposite side forming a cartilaginous continuation of the sternum. Seen from behind the body appears a little longer, a thin layer of ossification extending down between the 5th cartilages. The ensiform cartilage was almost wholly cut away. What little is left contains no bone and appears to spring from the deep surface of the united costal cartilages."

While comparatively little attention has been given to the mode of articulation of the 7th rib in this relation, yet, in connection with other work on the anatomy of the sternum several observations have been made which are of interest. In a few of the textbooks/

textbooks mention is made of the facts, that the metasternum generally lies in a plane posterior to the anterior surface of the mesosternum, and, that the 7th ribs sometimes articulate with one another in front. Paterson[48] found from the examination of a large number (236) of foetal Sterna that the 7th costal cartilages articulated with one another in front in 14.4% of the cases. Again, Musgrove[45] has pointed out that a true articular cavity is frequently wanting in the case of the 7th chondro sternal articulation - its absence having been noted in 55% on the right side and 50% on the left in his series.

The 8th rib normally is in the condition of the most degenerate form of the 7th rib. It is subject to variation however, and when it comes into relation with the sternum may present one of the following forms.

1. The cartilages may articulate directly with the end of the mesosternum.
2. The cartilages of opposite sides may be fused with one another across the front of the metasternum.
3. The cartilages of opposite sides may articulate with one another in frpnt of the metasternum.
4. The cartilages may be attached to the sternum by ligamentous bands.

The condition of fusion of the 8th ribs in front of the metasternum is found normally in the Macaci and Cercopitheci - the articulation of the rib cartilages with one another in front, in the higher apes.

In connection with these observations emphasis may be laid

on/

on the fact that this series of fusions and interarticulations of the 7th ribs and of the 8th ribs invariably takes place in front of the metasternum. I have never met with any case, nor am I acquainted with any recorded case in which the metasternum was placed in front of the ventral extremities of the 7th or 8th ribs.

See Plates VI. VII Figs 17 to 32

d. Abdominal Ribs. (fig 40) Under the consideration of these variations an interesting case may be recorded in which the presence of cartilaginous nodules indicated an attempt at the formation of abdominal ribs. In this case 7 sternal ribs were present on each side. The 9th rib on either side extended as far forwards as the border of the sheath of the rectus. From the tip of each 10th costal cartilage a band of fibrous tissue extended to the linea semilunaris. Into this band was attached, above, the 9th internal intercostal muscle, while into it below, some fibres of the internal oblique muscle were inserted. About midway between the tip of the cartilage and the semilunar line there was found in the fibrous band of each side a small nodule of cartilage. The shape of the nodule  differed somewhat on the two sides - that on the right side (measuring 12 mm) being also slightly larger than that on the left (1 cm). On opening the sheath of the rectus it was found that one of the tendinous intersections of the muscle on each side corresponded closely with the fibrous bands. In the left intersection an extremely small nodule of cartilage was present. I have not been able to find any record of a case comparable with this one. There seems no reason to doubt that the nodules of cartilage present in the fibrous bands were rudiments of the/

the continuations of the 10th costal cartilages and might thus be referred to the type of abdominal ribs as found in the Crocodilia. At the same time it is well known that fibro-cartilaginous nodules may develop in connection with fibrous tissue in other parts of the body, but, from the bilateral symmetry of this condition and the presence of the nodule in the tendinous intersection of the rectus, the inference seems justifiable that the condition in this case is of morphological rather than pathological interest.

[illegible] it is covered by a membrane. Pater- [illegible] includes under this heading perforations in the meta- [illegible] gives the following results from an examination of 288 [illegible].

	Percentage.
[illegible] men in metasternum	28·8
[illegible] "	2·1
[illegible] men in mesosternum	3·3
[illegible] more foramina in the mesosternum [illegible] metasternum)	2·1
	30·5

4. STERNAL FORAMINA, FISSURA STERNI and FISSURA THORACIS.

These three conditions may be grouped together as presenting the feature in common of giving rise to more or less deficiency in the ventral wall of the thorax. The aetiology of the three conditions is not however the same.

a. Sternal Foramina. Foramina in the Sternum are of fairly frequent occurrence, the apertures vary greatly in size from a small foramen transmitting a minute artery, to a large opening into which the tip of the finger can be introduced. The foramen is almost constantly found at the junction of the 3rd and 4th pieces of the sternum and is a result of defective ossification. In the recent state it is covered by a membrane. Paterson[48] who includes under this heading perforations in the metasternum gives the following results from an examination of 236 cases.

	Per centage.
One foramen in metasternum	22·8
Two foramina "	2·1
One foramen in mesosternum	3·3
Two or more foramina (in the mesosternum and metasternum)	2·1
	30·5

b. Fissura Sterni is a condition produced by the failure - partial/

partial or complete - of the fusion of the two original cartilaginous bars out of which the sternum is formed; an exaggerated condition of this with displacement of one or both bars to some considerable distance from the middle line is known as fissura thoracis.

Examples of both conditions are shown in the accompanying diagrams taken from Foster's "Die Missbildungen des Menschen."

In fig. 35 is shown the thorax from an acephalic foetus. 10 ribs are present on each side and of these the upper 6 articulate with a sternal plate. The two sternal plates are completely separated from one another in the middle line.

Fig 36 is also from an acephalic foetus, but in this case the two sternal plates are attached at their upper extremities by a transverse connecting piece.

Fig. 37 Shows a fissured sternum from a 6 year old boy. Each sternal half consists of a continuous piece with no division into gladiolus and manubrium. These sternal plates are ossified in the greater part but the external lateral borders are still cartilaginous. The rib cartilages are continuous with this cartilaginous portion, no articular cavities being interposed. Seven ribs are thus joined up on each side. The clavicles lie on the upper borders of the sternal plates and are bound to them by ligamentous tissue - an articular cavity being absent here also.

Figs. 38 and 39 represent fissura thoracis. In Fig. 38 from a full time foetus the presternum is complete and to it are attached the 1st ribs. The succeeding 9 ribs on the left side are joined to one another by a cartilage which is continuous with the/

the presternum. On the right side the anterior extremities of the ribs have failed. The spine is curved to the right. Fig 39 represents a somewhat similar arrangement. In this case however the spinal curvature is to the left so that it is the right sternal half which is developed in the median line. 8 ribs are attached separately to its border, the other 4 by a single common piece. On the left side the 6 upper ribs are connected by a plate, but the lower 6 are free and sharply marked off.

5. SUPRASTERNAL BONES.

Two small osseous nodules present in a few cases, and situated on the superior border of the presternum between the clavicular articular surfaces, are known as suprasternal or episternal bones.

The following were the conditions found in a case from the dissecting room of University College, Dundee (Specimen shown at British Association Meeting, Glasgow 1901 by Principal Mackay) (Fig 41) Seven thoracic ribs articulated with each side of the sternum. Each 7th rib articulated with the facet at the junction of the mesosternum with the metasternum. The extremities of the 8th ribs lay in front of the metasternum and were in apposition with one another in the middle line. Ligamentous tissue bound them to one another, to the lower end of the mesosternum, and to the front of the metasternum. The metasternum was bifid, ossified for a considerable portion and ankylosed to the mesosternum. The pre-mesosternal joint was freely moveable, and in addition a joint was present between the first and second segments of the mesosternum. At the junction of the 3rd and 4th mesosternal segments a large sternal foramen was present. With the upper margin of the presternum between the clavicular articular surfaces two bones - about the size of large pisiform bones - articulated. The articular surfaces for these bones occupied the greater portion of the interclavicular notch, only a small central notch being non-articular. Each articular surface was oval in outline and nearly flat both from side to side and from before backwards.

The position of the bones is well shown in the accompanying radiogram$/

radiograms (fig 104). The bones were firmly held in position by ligaments. The interclavicular ligament occupied its usual position, stretching across between the sternal ends of the clavicles. From its deep surface a fibrous sheet passed down to the anterior surface of the presternum. This ligament was specially strengthened over the anterior surface of each of the bones, the whole ligament, therefore, presenting the appearance of two strong lateral bands with a thinner intervening portion. A thinner ligament passed down from the interclavicular ligament behind the bones to be attached to the posterior surface of the presternum. Traced outwards these ligaments were found to become associated with the Capsule of the sterno-clavicular articulation, and with the anterior and posterior sterno-clavicular ligaments.

The bones themselves were bound to one another by strong interosseous fibres, extending between their mesial surfaces across the middle line. In addition each bone was attached to the corresponding fibro-plate of the sterno-clavicular articulation by means of ligamentous bands passing downwards and outwards.

The presence of two cartilaginous nodules corresponding in position with these bones was also noted in another case. The sternum was taken from a girl of 18 whose general development was very defective. At the sides of the interclavicular notch were two distinct cartilaginous nodules - that on the right being the larger - each articulating with the upper margin of the presternum and connected to it by a capsule of fibrous tissue.

Although in the normal adult presternum these distinct free bones are seldom present yet in a proportion of sterna they are/

are represented by projections from the upper margin. Out of 563 sterna, Paterson[49] found in 43 cases, examples of the presence of lateral tubercles on the upper border of the presternum. These he has divided into four groups :-

1. 11 Cases of prominent bilateral tubercles.
2. 10 Cases where the projections are in the form of ridges separated by grooves or notches from the clavicular facets. 22 cases with distinct articular projections. (Fig 42)
3. Separate from or
4. Continuous with the clavicular articular surfaces, but forming part of the articular surface for the sternal end of the clavicle. (Fig(43)

Carwardine[9] in 1892 demonstrated to the anatomical society a series of specimens illustrating the condition and showed the relationship of these bones to the interclavicular ligament. The interclavicular ligament has already been described (page 5) but reference may again be made to the presence of the additional bands (suprasternal ligaments) which connect this ligament with (Fig 44) the interclavicular notch. It is within these ligaments that the suprasternal ossifications are found. Carwardine's[9] conclusions are as follows:- (1) That the suprasternal bones occur as ossifications in ligaments which are almost constantly present in the adult, though to a variable extent. (2) That the suprasternal bones may fuse with the sternum at an early period, being represented by tubercles with the ligaments attached to them. (3) That in other cases the suprasternal bones are incorporated with the sternum leaving the ligaments attached to the site of incorporation.

Carwardine/

Carwardine[9] also pointed out that when these bones occur in man they are accompanied by signs of incomplete ossification or development in other parts of the sternum. In both the cases described above this was evident - in the first case (fig 41) the sternal foramen marked the defect in ossification - in the second case (fig 34) the arrangement of the lowest sternal ribs showed a defective development. This observation is interesting in view of the fact that the presence of cartilaginous nodules in the interclavicular ligament of the foetus was pointed out by Principal Mackay (Brit. Assoc. 1901) in three cases of foetal sterna of the 7th month dissected by him. In the dissection of a considerable number of foetal sterna I have been unable to find these nodules of cartilage but have occasionally noticed in the interclavicular ligaments small thickenings of fibrous tissue which may be homologous with them. Here also may be noted Parker's[44] observation that the suprasternal bone is reduced to a ligamentous condition in some animals, particularly in rodents.

PART III.

1. THE COMPARATIVE ANATOMY of the STERNUM

Pisces. In fishes a costal sternum is not developed. In several forms a set of osseous plates of epidermal origin are developed in the ventral wall. This is very marked for example in the dory (*Zeus faber*), in which two rows of osseous plates are present along the under surface, but their dermal origin is sufficiently indicated by their superficial position.

In association with the pectoral fins a girdle is developed in both cartilaginous and bony fishes. The two sides of the arch meet in the ventral median line and are connected to one another usually by a ligamentous symphysis (Cod, etc.) although in the simplest forms they are quite continuous forming a single cartilaginous bar across the middle line, whilst in other forms the junction is effected by means of a dentate suture (Siluri and Platycephali (Owen[46])).

In one of the elasmobranchs (Notidanus) two cartilages, an anterior and a posterior, have been noted in the median ventral line, segmented off from the coracoids.

Amphibia (figs 47-49) With few exceptions (e.g. Proteus anguines) a sternum is present in amphibia. It appears in the form of a plate of cartilage or bone in the ventral median line - the shape of this plate however being subject to much variation. In the simplest forms (Siredon, Derotremata and Salamandrida) it is a small somewhat rhomboidal cartilaginous plate, the antero-lateral edges of which are grooved to receive the coracoids. For convenience/

convenience of classification, and without introducing any present inference, the skeletal parts lying in the ventral wall of the thorax - including the ventral portions of the shoulder girdle - may be grouped under the term "Sternal apparatus." The parts entering into the sternal apparatus in these forms are :-

(1) Coracoids

(2) Sternum

In the anura the sternal apparatus is very greatly modified in the direction of increase in its elements. The coracoid arch is now represented by three portions - coracoid, epicoracoid and precoracoid - and an additional element, the Clavicle, investing or partly replacing the pre-coracoid, is introduced. The sternum itself is divided into a series of parts so that the whole arrangement may be thus summarised :-

a.	Bilateral	1. Coracoid
		2. Epicoracoid
		3. Precoracoid with Clavicle
b.	Mesial.	4. Episternum
		5. Omosternum
		6. Sternum
		7. Hyposternum

As free ribs are absent the sternum is not associated with ribs in present day amphibia, although ribs connected with a ventral sternum were present in the fossil amphibia.

Reptilia. (figs. 50 & 53) A sternum is absent in Ophidia but/

but except in the case of amphisboena is represented in all the lacertilia. The typical form of the sternum is that of a rhomboidal plate, from the posterior angle of which a single or double backward prolongation passes into the abdominal wall. With the anterolateral borders of the rhomboidal plate the coracoids articulate. Two or three pairs of ribs are connected with the postero lateral margins. The succeeding ribs may be attached to the abdominal prolongations or behind these may be continued to meet those of the opposite side in the middle line, forming in this way complete loops across the wall of the abdomen (Gecko, Chamaeleon, etc) In Acontias Meleagris the sternum is represented by two triangular bars which lie near one another but fail to join.

The crocodilian sternum follows the same type as that of the lacertilia. The sternum again is rhomboidal in form and is composed of cartilage bone. Two pairs of sternal ribs articulate with its postero-lateral edges - the coracoids articulating with the antero-lateral. The posterior angle is prolonged backwards into a median plate which usually terminates by dividing into two divergent cornua. With the sides of this prolongation and its cornua 5 to 7 pairs of ribs articulate. In crocodilia there is also developed an abdominal sternum associated with a number of ventral ribs without dorsal portions. This abdominal sternum extends backwards in the mid ventral line of the abdomen to the pubis.

In lacertilia and crocodilia a long slender interclavicle lies in a groove on the middle of the ventral surface of the rhomboidal sternum. The interclavicle extends forwards, and either terminates anteriorly by diverging into two transverse limbs (crocodilia/

(crocodilia), or articulates with a small episternum which is associated with the clavicles (lacertilia).

The structures entering into the formation of the sternal apparatus in the higher reptiles may be grouped thus:-

a. Bilateral
   1. Precoracoid (with or without Clavicle)
   2. Epicoracoid
   3. Coracoid

b. Mesial Superficial
   4. Interclavicle
   5. Episternum

c. Mesial deep
   6. Rhomboidal Sternum
   7. Sternal Continuation (Single)
   8. Sternal Horns (bilateral)

In chelonia the sternum differs very greatly from the general reptilian type and is represented by a flat plastron which lies ventral to the coracoids.

Mammalia. In mammals the sternum is much modified throughout the separate forms. In general it may be said to consist of three portions.

1. Presternum
2. Mesosternum
3. Metasternum.

Only in the monotremata are separate coracoids, extending to the sternum, developed. In these forms also a large interclavicle associated with the clavicles is present. Traces of the interclavicle are also found in some of the marsupialia (fig 45) Small suprasternal nodules are present in South American Cavies, in/

in porcupines and other rodents, etc. (Wiedersheim). In the tapir a portion of the presternum commonly remains as a distinct ossification (Flower).

In a sternum from a brown bear (fig 46) in the museum of Owen's College, there is a distinct bony nodule on the anterior border of the presternum. This nodule in form resembles that in the kangaroo presternum but is without the small prolongation backwards on the ventral aspect.

The mesosternum usually consists of a series of segments the number of which bears a very intimate relationship to the number of sternal ribs. The metasternum is in a few instances absent but as a rule it takes the form of a small, partly bony, partly cartilaginous appendage, either single and median or bifid. It is most largely developed in the long tailed pangolin where it extends backwards as two cartilaginous processes about 9" long which are connected posteriorly with some rudimentary ribs.

See Plates XVII & XVIII Figs 54 - 62

OBSERVATIONS on DEVELOPMENT.

1. Newt embryo about 3 cms long (fig. 68)

In the series of sections the coracoids can be followed out and found to be well developed, overlapping in the mid-ventral line. The muscles are distinct from the general mesoblast.

The special section chosen is a transverse one taken through the body of the embryo at the level of the liver. The epithelial covering is composed of a single layer of cells except in the mid dorsal line and in the ventral wall where the cells are arranged in two, sometimes three rows. The whole of the ventral wall is covered in this manner, a basement layer of large round cells supporting a layer of small closely packed cells. The section passes through the region occupied by the sternum in the adult animal, postaxial to the overlapping of the coracoids. In the mid ventral line between the epithelium and the coelomic cavity a differentiated mass of mesoblast is present into which the muscles of the body wall are continued. This small mass consists chiefly of spindle shaped cells with elongated nuclei, the long axes of the cells and nuclei being parallel to the plane of the section. Followed outwards these nuclei are found to be similar to the nuclei of the muscular fibres, - followed inwards they become mixed with rounded nuclei (probably cut obliquely), but distinct elongated nuclei can be traced up to and across the mid ventral line.

2. Rabbit embryos. Examination of a series of embryos of 7,8,9, and 11 days, undertaken with a view to determine the earliest appearance of the sternum, was entirely negative; there was no/

no differentiation of the muscles or clavicles.

3. Rat embryos.

a. Rat embryo (A_6) 8 mm long (fig 69)-(fig 70)

The embryo was stained in bulk with borax carmine and cut in a series of transverse sections.

Traces of commencing muscle differentiation are present. The clavicles which are partly cartilaginous form a continuous bar of mesoblast across the ventral wall preaxial to the pericardial sac. Cartilage is developing also in the bodies and neural arches of the vertebrae and in the vertebral ends of the ribs. The ribs can be traced only to the sides of the dorsal aspect of the pericardium. The thin ventral wall of the pericardium appears somewhat denser than the surrounding tissues on account of the sparseness of the mesenchyme but there is no evidence of any prolongation into it from the conjoined clavicular masses.

b. Rat Embryo (A_{25}) 10 mm long (Fig 71)-(fig 72)

The embryo was stained in bulk with borax carmine and cut in a series of horizontal sections.

The muscles are becoming differentiated. The clavicles are still cartilaginous, and, as before, are continuous across the mid ventral line. This continuity however is not effected in the uniform manner of the earlier series. Each clavicle terminates in a rounded mass of cells close to the mid ventral line, and these two masses are joined with one another by a narrower band of looser texture. Connected with the clavicles is a plate of comparatively dense mesoblastic tissue. This plate is of triangular/

triangular form with its apex at the union of the clavicles. It extends over the ventral wall of the pericardium, reaching as far back as the diaphragm, where the cells composing it spread out into the general mesoblast of the abdominal wall, and laterally to the ends of the developing ribs. Examined under a higher power the masses in which the clavicles terminate are seen to have a concentric appearance, the cells being arranged in circular laminae. The ventral plate of mesoblast on the other hand is composed of lamellae running longitudinally - the lamellae separating to enclose the clavicular masses. Followed laterally the mesoblastic plate is found to be continuous with the intercostal mesoblast, which is becoming differentiated, between the developing ribs, into the intercostal muscles.

The first ribs on each side can be traced into the line along which the longitudinal lamellae are splitting to enclose the clavicular masses.

4. Mouse embryos. (fig. 75). The mouse embryos used were 1 cm long. They were stained in bulk with borax carmine. Some were cut in transverse section, the others in horizontal section.

The sections merely emphasise the points noted in connectionwith the second rat embryo. The ribs are somewhat better developed and can be traced into the ventro-lateral wall of the pericardiac space-joining the ventral plate of the mesoblast. The first ribs present cartilaginous expansions at their extremities as they join the ends of the clavicular masses.

5/

5. Guinea pig embryo. 2·5 cms. long (fig. 74) (Fig 75)

The embryo was cut in a series of transverse sections which were stained in haematoxylin and eosin.

The muscles are differentiated.

The bodies of the vertebrae and a considerable part of the neural arches consist of well formed cartilage. The clavicles also are cartilaginous almost to the mid-ventral line. Across this line they are joined with one another by a band of tissue which presents the characters of cartilage in an early stage of development. The ribs are composed of well developed cartilage cells for some considerable distance from their vertebral extremities. The tissue of their ventral extremities however is still in an early cartilaginous stage.

The sternal bars are present, and are also composed in their whole extent of this early cartilaginous tissue with which the ventral ends of the upper ribs are continuous. At their anterior ends the two bars are inseparable from one another and from the tissue between the ends of the clavicles. Behind their junction with the first ribs the bars diverge as they pass back in the ventral wall, so that they are widely separated at their caudal extremities. They are not of uniform texture - the tissue being most dense at the places where the rib ends become continuous with them. The end of the rib is directly continuous with the side of the sternal bar - there is no indication of the rib end passing on to the ventral aspect of the bar.

6/

6. Human Embryos.

a. The sternum was dissected out from an embryo 3·75 cms. in length - stained with haemalum and mounted entire (fig 18). The upper portion was unfortunately lost in dissection but the specimen shows the two sternal bars with 6 (? 2nd - 7th) rib cartilages attached to the right one and 5 (? 3rd - 7th) to the left. The sternal bars are in apposition as far as the interval between the 4th and 5th rib cartilages - the line of separation however being distinct. Below this level the bars diverge and separate from one another.

Viewing the sternum from its ventral aspect, the 2nd, 3rd and 4th ribs on the right side and the 3rd and 4th on the left are seen to be continuous with the sternal bars. The 5th ribs on each side, and the 6th rib on the right side, are expanded at their extremities, and extend inwards to be continuous with the sternal bars, which at this level are very narrow. The 7th rib cartilage on the right side extends into the substance of the bar almost as far as its mesial border. The two structures - rib cartilage and sternal bar are not however uniformly continuous. A layer of more deeply stained (denser) tissue serves to mark off, somewhat indistinctly, the extreme end of the rib cartilage.

The 6th and 7th cartilages of the left side are joined to one another by a cartilaginous bar forming a distinct loop of cartilage. The mesial border of the sternal bar oneach side extends a little further downwards (caudalwards) than the place of junction of the 7th rib cartilages.

On/

On deeper focussing the lower ribs (5th - 7th) are found to be lying on the ventral aspect of a band of mesoblast which stains deeply with the haematoxylin.

The band is well seen by viewing the dorsal aspect of the sternum. It is then found to extend below the level of the 7th ribs, narrowing and becoming less dense in texture as it passes into continuity with the muscular structures of the abdominal wall. This mesoblastic band from its well defined lateral limits and from its position cannot be confused with the pleura - neither does it compose the sternal bars as it extends outwards so as to lie behind the anterior ends of the intercostal spaces. The cartilages of the sternal bars are apparently formed in front of it and extend into it but are not formed from it.

b. Human embryo 4·5 cms. long. (fig 19)

The sternum was dissected out and mounted unstained.

Seven ribs are attached on the right side, eight on the left. The sternal bars are joined to one another as far down as the 4th ribs, but the line of original separation is still distinct. The first ribs on each side are continuous with the sternal bars; the separation between the rib ends and the sternal bars is distinct in the case of the other ribs. The 7th rib cartilage on the right side, and the 8th on the left, extend into their respective sternal bars almost up to the mesial borders. The lines of separation for these ribs are present therefore between the rib cartilages and the ends of the sternal bars. This separation is distinct on the right side, but indistinct on the left. Further, the 8th left rib/

rib cartilage presents a second line of separation corresponding in position to the lines of separation between the proserial ribs and the sternal bar. The appearance presented by this arrangement is that of a portion of the rib cartilage being segmented off to form part of the sternal bar.

The clavicles are ossified in great part and the sterno-clavicular articulations formed. The upper portion of the pre-sternum is marked off from the lower portion by a somewhat indistinct line of separation extending across at the level of the upper margins of the 1st ribs. The point where this line crosses the median line of separation forms the apex of a small triangle, the base of which is formed by the interclavicular border. This triangle is divided into two by the median line of junction of the sternal bars, the separation being accentuated by a small notch in the upper border of the presternum the result of an incomplete fusion of the bars at this part.

The two triangles, lying thus between the clavicular attachments, are composed of denser tissue than the remaining portion of the presternum, as indeed is the whole of this upper area.

c. Human embryo (fig 80) - length from vertex to coccyx 6 cms. - age from history, probably 3 months.

The sternum as before was dissected out, stained and mounted.

The sternal bars have fused with one another but the line of separation is still distinct. The 7th ribs on each side are attached to the lower ends of the sternal bars and to one another in the mid ventral line.

Summary/

Summary. The chief points to be emphasised in the above observations are:-

1. Before the appearance of the Sternum, a plate of mesoblast becomes differentiated in the ventral wall of the thorax. This plate is at first continuous with the intercostal mesoblast laterally, and is prolonged behind (postaxially) into the mesoblast of the abdominal wall and in front (preaxially) into the mesoblast of the neck behind the clavicles.

2. The tissue from which the clavicles are formed, while yet in an early cartilaginous state is continuous across the mid ventral line.

3. The first appearance of the sternum is in two lateral strips composed of this early cartilaginous tissue quite continuous with the rib ends which at this stage are also composed of early cartilage.

4. The sternal bars are at first continuous also with the early cartilaginous tissue which joins the clavicles across the mid-ventral line.

3. The COMPARATIVE EMBRYOLOGY of the STERNUM.

The following brief description of the comparative embryology of the sternum is taken chiefly from Balfour's "Comparative Embryology" and from Wiedersheim's "Comparative Anatomy." Where supplementary statements are given the author's name is appended.

Amphibia. In the lower amphibia where the shoulder girdle is of the simplest type the sternum is developed as a paired cartilaginous plate in the inscriptiones tendineæ of the rectus abdominis muscle. In higher forms (Triton and Rana) it arises as an unpaired structure. In the Anura the coracoids have become differentiated into the two transverse bars, coracoid and precoracoid, joined together by a longitudinal bar - the epicoracoid. The two pectoral girdles are brought into association with one another by the apposition of the epicoracoids. Two processes grow forward (Gœtte[24]) from the conjoined ends of the precoracoids (clavicles of Gœtte[24]) and epicoracoids, and unite in the middle line giving rise to the omosternum and episternum. The two processes sometimes overlap the epicoracoids behind, and fusing with them bind them together in the middle line. There are two views on the development of the sternum and hyposternum of these forms. According to one view (Gœtte[24]) the sternum and hyposternum grow backwards from the coraco-epicoracoid junction - while according to the other (Wiedersheim[66]), both the sternum and the hyposternum are formed in the inscriptiones tendineæ of the rectus abdominis/

abdominis.

Reptilia. The sternum in reptiles arises later than the ribs, and in connection with them as two lateral triangular bars. The hinder portions remain separate as the sternal horns. In Anguis fragilis where, in the adult form no ribs are in contact with the sternum, the sternum is at an early stage associated with the ribs, this association being afterwards lost (Gotte[24]).

The interclavicle of the reptiles is developed as a membrane bone in relation with the ends of the clavicles where these are present. It originally develops in two lateral halves which afterwards unite in the middle line. The chelonian plastron is developed independently of the ribs. It is an exoskeletal structure and is formed in a plane distinctly ventral to the ends of the clavicles and coracoids.

Aves et Mammalia. Rathke[52] showed that in birds, and in the pig, the sternum was formed later than the ribs and was developed in two lateral halves. These - at first distant from one another, although nearer in front than behind - gradually approach until they meet and finally fuse to form a single median plate. Rathke found also that the hinder portions of the sternum remained separate as the sternal horns.

Although Rathke[52] almost suggests that the sternum arises from the ribs, he does not give a definite opinion on the point. From his description however the sternum must develop in one of two ways:-

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1. It may develop in connection with the ribs and be secondarily segmented from them.

2. It may rise apart from the ribs and become associated secondarily with them. Parker[47], Gotte[24], Kolliker[33], Hoffman[27], and Ruge[56] all support this first view - at least for the greater part of the sternum. Bruch[7], Cleland[12], and Paterson[48] however incline to the second view.

Bruch[7] finds that in birds and mammals the sternum arises as two lateral cartilaginous bars which join with one another, first at their ends and afterwards in the middle. The cartilages of the sternal ribs arise, according to this author, as separate cartilaginous nuclei and join later, with the sternum on one hand, and the ribs on the other. Cleland[12], referring to the development of the human sternum states that, "the sternum is at first laid down in the form of two lateral strips at right angles to the tips of the costal cartilages. It is impossible however to refer these strips to prolongations from the costal tips. Judging from the appearance in the 3rd 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 6th and 7th costal cartilages meeting in the middle line."

Paterson[49] has described the first appearance of the Mammalian sternum as a median band of mesoblast. In this band develop the two lateral strips of cartilage, which at a later stage fuse, on the one hand with the costal tips, and on the other with one another.

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A secondary segmentation separates the ribs from the sternum to produce the adult form. Paterson[49] also holds the view of the origin of the metasternum in situ. and independent of the ribs. Goette[24] put forward two views as to the origin of the metasternum.

1. That it was a development (an outgrowth) from the lateral halves of the sternum.

2. That it originated in Situ.

Ruge[56] has found that the greater part of the presternum, the mesosternum and the metasternum arise from two lateral cartilaginous bars. These bars are developed on each side from the ends of the upper 9 cartilaginous ribs. The connections of the 8th and 9th ribs with the bars is afterwards lost but their ventral ends still remain to form the metasternum.

A portion of the presternum according to Ruge[56] is however formed independently of the ribs.

In the monotremata the interclavicle is developed as a membrane bone in association with the ends of the clavicles.

See plates XXIV • XXV Figs 81 to 88

PART IV.

1. THE MORPHOLOGY of the MESO- and METASTERNUM.

In dealing with the morphology of the meso- and metasternum there are two theories which have to be reviewed:-

1. That the sternum arises primarily from the ribs and loses its continuity with them later.

2. That the sternum arises apart from the ribs, unites with them in a secondary manner and finally becomes again separated from them.

These hypotheses may be modified according to the most recent views into the following:-

1. That the sternum is a costal structure.
2. That the sternum is developmentally associated with the shoulder girdle.
3. That the sternum arises independently of either the ribs or shoulder girdle.

The whole question may be investigated from each of the points elaborated in the preceding sections, namely:-

1. From observations made on the early development of the sternum.
2. From a consideration of the comparative anatomy of the sternum.
3. In the case of the human sternum from a study of the variations/

variations, including teratological conditions, which it occasionally presents.

1. Embryological. As has already been noted, Goette[24], and Ruge[56], from their researches, were led to the conclusion that the sternum was developed from the ribs - with which conclusion my own observations are in accord. The chief critics of this view are Cleland[12], and Paterson[49] - the former observer recording his criticism as a note in Cleland & Mackay's textbook - the latter in a series of papers summarised and elaborated in the lectures delivered before the Roy. Coll. of Surg. Eng. 1903. The observation of Cleland[12] will be better considered with the sternal variations. Paterson[49], in criticising Ruge's[56] work, quotes Minot's[44] suggestion, that observations on earlier forms were necessary before the conclusions arrived at could be supported. This objection, however, cannot be held applicable to Goette's[24] work - at least on reptiles and birds - and the plates of this latter observer are extremely difficult to explain by the second hypothesis. From these plates it is evident that, in reptiles, the ribs are essentially continuous with the sternum from the earliest stages. (Figs 81 & 82)

In my series of guinea pig embryos (page 43) it is seen that the ribs and sternal bars are continuous, even in the transition stage before the cartilage has become fully differentiated. Again in the human sterna, described above (pages 44 & 45), the expansions of the rib cartilages to join with those adjacent to form the sternal bars have been noticed. Paterson[49] finds that there is first differentiated in the mid-ventral line a strip of mesoblastic tissue in/

in which the cartilaginous sternal halves develop. This strip, connected above with the mesoblast in which the ventral extremities of the shoulder girdles are developing, had been pointed out by previous observers but its significance had not been discussed. A plate of mesoblast in the ventral thoracic wall has been shown to be present in all the embryos examined by me, but, as in the early stages its limits were less definite than those of the bands described by Paterson[49], I have attached to it a somewhat different significance to that given by this observer. Only in one case (Human embryo **a**) and that a comparatively late stage could this mesoblast be described as consisting of two distinct bands. The ends of the ribs were not joined to the sides of these but extended across their ventral aspects a relationship which may be observed in two diagrams (figs 76 and 77 from Paterson[49]) given by Paterson[49] but not explained by him.

This mesoblastic plate is found in cases where ribs are absent, and I have also noticed its presence in fishes at an early stage of development. In the later stages, in the fish, (a sternum being absent) the central portion of the plate is converted into the ventral longitudinal muscle, which extends along the whole length of the body wall to be attached to the coracoids, and continued onwards from there to the hyoid and mandibular apparatus. In ophidia the primitive condition is retained, the long ventral muscle being divided up into segments by short rib cartilages.

In the higher forms, where a sternum is developed, the plate does not undergo any further differentiation, but remains as a mass of/

of mesoblast, continued into the tissue in which are developing those muscles which represent in the higher forms the ventral longitudinal muscle of fishes, namely, the rectus abdominis and the muscles of the hyoidean and mandibular arches. Further, it may be noted, that in amphibia, where the change is first effected, the rectus abdominis is inserted into the dorsal aspect of the sternum, and that the sterno-hyoid muscles arise from the dorsal surfaces of the coracoid and clavicle.

In mammals, the rectus abdominis, by a series of secondary changes, comes to be inserted into the ventral surfaces of the rib arches, but its continuations upwards - the infrahyoid muscles - still take origin from the dorsal surface of the sternum. In addition, the tendinous intersections representing ribs are always associated chiefly with the ventral aspect of the rectus abdominis muscle, and are intimately adherent to the ventral wall of the muscle sheath. In my series of early human, guinea pig, rat and rabbit embryos, there is no trace of differentiation of the mesial mesoblastic structure until the differentiation of the muscles of the body wall has begun.

In the newt embryo, as described (page 40), the mesial mesoblastic plate is very distinctly differentiated, but at the same time its close connection with the muscles of the body wall is also clearly demonstrable. The fibres of the lateral muscles run into continuity with it, and the cells composing it are similar to those of the fibres. Briefly, the plate, in so far as it is directly related to the sternum, is an embryonic rudiment of the

paired/

paired ventral longitudinal muscle of fishes, and, like that structure, is in connection with the shoulder girdle. The mesoblast in which it is developing in the early mammalian forms is the mesoblast from which the ventrolateral musculature is forming, and the separation of the two lateral strips is merely a retention of the primitive form - the complete development of which is not carried out.

Throughout the whole series the band preserves its original relation to the sternal apparatus, lying dorsal to it - terminating in mammals apparently at its preaxial end in the developing shoulder girdle where the infrahyoid muscles continue the original muscle - and terminating postaxially by tapering gradually off into the general mesoblast of the body wall.

2. Comparative. It may be said that in practically every case where a sternum is present, ribs are associated with it. The most important exception to this is in the case of amphibia. Here, however, it must be borne in mind that the fossil amphibia were provided with ribs connected to the sternum. In present day amphibia free ribs are absent, and an abbreviation of the process of development has become necessary, but it is obviously unreasonable to infer that the sternum formed is, therefore, not a costal one. Similarly arguments as advanced by Paterson[49], and based, without special embryological examinations, on such examples as the Sirenia and Cetacea, in which the whole skeletal apparatus has undergone considerable modifications to adapt it to aquatic conditions, must be disregarded in such a general discussion.

The interesting form of the so-called sternum (plastron) of Chelonians is worthy of some consideration. The Chelonian plastron/

plastron is a dermal structure, as is also the greater part of the carapace, and it belongs therefore to the exoskeleton. It must be noticed, however, that the ribs and parts of the vertebrae, belonging to the endoskeleton, are fused with the carapace. The carapace, then, might be considered to consist at least in part, of a fusion of the two types of skeletal elements. It is necessary to consider the question, whether, in the same manner, the chelonian plastron is also a composite of the two elements. In the chelonian, the exoskeleton is the predominating factor, the endoskeleton taking a comparatively small part in the formation of the general skeleton. In the case of the other reptiles the position is reversed. The endoskeleton is now dominant, and the exoskeleton has almost completely disappeared. If any trace of it existed in the sternal apparatus it should be found occupying a position ventral to the costal sternum, - as in the chelonian, the plastron lies ventral to the ends of the clavicles and coracoids. In reptiles the episternum and the interclavicle are the only structures which correspond to this position. There is no evidence in the series of mammalian embryos examined, of any structure which might correspond to the plastron. In the embryos of the frog and newt the special thickening of the epidermis of the ventral wall may have some interest in this connection.

The sternum, as found in reptiles, birds, and mammals, may be explained by reference to the primary costal circle - the structure of which has been clearly enunciated by Cleland." In its simplest and earliest form this Circle is present as a band of tissue commencing in the mid-dorsal line, extending outwards between the mesoblastic somites, running ventralwards between the myocommata, and/

and terminating, after passing inwards between the segments of the ventral longitudinal mesoblastic band, in the midventral line. As the phylogenetic history of the band is traced, various modifications are found to be effected in it. Vertebrae develop from the adjacent halves of the mesoblastic somites, and, as an outgrowth from these, transverse processes and ribs grow between the myocommata, their terminations being seen well in the snake as a series of cartilages, marking off the segments of the ventral longitudinal muscle. With further development these ventral ends undergo an increase in growth, and give rise to a ventral median column corresponding to the vertebral column on the dorsal aspect. An important difference between the two columns must be noted. In the case of the dorsal column, the primitive segmentation has been replaced by a secondary one, but in the case of the ventral column, the primitive segmentation has been retained. The sternebrae are homologous therefore, not with the vertebrae but with the original somites. The original continuity in development of the vertebrae and rib arches has its counterpart in an original continuity of rib arches and sternebrae. In both instances a secondary change ~~has given~~ has given rise to joint cavities between the ends of the rib arches and the dorsal and ventral columns.

An early stage in the development of the ventral column is seen in the flattened expansions of the rib ends, which, in some reptiles (page 37) and in monotremes, meet to complete hoops round the abdominal wall.

3. Variations. From the preceding speculations it will be evident that, theoretically, the sternum should be a ventral longitudinal/

longitudinal bar extending along the whole length of the midventral line. In no form is such a sternum present. The sternum, as will be shown later (page 69), is modified to suit certain conditions of life, and the nearest approach we get to the complete condition is in the crocodile, where a sternum extends practically (Fig 89) between the anterior and posterior limb girdles. It is to be expected, therefore, that evidences of modification will be found at both ends of the sternum. Evidence has already been adduced to (page 21) show that, in the mammalian sternum, the degeneration at the caudal end is a progressive one. This being so we must expect to find that the metameric segmentation of the sternal column also has been disturbed at the caudal end. Such modifying factors would be sufficient to account for the fact of the absence of distinct segmentation of the sternum at the level of the lowest sternal ribs.

In opposition to this view it may be noted that Paterson[49] in discussing it characterises the statement that "they (the segments) have been lost in the process of evolution," as bare and meaningless. He prefers to regard the segmentation of the sternum as an independent (accidental) formation, designed merely to subserve certain functions in the animal economy, but it is exceedingly difficult to see that this explanation is more definite or more satisfactory.

In the case of the human sternum, facts have been brought forward (page 20a) to show that the 8th rib in man is a degenerated sternal rib, and that the 7th rib shows evidence of undergoing a similar degeneration. The fact that the series of changes related to this degeneration takes place invariably in front of the metasternum, and is associated with a fusion of the cartilages of the ribs/

ribs undergoing degeneration, may be used as evidence of the costal origin of the sternum. If, with Bruch[7] and Paterson[44], we regard the mesosternum and metasternum as median structures formed independently of the ribs, then, the advance of the 7th and 8th costal cartilages to the front of the metasternum must be regarded, either as indicating a tendency to an increase in the length of these ribs, or as a malformation produced by some constricting force applied to the trunk - as in Hyrtl's theory that it was brought about by tight lacing. The first of these inferences is disproved by the history of degeneration of the ribs throughout the order Primates, and the second by the frequent occurrence of the condition in both male and female adults, and in the foetus.

On the other hand, the facts all tend to corroborate Ruge's[56] view of the origin of the human sternum from the first 9 ribs. It has been seen that the sternum is developed from expansions of the rib cartilages. These undergo an increase in thickness in an antero-posterior direction, and Ruge has shown that, in the process of coalescence of the two sternal bars, the fusion takes place first dorsally, and gradually proceeds ventrally. If now the case of a rib undergoing degeneration be considered; the rib would in the first instance tend to dissociate itself from taking part in the formation of the sternum. The ventral portion being the last to unite would be the first to fail, but as degeneration proceeded the dorsal portion also would fail. The rib would therefore be reduced to the primitive condition already noted in the human embryonic sterna, and would reach to the middle line meeting its

fellow/

fellow there and fusing with it. This arrangement, at a still earlier stage, was that noted by Cleland[12] in the human embryo of the 3rd month, where he describes the 6th and 7th costal cartilages meeting in the middle line. The interest of these cases is further enhanced by comparing them with the three cases reported (Part II page 23), where, from developmental arrest, the sternum and ribs retained this primitive form up to adult life.

The separated rib cartilages would therefore, at first, be continuous with one another in front, but later the cartilaginous junction would give place to a fibrous one. These changes, it will be seen, correspond exactly with the conditions found in the case of the 7th and 8th ribs:-

1. The articulation of the rib end with the lateral facets on the meso - and metasternum.
2. The articulation by a dorsal projection with the lateral facets.
3. The fusion of the ribs in front of the metasternum.
4. The attachment of the rib to the sternum by fibrous tissue.
5. The attachment of the rib to the proserial rib. (figs 21 & 27)

In the case of the metasternum, the anterior extremity of the 9th rib, (or occasionally 8th and 9th), has been separated from the remainder of the rib. The ventral portion of it has failed, while the dorsal portion remains attached to the mesosternum forming the metasternum. The failure of the 8th rib, and sometimes even of the 7th, to take part in the formation of the sternum, does not usually interfere with the continuity of the meso and metasternum, but, when any of the higher ribs fail as in the cases described/

described (Part II pages 23 et seq), the metasternum becomes separated from the mesosternum. At the same time, a certain limited power of growth must not be denied to the sternal bars, this growth tending to connect the meso-and metasternum when the rib fails to contribute its quotum. This arrangement is met with constantly in teratological processes, where, if one element fails, the higher and lower naturally expand to meet one another.

Teratological Conditions. In fig (38) it will be seen that 9 ribs enter into the formation of the hemisternum, the metasternum being absent - a point in favour of Ruge's view. The most striking feature however of figs (38 & 39) is that, while the shoulder girdle in each case reaches to the midventral line, a hemisternum only is developed. On the other hand, in both cases, the hemisternum formed is in relation with the ribs which reach the ventral line.

In each case the separation of the ribs is associated with a spinal curvature. In the case represented in fig (38) the rib ends on the right side have been widely separated, and no attempt at the formation of a sternal bar is made. In the other case the upper ribs have formed a hemisternum, the lower ribs being widely separated from one another.

It is only by accepting the hypothesis of a costal sternum that such cases are capable of explanation. If the sternum is developed purely in association with the shoulder girdle, it is difficult to see why half of it should fail while the girdles are intact, and still more difficult to understand why a hemisternum should in one case, develop, independently of the shoulder girdles, in the body wall but still in association with the ends of the ribs.

2. The MORPHOLOGY of the PRESTERNUM.

As has been noted in the examination of the series of embryos, the developing sternum is, in its early stages, closely associated with the limb girdles. Further, in one of the human embryonic sterna it was shown that the upper portion of the presternum was separable from the lower portion - an observation made in a younger specimen by Ruge[56]. The presternum seems therefore to be derived from two sources - from the shoulder girdle and from the ribs. In the human subject, the shoulder girdle is very greatly modified from the much more complicated girdle found in reptiles, so that, in order to this discussion, the shoulder girdle in these forms must be considered.

The earliest appearance of a distinct coracoid element in the mid-ventral line is that found in the elasmobranch - Notidanus indicus. # In the lower amphibia the sternum is a separate element, the coracoids overlapping in the middle line and contributing no part to it. In the higher amphibia however, derivatives of the coracoids are again found in the midventral line. Thus, in the frog, the omosternum and episternum represent a cephalic prolongation from the coracoids, while the sternum proper is a caudal outgrowth from them (Gœtte[24]). The hyposternum of the frog is costal (Wiedersheim[66]) and homologous with the greater part of the mammalian sternum. Judging from the appearances in the course of development of the Mammalian sternum, it seems probable that, in Amphibians the precartilaginous stage the ribs may be continuous with the sternum.

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My own observations are not yet sufficient to enable me to make any definite statement on this point. In the reptile, the sternum, from its close association with the shoulder girdle in the earliest stages, probably receives a contribution from this source, but there is no separable portion in the later stages. In monotremes however, which conform closely to the same type, a separate bone (proosteon of Parker) between the epicoracoids probably represents the coracoid element. In reptiles two membrane bones, the episternum and interclavicle are present, but in monotremata, as will be sufficiently evident from figs 53 and 54, they are fused into a single bone known as the interclavicle. The interclavicle of reptiles lies ventral to the epicoracoids, and also extends along the ventral aspect of the rhomboidal sternum, but in monotremata this sternal extension has been lost (fig 54).

In the human presternum, the two small triangular portions described, (page 46) are probably the representatives of the derived part of the coracoids, i.e. they are homologous with the sternum of the frog and the proosteon of monotremes, structures to which Albrecht[2] has given the name "postomosternum". According to Sutton[60] the remains of the coracoids in the human sternum are as follows:-

Ventral end of Precoracoid = Interarticular fibro cartilage between clavicle and sternum and the so-called episternals.

Scapular end of predoracoid = Acromial interarticular fibro cartilage.

Coracoid = Coracoid and Costo-coracoid ligament

Interclavicular bone Lizards & monotremes = Interclavicular ligament.

The suprasternal bones however require further consider- (Figs 90 & 93)
ation. At first regarded by Breschet[6] as part of the 7th cervical rib they are now generally recognised as belonging to the shoulder girdle apparatus. In the case of the human subject where so much degeneration has taken place at the sternal end of the shoulder girdle it is difficult to define exactly the homologies of the different portions of the coracoid apparatus. The coracoid proper has degenerated into a ligament at its sternal end,- the precoracoid remains as a part of the clavicle and as the fibro ~~cartilage~~ plate in connection with the sterno clavicular joint. The interclavicular bone has also disappeared, its place being taken by a ligament. We should expect then to find that the epicoracoid also is reduced to a ligamentous condition, and, if the relationships of the lower forms are to be retained, the ligaments representing it should be found in a plane dorsal to the interclavicular. Such ligaments are those named suprasternal and described by Carwardine[4]. The projections from the upper border of the presternum to which these ligaments are attached are probably therefore to be regarded as rudiments of the epicoracoids. While this seems to me the most likely explanation of these projections, yet Principal Mackay's view may be here noted. He, regarding the occurrence of suprasternal nodules as probably constant at an early stage, thinks it probable that these projections are articular in nature for the reception of the suprasternal bones. When the bony nodules become detached as the separate suprasternal bones we find, as in the case described (Part II page 32) that they are closely associated with the sternal end of the clavicle and the sterno clavicular interarticular fibro-

~~cartilage~~ plate/

~~cartilage~~ plate. Sutton's[60] table might therefore be somewhat modified thus:-

Ventral end of Precoracoid	=	Interarticular fibroplate between Clavicle and sternum.
Scapular end of Precoracoid	=	Acromial interarticular fibroplate
Coracoid	=	Coracoid & costocoracoid ligament
Epicoracoid	=	Suprasternal ligaments and/or suprasternal bones.
Coracoid derivative	=	Part of presternum
Interclavicle of reptiles = Episternum) interclavicle of monotremes	=	Interclavicular ligament.

The coracoid part of the presternum then consists chiefly of the so called postomosternum together with an occasional part of the epicoracoids.

The greater portion of the presternum is derived from the cartilages of the first and second ribs, but there is a small area left between this portion and the coracoid portion still to account for. This small part is probably a derivative of the 7th cervical rib. Albrecht[2] has traced it upwards in the Mammalian series and has completed the demonstration by showing its relations in a case where a complete 7th cervical rib was present. (Figs 90 & 93)

The recognition of these elements in the presternum is of considerable importance in dealing with cases of irregular ossification of this bone. Albrecht[2] has shown that the sternal ends of the 7th cervical and 1st thoracic ribs may have separate centres of ossification so that by resolving the presternum into its component/

component parts, with one centre for each, there should be in all 10 primary centres. In addition to these 8 secondary centres may be recognised.

These centres are on each side as follows:- (figs 94-95-98)

I. Primary.

1. Postomosternum.
2. For sternal end of 7th cervical rib.
3. For sternal end of 1st thoracic rib.
4. For sternebra between 7th cervical and 1st thoracic ribs.
5. For sternebra between 1st and 2nd thoracic ribs.

II. Secondary.

6. Epiphysis for clavicular articular surface.
7. Epiphysis between pre - and mesosternum.
8. Epiphysis between halves of presternum.
9. Centre for epicoracoids.

In the great proportion od cases the primary centres are fused into a single centre of ossification for the presternum, but in some cases small additional centres are present. Several of the modifications are shown in the accompanying diagrams (figs 96 & 103)

SUMMARY of MORPHOLOGY.

1. The sternum as a whole is developed from two elements - one derived from the shoulder girdle, the other from the ribs.
2. The portion derived from the shoulder girdle forms only a small part of the presternum
3. The remaining portion of the presternum, together with the mesosternum and metasternum, is truly costal in its origin and is developed in the human subject from the first nine thoracic ribs, receiving an additional portion from the 7th cervical rib.
4. The metasternum is derived from the ventral extremities of the 9th (or 8th and 9th) ribs.
5. The segmentation of the mesosternum is homologous with the segmentation of the ventral longitudinal muscle and of the mesoblastic somites.

The RELATION of the FORM of the STERNUM to its FUNCTIONS.

The sternum in vertebrates subserves four functions :-

1. It acts as a defensive agent for the heart and great vessels.
2. It forms a median ventral support for the shoulder girdles.
3. It affords a fixed surface and also tends to fix the rib ends for the attachment of some of the anterior limb muscles.
4. It forms the ventral pillar for articulation with the ribs completing in this way a framework which can be moved as a whole in the actions of respiration.

In quadrupeds the sternum is separated into moveable segments to meet the conditions of locomotion.

In amphibia where a considerable part of the animal's existence is spent in water and where the heart is comparatively simple we find that a simple protective agent is all that is required. The lowest forms, provided with gills, are sufficiently served with a pair of overlapping coracoid processes with which is associated a single sternal cartilaginous plate.

In the frog the chief change is in the direction of further development of the forelimbs. To meet the required stronger pillar for support of the shoulder girdle and for muscular attachments the coracoid apparatus is called upon, the costal sternum retaining its simple form. The respiratory action is not in these forms

associated/

associated directly with thoracic movements, the air which passes into the lungs being swallowed.

In reptiles which move in comparatively shallow water or creep amongst stones on land a very direct call is made for a protective agency. We find therefore in these forms a sternal apparatus which extends from the neck backwards along the thoracic region and it may be also along the abdominal regions. In addition for respiratory purposes the rib arches are completely developed in the thoracic region. Whether resulting from this largely developed apparatus or partly a cause of it, both inspiration and expiration in these forms is a muscular act. The shoulder girdle is also strongly developed to protect the important underlying organs and this increase is reflected in the largely developed rhomboidal sternum.

In mammals all four sternal functions are directly required. The specialised functions of the shoulder muscles and of the abdominal muscles require the presence of a large comparatively stable area for muscular attachment. The respiratory movements also are directly associated with the thorax and arrangements are necessary so that inspiration and expiration may be muscular in their action. The erect posture peculiarly demands the presence of a strong stable sternum hence the broadening of the human sternum. At the same time the anterior limbs are not now used in locomotion but are highly specialised so that a single pillar subserves their requirements much more efficiently than the segmented sternum of the lower mammals would. In those mammals where the thorax is protected/

protected either by habit or by height, the sternum consists of a series of narrow, almost equal segments while in forms in which the thorax is liable to injury the presternum at least, and generally also the upper segments of the mesosternum protecting the great vessels are strongly developed. In these latter forms however the greater strength of the anterior extremities often associated (for digging, etc.) also has an influence in determining this greater development of the anterior portion of the sternum.

In the aquatic mammals the conditions determining the form of the sternum are altogether different from those of terrestrial mammals. The anterior limbs have lost their complicated functions hence a feebler musculature is sufficient and consequently a smaller area for muscular attachment is required. Also the respiration is of a modified type and does not demand the regular rapid movements seen in terrestrial mammals. Finally the fluid medium in which the animal lives removes the necessity for a strongly developed defensive agent so that but for the respiratory methods a return might be made in these forms to the fish type in which a sternum is completely wanting. (Figs 63 to 67)

See also Plates XV, XVI, XVII + XVIII.

B I B L I O G R A P H Y.

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DESCRIPTION OF PLATES.

Letters used.

C	=	Coracoid
C.C	=	Costal Cartilage
C.F	=	Clavicular Articular Surface
Ce.	=	Clavicle
D	=	Diaphragm
E	=	Epidermis
E C	=	Epicoracoid
E S	=	Episternum
F	=	Foramen
G	=	Glenoid Cavity
H	=	Heart
H S	=	Hyposternum
I C	=	Interclavicle
I.C.L.	=	Interclavicular ligament
I.O.A	=	Obliquis Internus abdominis
L	=	Liver
M	=	Muscle
M.P	=	Mesoblastic Plate
M.S.	=	Mesosternum
Mt S	=	Metasternum
O.S	=	Omosternum
P	=	Pericardium
Pr	=	Proosteon
P.C	=	Precoracoid
P.S.	=	Presternum
R	=	Rib.
R.A	=	Rectus Abdominis
S	=	Sternum

Letters used.

Sc	=	Scapula
S.B	=	Sternal Bar
S.C.	=	Sternal Continuation
S.Cd	=	Spinal Cord
S.H	=	Sternal Horn
S.S	=	Supra Sternal Bone
S.S.L	=	Suprasternal ligament
T	=	Tendon
T.I	=	Tendinous intersection
V.L.M	=	Ventral longitudinal muscle

PLATE I.

Figs. 1 - 6 — Six human metasterna to show the variations in form.

PLATES II & III

Bifid Ribs. — For Description see text.
Fig. 7 — See Page 15
Fig. 8 — See Page 15
Fig. 9 — See Page 15
Fig.10 — See Page 16
Fig. 11 — See Page 16
Fig.12 — See Page 16

PLATE IV.

For description see text
Fig.13 — See Page 18
Fig.14 — See Page 19

PLATE V.

After Dwight.
Fig.15 — Sternum of Hylobates lar
Fig.16 — Sternum of Hylobates Syndactylus

PLATE VI.

A series of diagrams to illustrate the modifications of the 7th and 8th ribs.

Figs.17-20 — After Tredgold, to show the variations of the 8th rib in primates.
Fig.17 — 8th Ribs fused in front of the sternum ((monkeys)
Fig.18. — 8th ribs partially fused with 7th ribs and joined by their extremities to one andther across the mid line either by ca rtilage or by fibrous tissue (apes)
Fig.19. — 8th ribs joined to 7th and to side of sternum by cartilage or by fibrous tissue (apes).
Fig.20 — Sternal attachment of 8th ribs lost or represented merely by a thin band of fibrous tissue; attachment to 7th ribs by fibrous tissue. (Man).
Fig.21-24 — Diagrams to illustrate the variations of the 7th rib in the human subject.
Fig.21. — 7th ribs fused with one another in front of the metasternum.

Fig./

Fig.22 — 7th ribs joined at their extremities by fibrous tissue in front of the metasternum.

Fig.23 — 7th ribs encroaching on the front of the metasternum.

Fig.24 — 7th ribs articulating with the lateral facets on the meso- and metasternum.

Figs.25-27 — Diagrams of transverse sections across the chondro - metasternal junctions to emphasise the relationship of the 7th ribs to the metasternum.

Fig.25 — Articulation of the 7th ribs with the sides of the metasternum.

Fig.26 — Approach of the 7th ribs on to the front of the metasternum - Articulation with the lateral facets on the metasternum by dorsal projections.

Fig.27 — Fusion of the 7th ribs across the front of the metasternum.

PLATE VII.

Fig.28 — Sternum from a foetus of the 9th month showing the extremities of the 7th rib lying on the anterior surface of the sternum.

Fig.29 — Posterior aspect of sternum shown in fig 28.

Fig.30 — Sternum from a young adult.
The articular cavities between the 4th, 5th, & 6th costal cartilages are shown. No synovial cavity is present in the 7th chondro-sternal articulation. The 7th ribs are bound by fibrous tissue to a small bony continuation of the meso-sternum on the front of the metasternum.

Fig.31 — Anterior aspect of sternum of young chimpanzee showing the fusion of the 8th ribs in front of the metasternum.

Fig.32 — Posterior aspect of sternum shown in fig.31.

PLATE VIII.

For description see text.

Fig.33 — See Page 23

Fig.34 — See page 23

PLATE IX.

Fissura Sterni & Fissura thoracés. The figures are copied from Foster's "Die Mássbéldungen des Menschen."
For description see text.

Fig.35 See page 29

Fig.36 See Page 29

Fig.37 See page 29

Fig.38 See Page 29

Fig.39 See page 30

PLATE X.

Fig.40 Anterior abdominal wall showing cartilaginous nodules in the fibrous continuations of the 10th ribs and in the tendinous intersection in the left rectus abdominis muscle.

For complete description see page 26

PLATE XI. Supra Sternal Bones.

Fig.41 The ligaments associated with the bones are shown somewhat diagramatically in order to demonstrate the different bands. For complete description see text page 31

PLATE XII.

Fig.42 Presternum showing bélateral projections from the sides of the interclavicular notch. On the right aide a small notch separates the projection from the clavicular articular surface - on the left side the division is made by the border of the clavicular articular surface. Both projections are rough with no articular surfaces.

PLATE XIII.

Fig.43 After Paterson.
On the upper border of the presternum between the clavicular articular surfaces a prominent ridge with a small median notch/

notch is shown. The clavicular articular surfaces are prolonged on to the sides of this at A.

Fig.44 After Carwardine.

Diagram showing the position of the suprasternal ligaments and their association with the interclavicular ligaments.

PLATE XIV.

Fig.45. Presternum of Kangaroo showing small nodule of bone (I.C.)on its cephalic angle.

Fig.46 Sternum of brown bear showing the presence of a somewhat similarly placed bony nodule.

PLATE XV.

Fig.47 After Wiedersheim
Sternum and shoulder girdle of Urodela.

Fig.48 After Wiedersheim.
Sternum and shoulder girdle of Bombinator igneus.

Fig.49 Sternum and shoulder girdle of Rana Esculenta.

PLATE XVI.

Fig.50 After Parker
Sternum and shoulder girdle of Anguis Fragilis

Fig.51 After Wiedersheim
Sternum and shoulder girdle of a Gecko (Hemidactylus Verrucosus).

Fig.52 After Owen
Shoulder girdle of Chelonia.

PLATE XVII

Fig.53 Sternum of a lacertilian (? species).

Fig.54 Sternum of Ornithorhyncus.

Fig.55 After Parker
Sternum of young Echidna Hystrix.

Fig.56 After Flower
Presternum of Ornithorhyncus to show Parker's proosteon (Pr.)

PLATE XVIII.

Fig.57 Sternum of pig. (Sus scrofa)

Fig.58 Sternum of dog. (Canis familiaris)

Fig.59 Sternum of mole. (Talpa Europaea

Figs 60-61 Presternum of Vulpes. (fox)

Fig.62 Presternum of Arabian Gazelle. (antilope)

PLATE XIX.

Figures taken from Flower.

Fig.63 Sternum of Greenland Whale (Balaena mysticetus)

Fig.64 Sternum of Pike Whale (Balaenoptera Rostrata)

Fig.65 Sternum of young dugong (Halicore indicus).

Fig.66 Sternum of Fin Whale (Balaenoptera Musculus)

Fig.67 Sternum of Cachalot (Physeter Macrocephalus)

PLATE XX.

Fig.68 Transverse section of newt-embryo.
For description see text page 40

Fig.69 Transverse section of rat embryo (A6)
For description see text page 41

PLATE XXI

Fig.70 Transverse section of rat embryo (A6)

This diagram represents under a higher power the portion of the section shown in fig 69 marked off by the lines A.A.

Fig.71 Horizontal section of rat embryo ($A_2$6)
For description see text page 41

a. is the concentric laminated mass into which the clavicles are continued.

b. is the mesoblastic plate of longitudinal lamellae splitting to enclose the concentric mass.

Fig.72 Horizontal section of rat embryo (A26)

This/

This diagram represents under a higher power the region of the splitting of the longitudinal lamellae on the concentric lamellae shown in Fig.71.

Fig.73 Horizontal section of mouse embryo. Section shows the continuity of the clavicular tissue across the mid neutral line - See text page 42

PLATE XXII

Figs 74 & 75 Transverse sections of guinea pig embryo. Fig.74 represents a section taken across the embryo a little anterior to that shown in fig 75.

Fig.74 Shows on one side (right) the rib end just fusing with the sternal bar - on the other side (left) the fusion is complete.

Fig.75 Shows the succeeding rib end approaching the sternal bar.

PLATE XXIII.

Figs.76-77 After Paterson
See Text page 54

Fig.78 Sternum from human embryo.
For description see text page 44

Fig.79 Sternum from human embryo
For description see text page 45

a. Denser triangular areas in upper portion of presternum.

Fig.80 Sternum from human faetus
For description see text page 46

PLATE XXIV.

Fig.81 After Goette
Developing sternum of Cnemidophorus.

Fig.82 After Goette
A later stage in the development of the sternum of Cnemidophorus.

Fig.83 After Goette
Developing sternum of Echidna.

Figs 84-85. Aft er Goette.
Two stages in the development of the presternum/

sternum of the mole shpwing the presence in the early stage (fig.84) of a mass a continuous with the clavicles and in the later stage (fig 85) the differentiation of this mass into a central portion a and two lateral portions a'.

Fig.86 After Ruge
Sternum from a human embryo to show the presence of two masses a of denser tissue in the upper ends of the sternal bars.

PLATE XXV.

Figures taken from Goette.

Fig.87 Development of the sternum in menopoma showing the close association of the sternal elements with the tendinous intersections in the ventral longitudinal muscle.

Fig.88 Developing sternum of Anguis Fragilis to show the attachment of the ribs to the sternum in an early stage of development.

PLATE XXVI.

Fig.89 After Owen.
Diagram represents a theoretical conception of a complete sternum in the crocodile.

PLATE XXVII. After Parker
The modifications of the interclavicular tissue.

Fig.90 Presternum of Mus Decumanus.
A single cartilaginous mass a is present between the clavicle and the presternum on each side.

Fig.91 Presternum of Arvicola Agrestis.
Two small cartilagenous masses a & a' are found on each side between the clavicles and presternum.

Fig.92 Presternum of Mycetes Seniculus.

Fig.93 Presternum of Mycetes Ursinus.
These figures (92 & 93) show the presence of a distinct pre-manubrium apparently related in part to the separate masses shown in the interclavicular tissue in the preceding figs. 90 & 91.

PLATE XXVIII

Fig.94 Diagram (after Albrecht) to show the type arrangement of the primary centres of ossification in the presternum.

1. Centre for left hemi-postomosternum
2. Centre for sternebra between 7th cervical and 1st thoracic ribs.
3. Centre for sternebra between 1st & 2nd thoracic ribs.
4. Centre for sternal portion of 7th left cervical rib.
5. Centre for sternal portion of 1st left thoracic rib.

Fig.95 Diagram(after Albrecht) on similar lines but with the mesial centres fused.

Fig.96 After Quain
Arrangement of the centres in a particular case.

Fig.97 After Rambaud et Renault.
Arrangement of the centres in a particular case.

Fig.98 Diagram (modified from Albrecht) to show the arrangement of the secondary centres of ossification for the presternum.

6. Centre for epiphysis on the left clavicular articular surface.
7. Centre for central epiphysis on left hemi-presternum.
8. Centre for caudal epiphysis on left hemi-presternum.
9. Centre for left epicoracoid.

PLATE XXIX. Figures from Albrecht.

Figs.99-103 To show some types of modification of the centres of ossification of the presternum

PLATE XXX.

Fig.104 Radiogram of presternum described at page 31 and shown in diagram fig.41 showing position of the suprasternal bones before any dissection of the ligaments was made.

PLATE XXXI

Figs 105-6 Radiograms of foetal human sterna of the 9th month to show position of centres of ossification.
In Fig. 106 a centre is present in the metasternum.

PLATE XXXII

Fig.107 Young human sternum (age ?).

Radiogram to show fusion of lowest centres in the mesosternum.

PLATE XXXIII

Fig.108 Young human sternum (age ?).

Radiogram to show extreme irregularity of centres in mesosternum - double centre in presternum.

PLATE XXXIV.

Fig.199. Young human sternum (age ?).

Radiogram to show bilateral centres in the mesosternum - apparent fusion of two centres in presternum.

PLATE I.

Fig. 1.

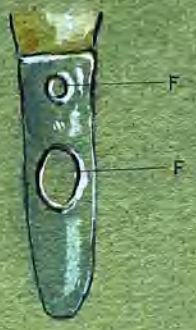


Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

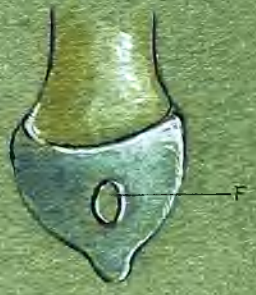


Fig. 6.

PLATE II.

Fig. 7.

Fig. 8.

Fig. 9.

PLATE III.

Fig. 10.

Fig. 11.

Fig. 12.

PLATE IV.

Fig. 13.

Fig 14.

PLATE V.

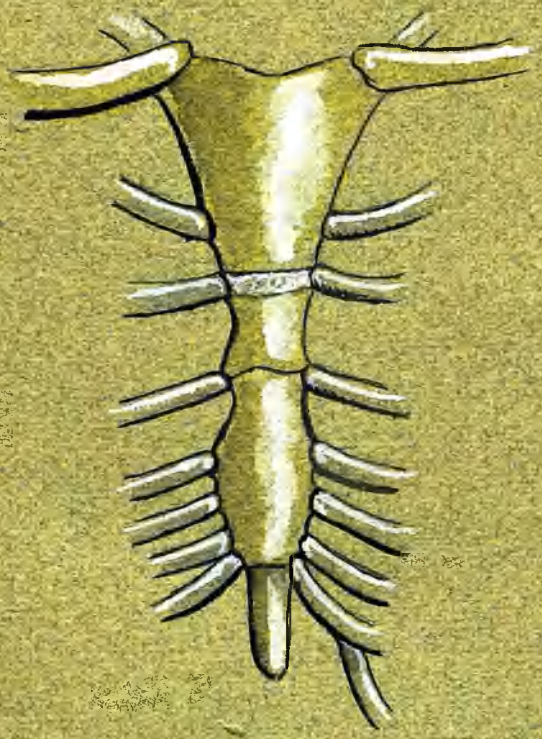


Fig 15.

Fig. 16.

PLATE VI

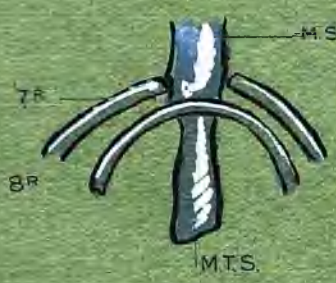
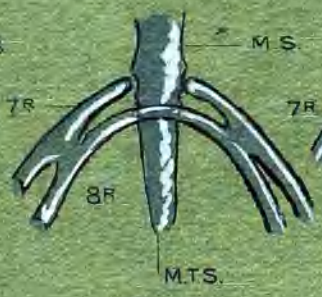


Fig 17.



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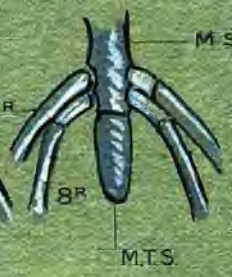


Fig 19.

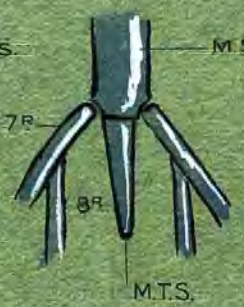


Fig 20.

Fig 21.

Fig 22.

Fig 23

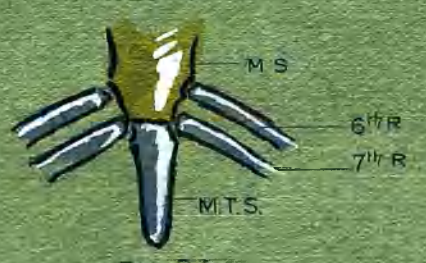


Fig 24.

Fig 25

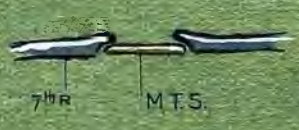


Fig 26.

Fig 27.

PLATE VII

Fig 28.

Fig 29.

Fig 30

Fig 31

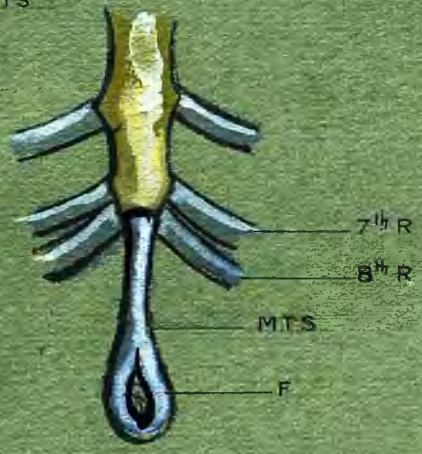


Fig 32.

PLATE VIII.

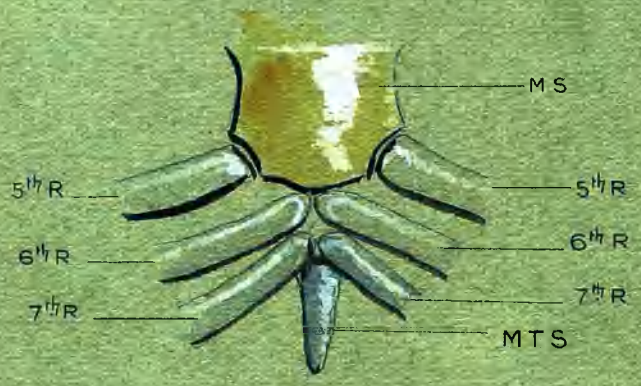


Fig 33.

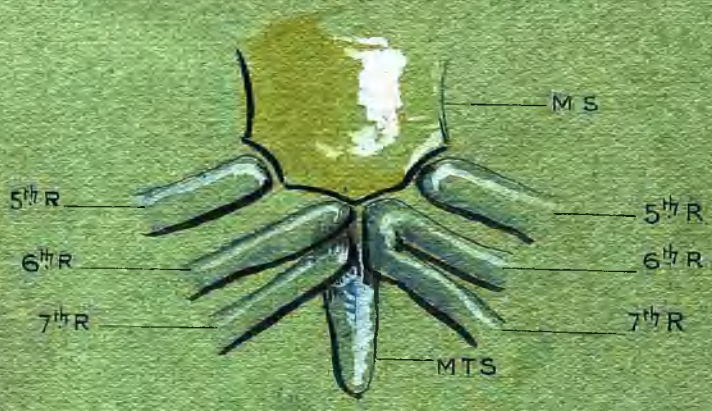


Fig 34

PLATE IX.

Fig 35.

Fig 36.

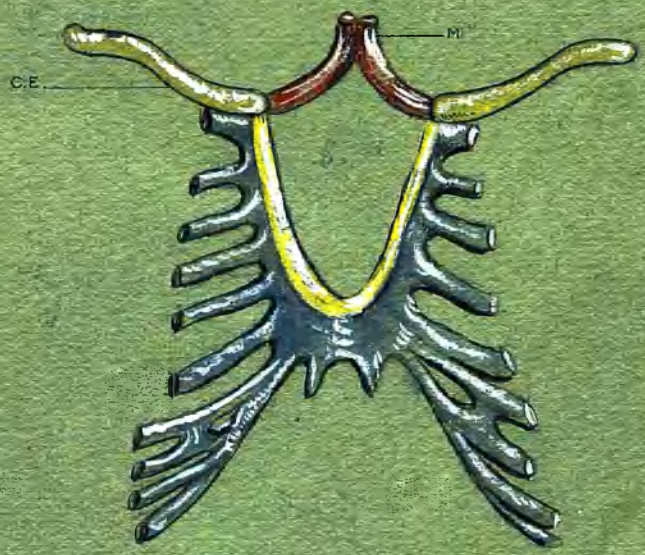


Fig 37.

Fig 38.

Fig 39.

PLATE X

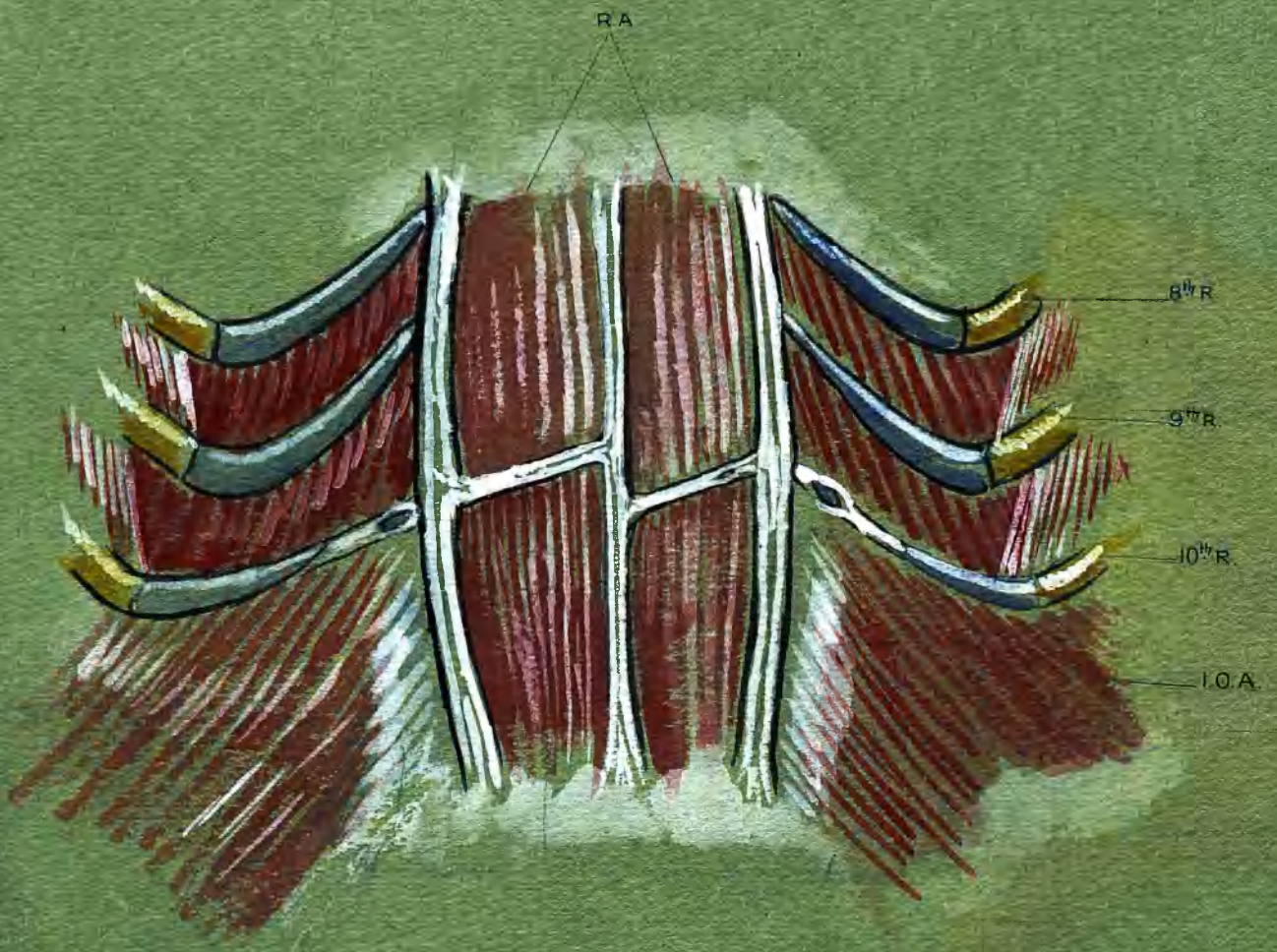


Fig 40.

PLATE XI.

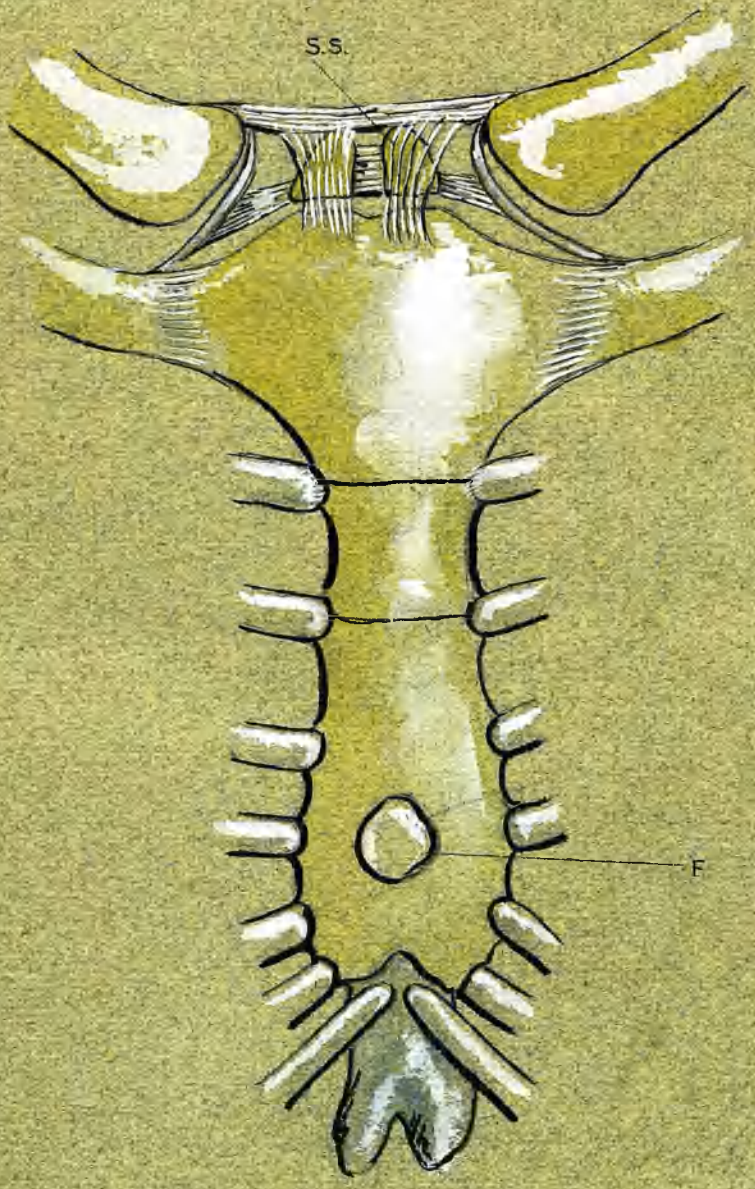


Fig. 41.

PLATE XII.

Fig. 42.

PLATE XIII.

Fig 43

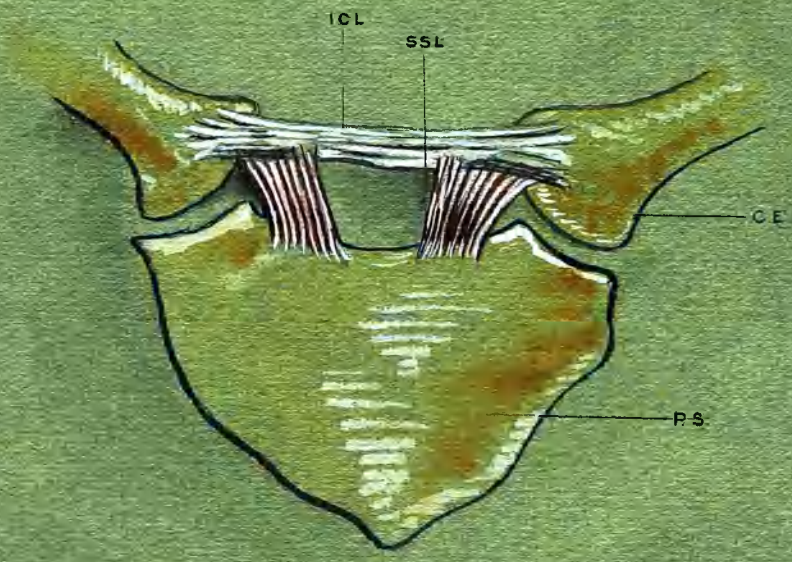


Fig 44.

PLATE XIV.

Fig. 45

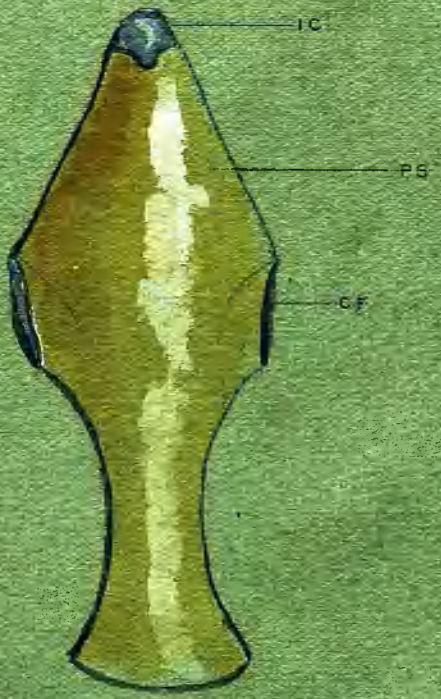


Fig. 46.

PLATE XV.

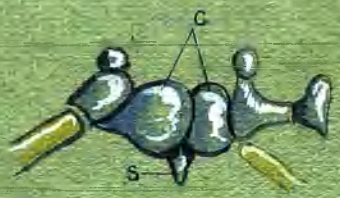
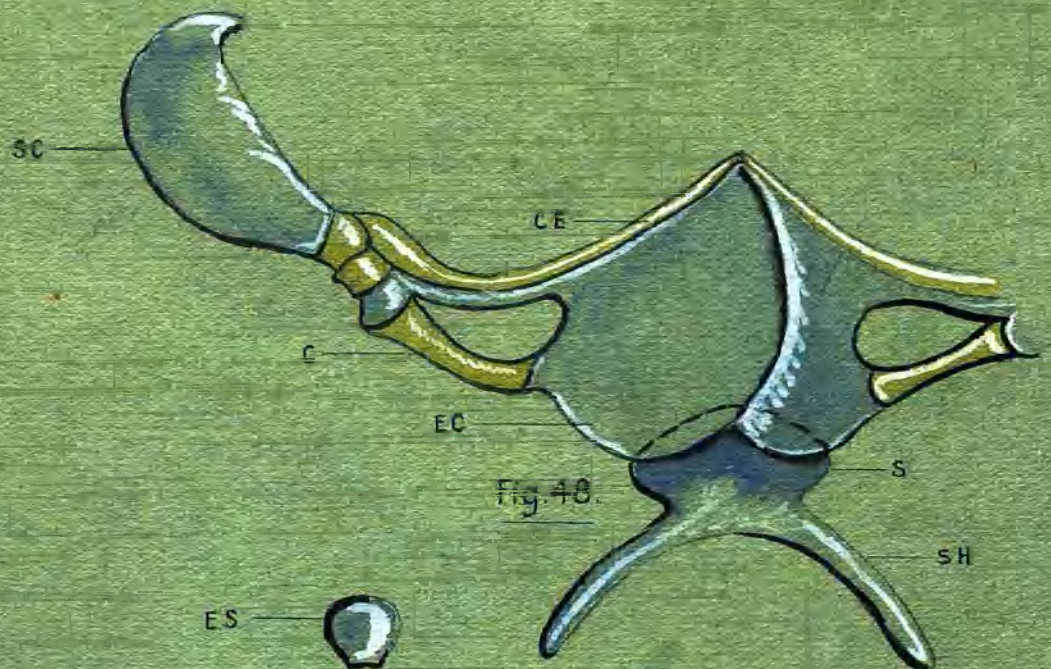


Fig. 47.



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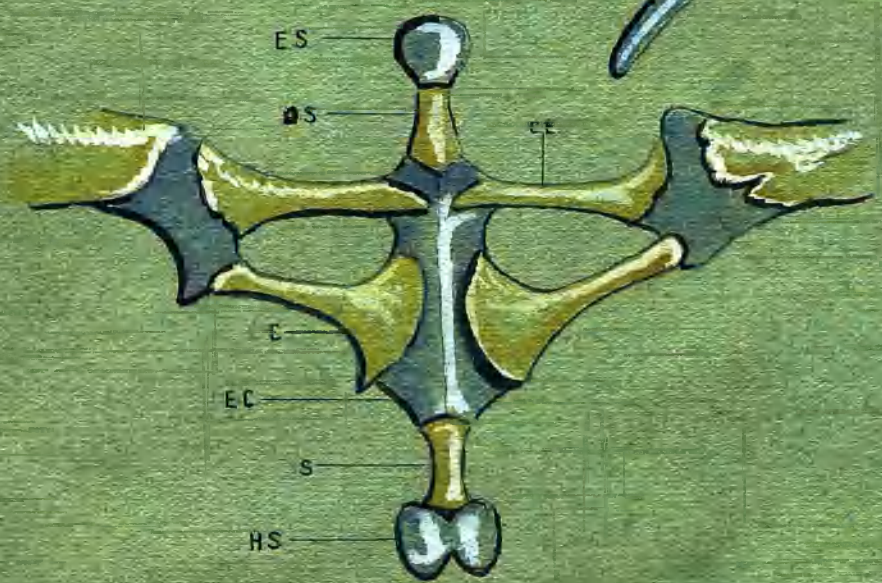


Fig. 49.

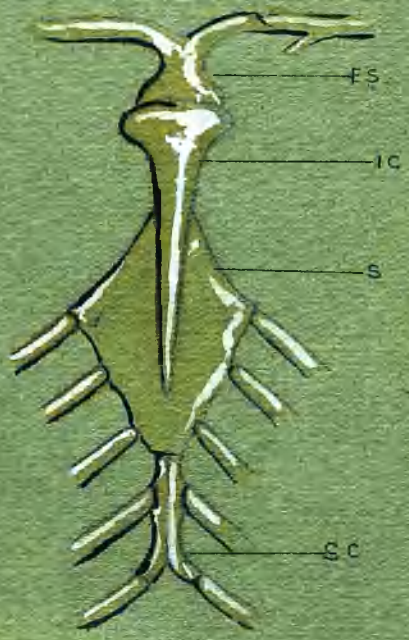
PLATE XVI

Fig 50

Fig 51

Fig 52

PLATE XVII



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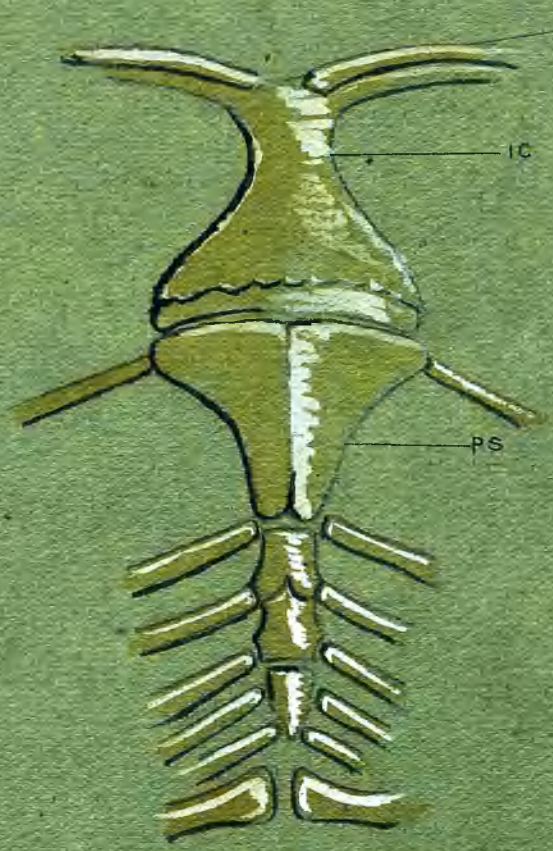

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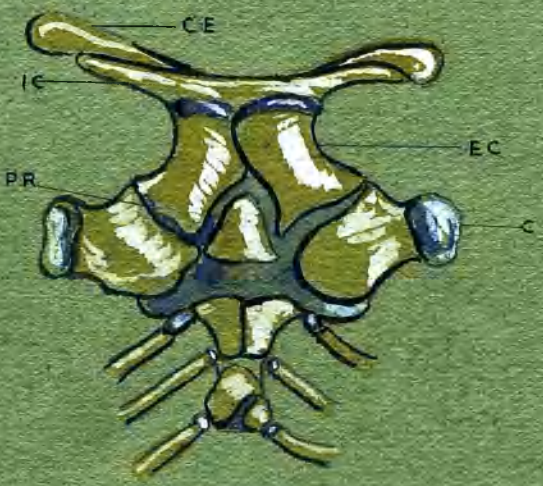


Fig 55

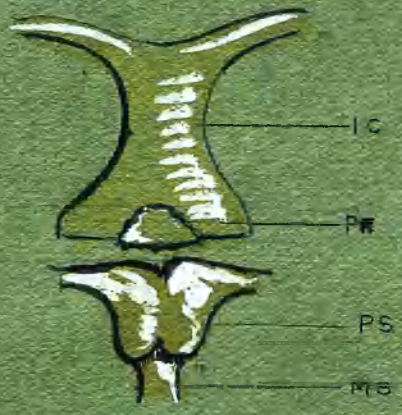


Fig 56.

PLATE XVIII

Fig. 57.

Fig. 58.

Fig. 59.

Fig. 60.

Fig. 61.

Fig. 62.

PLATE XIX

Fig 63.

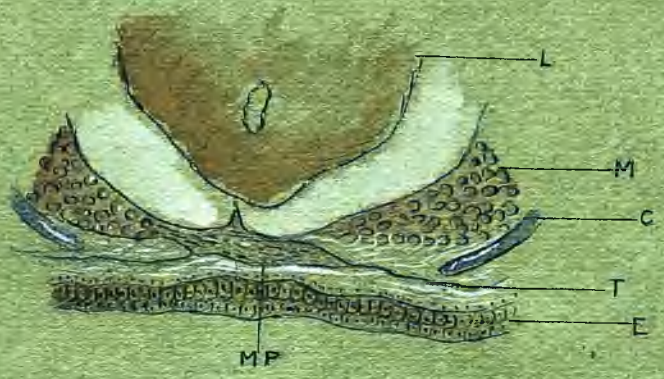
Fig. 64.

Fig. 65.

Fig. 66.

Fig. 67.

PLATE XX.



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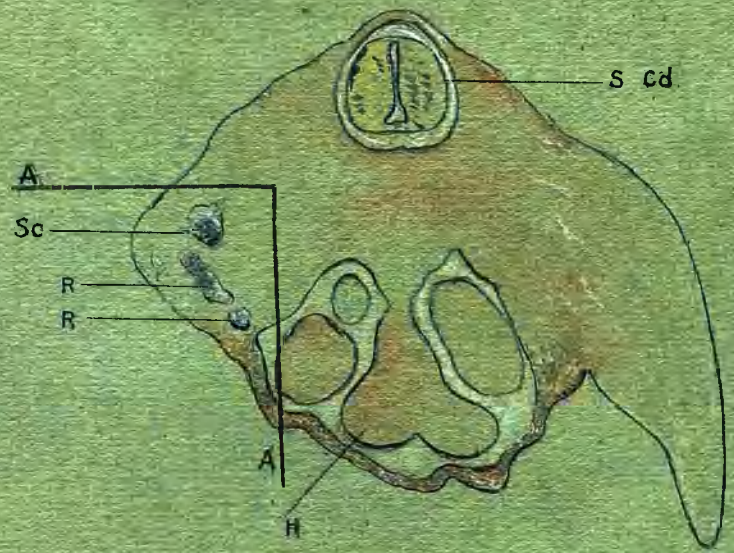


Fig. 69.

PLATE XXI.

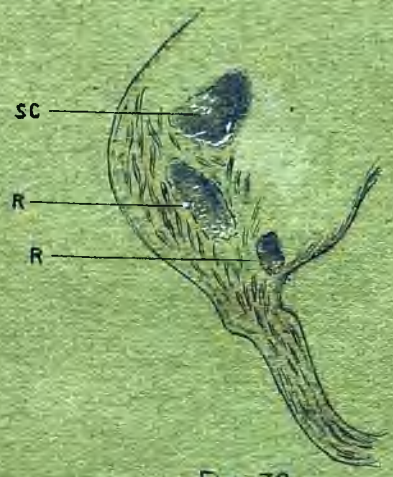


Fig. 70

Fig 71

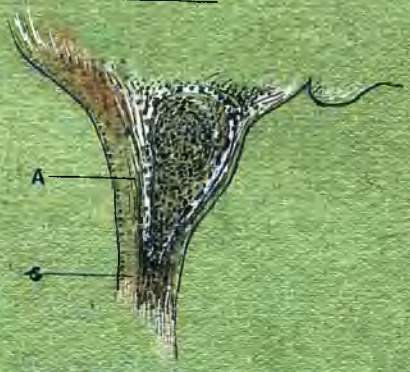


Fig 72

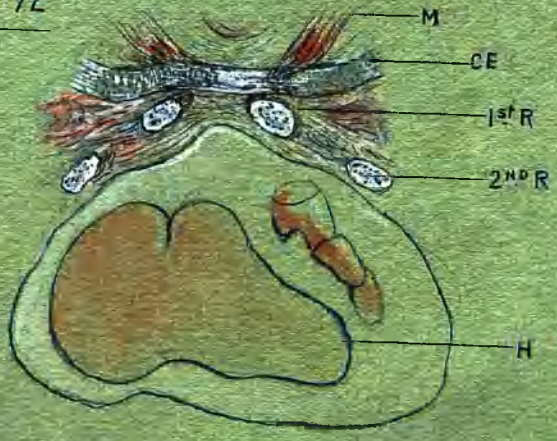


Fig. 73.

PLATE XXII

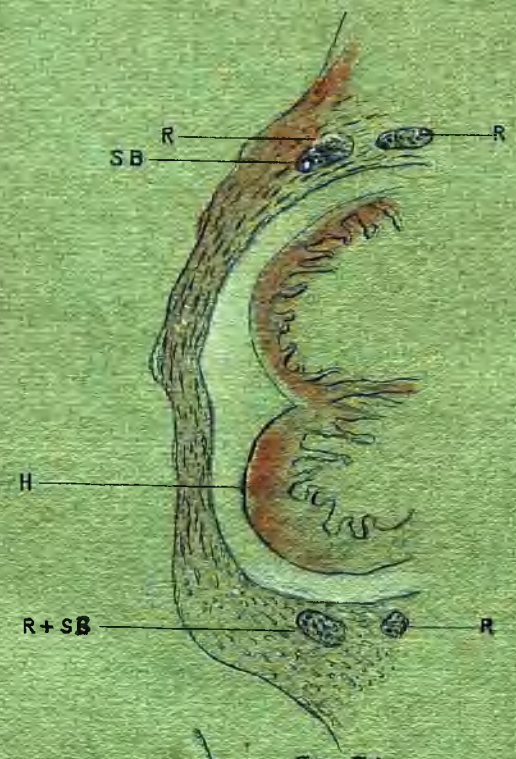


Fig. 74.

Fig. 75.

PLATE XXIII

Fig. 76.

Fig 77.

Fig 78.

Fig 80.

Fig 79.

PLATE XXIV

Fig 81

Fig 82

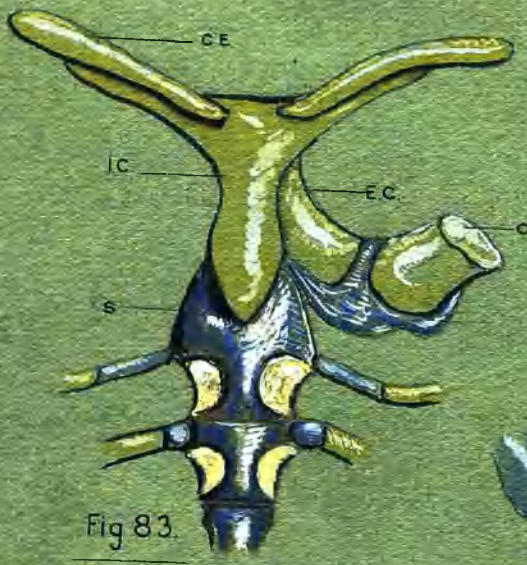


Fig 83.

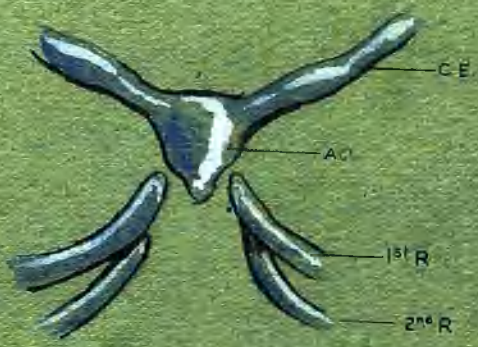


Fig 84

Fig 86

Fig 85

PLATE XXV

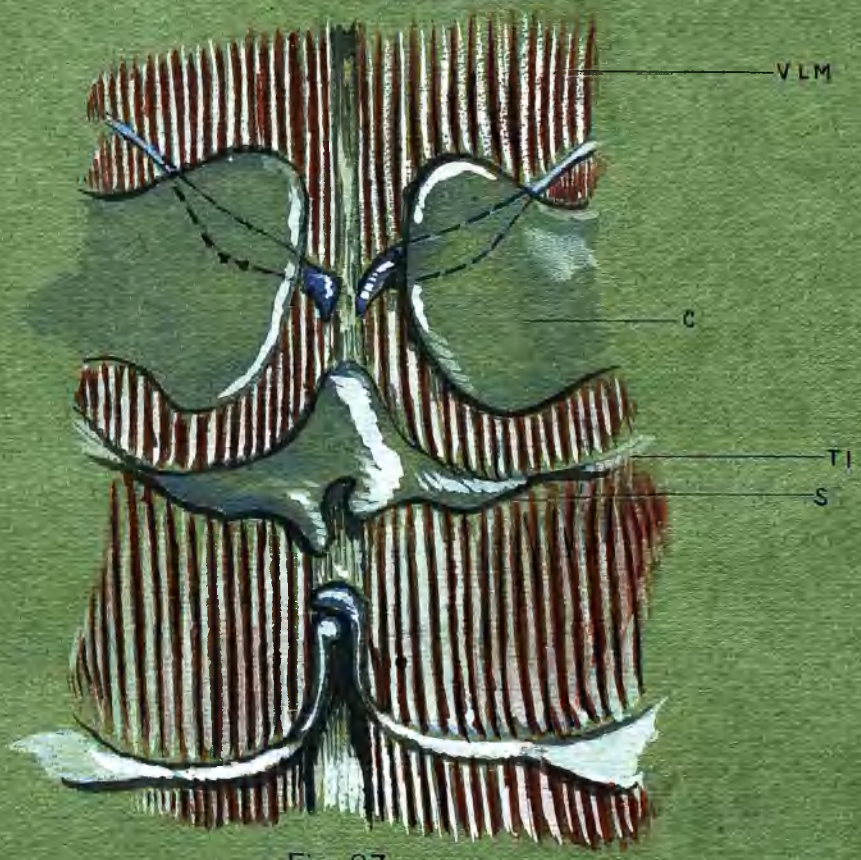


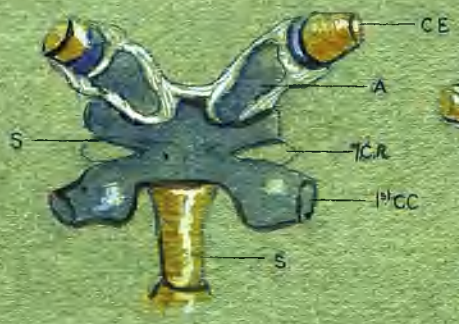
Fig. 87.

Fig. 88.

PLATE XXVI.

Fig 89.

PLATE XXVII.



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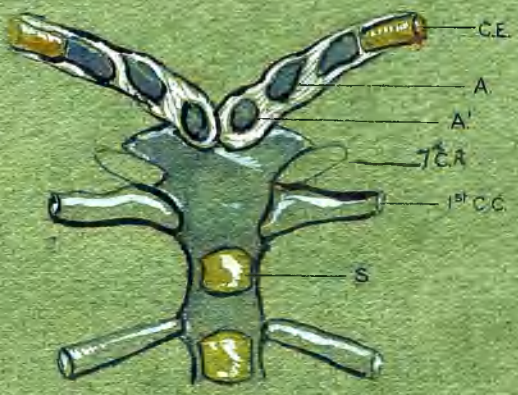

Fig. 91.

Fig 92.

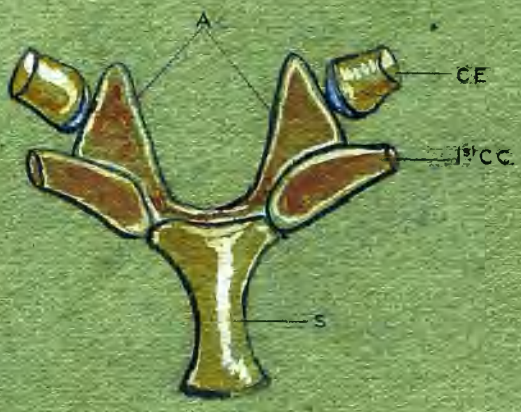

Fig 93.

PLATE XXVIII.

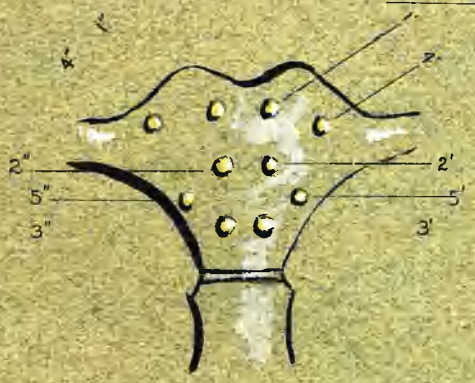

Fig. 94.

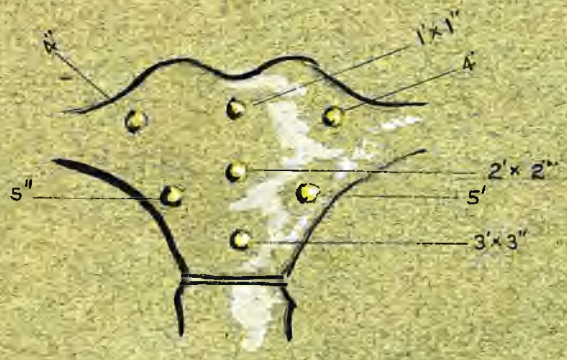

Fig. 95.

Fig. 96.

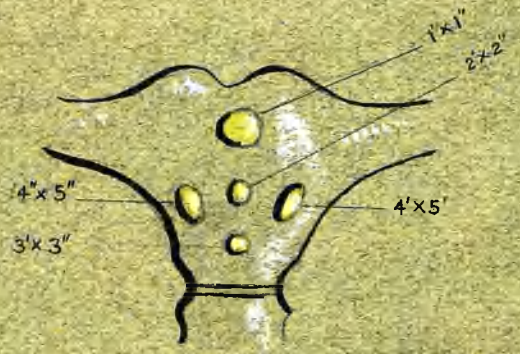

Fig. 97.

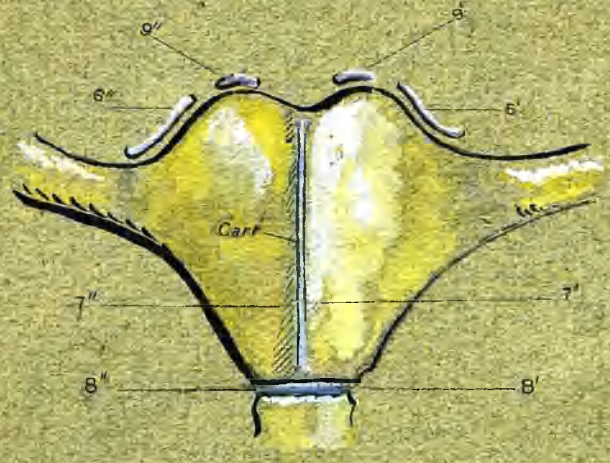

Fig. 98.

PLATE XXIX.

Fig. 99.

Fig. 100.

Fig. 101.

Fig. 102.

Fig. 103.

PLATE XXX.

Fig 104.

PLATE XXXI.

Fig. 105.

Fig. 106.

PLATE XXXII

Fig 107

PLATE XXXIII

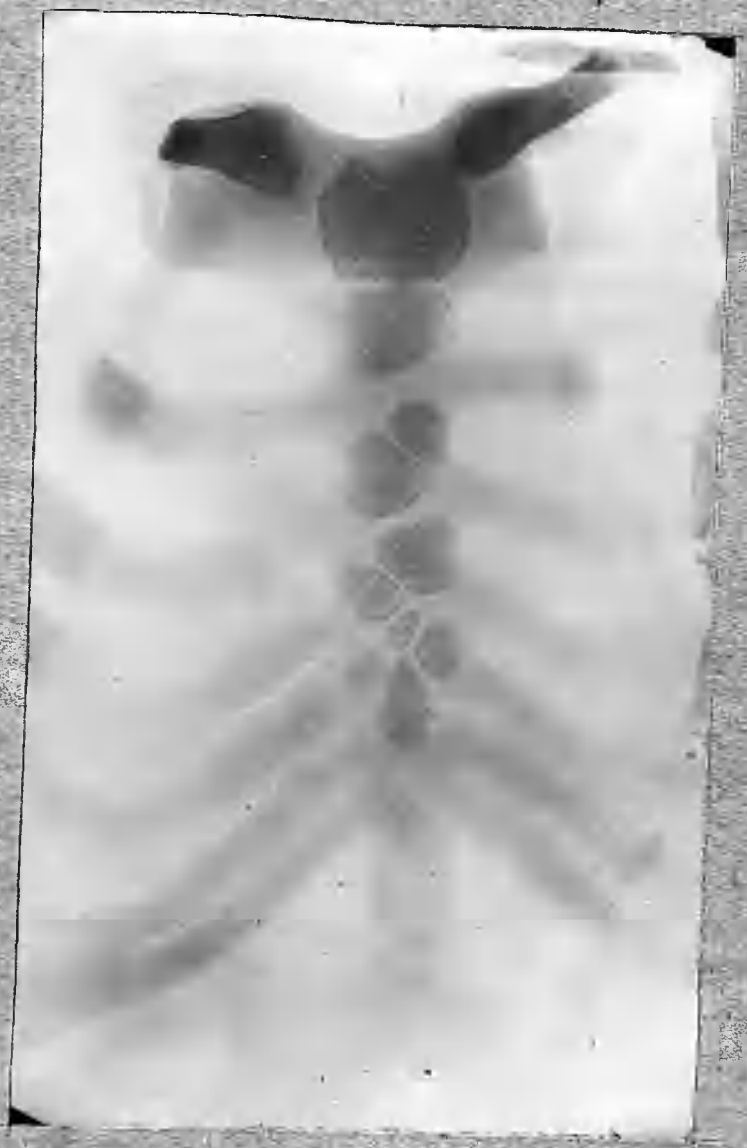

Fig.108.

PLATE XXXIV

Fig. 109