Some Growth Changes in the Walls of the Thorax in the Human Fetus.

A thesis submitted to the
Faculty of the Graduate School of the
University of Minnesota
by
Charles K. Roys
In partial fulfillment of the requirements
for the degree of
Master of Arts.

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THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Examination

This is to certify that we the undersigned, as a committee of the Graduate School, have given Charles K. Roys final oral examination for the degree of Master of Arts. We recommend that the degree of Master of Arts be conferred upon the candidate.

Minneapolis, Minnesota

May 31 1919

C. M. Jackson
Chairman

Thomas G. Lee

[signature]

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Some Growth Changes in the Walls of the Thorax in the Human Fetus.

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Contents.

I. Introduction.

In defining the title of this paper it is desired to make clear the limits of the work undertaken.

Growth changes in the human thorax are almost infinite in number, so that at the outset of the investigation it was necessary to make a selection. After a preliminary study of the literature on the fetal thorax, and of the material available for measurement, it was thought that the most promising field for investigation was the growth of the thoracic wall throughout fetal life.

Many careful observations have previously been made on both wall and contents of the thorax during its embryonic stage; but relatively fewer in the fetal stages. The gap between the embryological laboratory and the dissecting room is very great, and seems to offer large opportunities for research.

The organs contained in the thorax have hitherto received more attention than has the thoracic wall. The present investigation will deal only with the walls of the thorax, and their changes in form, size and relation occurring *in utero.* The organs contained will be merely incidentally considered as their growth influences the growth of the walls. Furthermore, the soft parts lying outside the thoracic cage, and connecting the upper extremity with the body, will be ignored as far as possible. They belong chiefly with the upper extremity rather than the thoracic wall, whose growth it is desired to analyse in this paper.

II. Literature.

The literature on the growth of the thoracic wall during fetal life is very scanty. Measurements heretofore undertaken on the thorax seem to have been made largely in relation to the phylogenetic theory of "recapitulation".

Duckworth ('04) says, "The importance of embryology (to the anthropologist) depends upon the well-known generalization of Kowalewsky following v. Baer and Meckel, to the effect that the individual organism recapitulates in its own developmental history the several stages through which its ancestors passed in their evolution". So "the human embryo should provide material for the reconstruction of the history of the human race". But he admits later that "this history is at best epitomized or abstracted"--- "with certain phases so abbreviated as to be hardly perceptible, or actually omitted".

The theory of an ontogenetic vertebral shortening of the thorax, claimed by Rosenberg ('07) to be comparable to the phylogenetic shortening in Primates, is not considered proved. Rosenberg claimed that a 13th rib is normally present in embryos of 20-30 mm. Minot ('97) says "Its proximal end chondrifies, and fuses with the vertebra. In its embryonic stage it is strictly comparable with the 13th dorsal vertebra of Troglodytes"; i.e. the Hylobatidae, Gorilla and Chimpanzee. Minot further says, "It disappears in Ontogeny as in Phylogeny". This is denied by Holl, Bardeen and Paterson ('10).

A favorite measurement for the anthropologist is the thoracic index, or the relation between the mid-sagittal diameter, and the lateral or coronal diameter at the same level. Without going into a complete historical review of the literature on the thoracic index, it will suffice to say that the index was at first reckoned (by Broca and others) like the cephalic index, which is the percentage ratio of the antero-posterior to the lateral diameter. Hutchinson, Seaver and other American anthropometrists reversed the formula, and expressed it as the ratio (expressed as a percentage) of the lateral diameter to the antero-posterior. Or, $\frac{\text{Depth} \times 100}{\text{Breadth}}$ = Thoracic Index. With this formula, a low index, 65-70, indicates a chest flattened antero-posteriorly. Cunningham and some others still use the old formula, viz. $\frac{\text{Breadth} \times 100}{\text{Depth}}$ = T.I. With this, an antero-posterior flattening would be shown by a high index. It is unfortunate that there is not a uniform usage in the literature. The writer has used the American type of formula.

It was found that this relation changed very much from the early embryonic period to the period of birth, and somewhat even after birth. The thorax in the early embryo is flattened from side to side, as it is in some quadrupeds; then becomes barrel-shaped, and finally flattened from before backward.

Wiedersheim ('08) says "One can in mammals distinguish two types of thorax-form, one primitive and one secondary". He describes the primitive type as "a form in which the dorso-ventral diameter far exceeds the transverse, so that the thorax appears 'keeled'". The secondary type he describes as "barrel-shaped, or even pressed flat from before backward". He further says "This secondary type has the primary as an antecedent, both ontogenetically and phylogenetically". The question as to the primary type of the mammalian thorax will be discussed in Section 4 of this paper, and need not be gone into here.

This division into Primary and Secondary types has apparently heretofore been accepted without question. Wiedersheim is quoted by Ludwig Mendelsohn ('06) as bringing "the transformation of the type into connection with a functional change in the method of progression of the race; viz. with the upright position of the body and the transformation of the upper extremity into a gripping organ."

Keith ('13) also says "In quadrupedal animals such as the horse or dog, in which the chest rests and is supported between the fore-limbs, the thorax has its greatest diameter in the dorso-ventral direction. In upright animals (man, anthropoids, and also some water-living animals such as seals, etc.) the transverse diameter becomes the greater. At birth the diameters of the child's thorax are nearly equal."

Jackson ('07) questioned whether the upright posture acting through gravity was enough to account for the change from the "primary" to the "secondary" type. He performed some experiments on a dog which from birth was kept in an upright position for about a year. It was then killed, and its thoracic index found to be 115.4, slightly greater than in the newborn dog (112.5), but much less than in the adult dog (134.3) from the same litter.

Jackson also pointed out that the two types, human and quadruped, are both evident before birth, and therefore cannot be explained as due entirely to gravity.

Rodes ('06) showed a racial difference in the thoracic index between negroes and whites (lower in negroes); and made a few measurements on the fetus, with curves showing the changes which take place both before and after birth. In his excellent review of the literature of the subject Rodes quotes Symington as saying that the index varies so much that it is "unsafe to draw conclusions from individual specimens". Frazer ('14) says, "Like other recently acquired characters, this shallowness of the thorax is variable".

III. Material and Methods.

1. Material.

It will be noted that not the same number of cases is represented in each table and graph. Certain measurements were impossible on the very small and delicate fetuses without destroying them.

a. Human embryos and fetuses.--From 35 mm. up, at fairly consistent intervals, a series of about 50 human fetuses was selected by Prof. R. E. Scammon from the collection in the department of Anatomy at the University of Minnesota. These were set aside for measurements of the thorax by the writer. The abdomen and pelvis of the same fetuses were studied by Miss Helen Mackeen. There was also a series of nine embryos taken from those figured by Hochstetter ('07) and Keibel and Elze ('08), measurements of which were made and used in the present study. A series of 25 figures of mid-sagittal sections of children and adults in the Collection of Prof. C. M. Jackson was measured in the study of the sterno-vertebral angle.

b. Living children.--A series of six living children from 6 months to 27 months old was measured, to check up certain relations and angles after birth.

c. Mammalian skeletons.--When a study of the literature of the thoracic index in mammals seemed to show the necessity for a further investigation both from the phylogenetic and the ontogenetic standpoint, the writer,worked over the material available in the collections of the Department of Animal Biology, and ran through a series of fetal pigs and sheep obtained from the stockyards at South St.Paul. This was supplemented during a trip to

New York by a study of mammalian skeletons in the American Museum of Natural History.

d. Some living mammals in the collection of the New York Zöological Society at Bronx Park were also measured.

e. Some mammalian embryos in the collections of Prof. G. S. Huntington of New York, of Prof. C. F. W. McClure of Princeton, and of Dr. C. H. Heuser of the Wistar Institute of Anatomy in Philadelphia were also measured.

2. Methods.

The methods of measurement may be summarized as follows. The intact embryo or fetus was used wherever possible, as measurement on cross-sections is often rendered unreliable by the uncertainty of the plane of the section, and other factors in the preparation of the specimens. Allowance had to be made in the fetuses for the swelling and oedema produced by preservation in formalin; but as most measurements were those of relation, it was assumed safe to ignore the swelling, as it would apply equally to all dimensions of a given specimen.

a. Instruments used.--In taking perimeters and diameters it was necessary to use the tape or micrometer calipers with the greatest care to maintain equal pressure at the different points, and sometimes to take repeated observations to get accurate results. Where measurement involved bony points it was necessary to press out the subcutaneous fluid (where present), as for example, over the lower end of the sternum and the costal arch, or over the last rib and dorsal spine. The details of the method of measurement employed there will be given later.

b. Models made.--A series of ten fetuses at fairly regular intervals from 50 to 319 mm. crown-heel, was selected for the purpose of making plaster casts of the trunk. The trunks were dipped in melted modelling wax, cooled and dipped again, till a coat of wax 1/4 to 1/2 inch thick had been formed. After thorough cooling this was cut down to a mere body-casing, and this casing was split into anterior and posterior halves by a cut from the upper limit, through the arm- and leg-holes, and across the perineum. This process furnished a very perfect matrix which recorded every wrinkle of the skin, and in some cases even the areola of the nipples. The two halves of the mould were then fastened together, the arm- and leg-holes plugged with "Plasticene", and the mould was filled with liquid plaster of Paris through the neck opening. This series of ten casts was then compared with the originals, and carefully measured with the micrometer calipers, to locate the principal bony landmarks of the thorax from my own measurements; and of the abdomen and pelvis from those of Miss Mackeen, who shared with me the labor of preparing both the wax moulds and the plaster models.

Silhouettes of these models in two planes were drawn under the Edinger projection apparatus with all lenses removed, and only the low-power condenser retained. While the rays were not parallel, yet the error was constant for all dimensions. These composite silhouettes were thought to be better for accurate comparison than photographs would be. (see graphs 2b", 3d, and 4b.)

On the silhouettes taken in the sagittal plane there was indicated the projection on the skin of the underlying bony points, which had been located and indicated with India ink before giving to the models their final coat of shellac. This furnishes a means of directly comparing the dimensions of a given region throughout a large part of its intra-uterine growth. For the anterior and posterior walls, these are well shown in the sagittal composite of the silhouettes.

A composite contour of these models at the level of the xiphi-sternal junction was made by tying a white string tightly at the indicated level, and standing the model upright under the glass plate of a dioptograph; then by carrying the cross-hairs of the instrument along the inner margin of the string, the exact contour of the chest at that level could be indicated by the pencil of the pantographic arm. The chest-pantograph described by W. S. Hall ('03) was tried, but seemed subject to considerable error, and much less convenient to use. This instrument would probably be better for an un-mutilated fetus, where arms and legs would interfere with the use of the dioptograph.

The larger material of these composites was measured direct from the fetal trunk. Here the projection apparatus was subject to a larger degree of error, due to parallax; but the error was equal in all directions for each specimen, so did not change the proportions. The four largest chest-contours were taken with a piece of insulated thin copper wire, easily bent into shape, and yet thick enough not to sink into the skin of the specimen. This was passed around the chest, and the ends hooked together over the sternum after the wire had been brought into continuous contact with the chest wall. It was then removed by unhooking the ends, and carefully slipping the loop of wire down over pelvis and legs without changing its contour. Its ends were then hooked up, and it was laid flat on the chart. Before the tracing was taken around its inner margin, both its lateral and antero-posterior diameters were checked up with the calipers and compared with the specimen.

c. Measurements taken.--In table I first comes a group of measurements for the identification of the specimen, and to afford a basis for calculation of its approximate age. Then are recorded two dimensions chosen to show linear growth of the sternum throughout fetal life. The sternum was measured from the xiphi-sternal joint to the incisura jugularis, omitting the meta-sternal segment as not significant of growth in the anterior thoracic wall.

Next come measurements having relation to the nipples, to see what changes in position (if any) took place during intra-uterine life, either vertically or horizontally. This location varied in both directions with the amount of swelling present in the subcutaneous tissues. The result of this measurement was not considered to justify any definite conclusion as to change.

Then are recorded two measurements having relation to the infra-sternal angle. This was first measured by a simple goniometer, and the quadrant-reading recorded in the appropriate column. Then the midclavicular line was determined on each side, and the point where this line intersected the costal arch taken to represent the tip of the ninth rib. It was recognized that the ninth costal cartilage may extend along the costal arch some distance medial to this point, but it was desired to fix a point on the lower part of the costal arch where comparative measurements could be made.

Next, the distance from this somewhat arbitrarily fixed point to the upper margin of the clavicle at its mid-point was recorded, and the distance from the midclavicular point to the mid-point of the inguinal ligament. These two measurements give a basis for. estimating the growth in length of the thorax in the midclavicular line at its various stages.

Then the length of the thoracic segment of the spinal column was taken by locating the two lower ribs through the skin, and inserting a pin at the angle formed between them. The vertebra prominens was then located, after pressing out the oedema over it, and another pin inserted just below it. The distance between the two pins could be measured accurately with the calipers, and the angle between the twelfth ribs at the spine measured by the goniometer. Leaving the two pins in place, the sterno-vertebral angle (to be more fully described later) could then be measured by a larger goniometer.

The perimeters recorded in Table II were taken at the three levels used by Wintrich ('54), viz. at the axilla, the nipple, and the xiphisternal junction. For the smaller material a cotton string was used at a definite tension; so there was a certain unavoidable error due to the softness of the tissues and to the personal equation. It was the aim, however, to make the error equal for all levels as far as possible.

The diameters were measured at four levels; the three of Wintrich and one corresponding to the superior aperture of the thorax. The instrument used was a pair of micrometer calipers, and here again some error was unavoidable, due to the compressibility of the tissues.

d. The series of graphs.--To make growth changes obvious it is necessary to compare them with some other quantity. So the rates of growth of the different dimensions of a given region may be compared with each other, or with similar dimensions of another region, as has been done in some of our graphs.

As these changes occur in the three dimensions of space, they can be best formulated by graphic illustrations. The long tables in which the measurements are recorded would be only a meaningless mass of figures if they were not supplemented by graphs, and curves of growth, by which the figures may be analyzed and more concisely presented in graphic form. These graphic data can be more easily grasped by the mind, and more readily retained by the memory.

The series of graphs which are based on the figures in tables I + II are plotted on the basis of the individual cases, using the standing height as the base-line for all the fetal material. For the very small embryos measured from figures in Hochstetter ('07) and Keibel ('08), the sitting height was used as the base-line.

The curves of the graphs were smoothed by inspection, not in segments but as a whole. So that at any given point the curve may be inaccurate as regards the measurements recorded, but taken as a whole it probably nearer right than if smoothed by segments.

The list of graphs recorded follows:

List of graphs, and purpose of same.

1. Growth of anterior wall.
    a) Length of sternum, comparing trunk length in anterior median line; to show linear growth of sternum.
    b) Length of thorax in mid-clavicular line, comparing trunk-length in same line; to show linear growth of thorax in mid-clavicular line.

c) Interpapillary diameter, comparing width and perimeter of thorax at mammary level; to show change in position of nipple (if any).

d) Infra-sternal angle in degrees, and distance between tips of 9th rib in millimeters; to show changes in infra-sternal angle and costal arch (if any).

2. Growth of posterior wall, and changes in relation of anterior and posterior walls.

a) Length of thoracic segment of spinal column compared to length of sternum; to show comparative linear growth of anterior and posterior walls.

b) Sterno-vertebral angle in degrees, to show change in position of anterior and posterior walls (if any).

(See also sagittal composite silhouettes.) (b")

c) Angle between 12th ribs at the spine; to show change in obliquity of the ribs (if any).

3. Horizontal growth of the thorax at various levels.

a) Three perimeters compared, to show changes in proportions at various ages (if any).

b) Mid-sagittal diameter superior aperture compared to that of inferior aperture; to show change in proportion at various ages (if any).

c) Lateral diameter level of axillae, compared with that at level of xiphi-sternal joint; to show variation in conical shape (if any).

d) Coronal silhouettes of trunk-models; to show variation in proportion compared to abdomen and pelvis (if any).

4. Relation of antero-posterior to lateral diameters, and discussion of the thoracic index.

a) Curve of index at level of xiphi-sternal junction; to show comparative growth of two diameters of the thorax in the human fetus.

b) Composite of tracings of perimeter at level of xiphi-sternal junction; to show changes in shape.

c) Curve of index in fetal pig; to show changes in shape of thorax of the fetal pig.

d) Curve of index in fetal sheep; to show changes in shape of the thorax in the fetal sheep.

e) Curve of index in fetal albino rats, and cats; to show changes in the shape of the thorax in these mammals.

f) Curve of index in fetal opossums; to show changes in the shape of the thorax in the fetal opossum.

g) Chart of mammals grouped according to thoracic index; to show the relation of the thoracic index to the various Orders of mammals, and to their habits of life.

Discussion of Observations.

As to the general proportions of the fetal thoracic cage we do not find much detail in the literature. The cuts in the various systemmic anatomies are often simply the adult type drawn on a reduced scale. The atlases of anatomy, such as Rauber-Kopsch, Spalteholz, and Toldt, do not insert special cuts of the fetal thorax. The best cut found was Fig. 15 in Mettenheimer's article (1893), which he took from Henke (1881). This cut was copied by the writer and a rubber stamp made for use in the laboratory. The figure is here reproduced. (see Fig. 2) It shows several things that are characteristic of the fetal thorax during nearly the whole of its growth; viz. its shortness compared to its width; the bluntness of its cone compared to the adult, and the flaring outward of the lower ribs over the dome of the liver. It shows also the lack of obliquity of the ribs compared with the adult type.

Gundobin ('12) describes two chief types of thoracic cage in the newborn, but does not trace them through intra-uterine life. The first is conical, when the circumference at the level of the axillae is 1-3 cm. less than at the xiphi-sternal junction. The second is barrel-shaped, when the two circumferences are equal. (The latter type has rarely been observed in the 50 fetuses measured by the writer.)

Chievitz (1899) calls attention to the transverse furrow on the outer surface of the thorax in the newborn, corresponding in position to the lower border of the lungs and pericardium. He also mentions the longitudinal lateral furrow, seen most markedly in the fetus at "from 6 to 8 weeks", and causing the "biscuit-shape" of cross sections of the upper thorax. (This shape is rather that of a pear than a biscuit; with the large end in front containing the heart and liver.) C. Müller ('06) in her article on the development of the human thorax, says that the large size of the ventral part of the thorax at this stage is due to the great expansion of the heart and liver, two already functioning organs; while the lungs in the dorsal part have, of course, hardly begun to develop. The "heart-shaped cross-section" figured by Wiedersheim ('08) as the primitive type, was not found in any of the embryos examined. The pear-shaped cross-section is well shown in Fig. 4.

1. Growth of the Anterior Wall.

The conclusion drawn from a study of Graphs 1a,b,c,and d, showing comparative dimensions of the anterior wall of the human fetal thorax at various stages is that after the formation of the ribs and sternum is complete, the changes up to the time of birth are mainly those of size and very slightly of shape. In other words the shape of the anterior wall at birth is characteristic of the anterior wall as soon as it is fully formed in its cartilaginous condition.

This is shown by the fact that the graph-curves have a uniform sweep, and are almost straight lines. The slight undulations perceptible are probably due to scarcity of observations. If the cases could have been numbered by hundreds instead of by tens, these undulations probably would have been flattened out. The general course of the curves, however, is unmistakably, and seems to show that the laws of growth of the thoracic wall during the period observed are much simpler than has usually heretofore been believed.

2. Growth of the Posterior Wall, and Changes in Relation of Anterior and Posterior Walls.

Graph 2a, comparing the linear growth of the anterior and posterior thoracic walls in the median line, shows the same simple relation between the two as in the graphs relating to the anterior wall alone.

Graph 2b, however, showing the angle between the anterior and posterior walls, is more complicated. As it brings in the measurement of an angle not often observed before, it will be given a fuller discussion than the others.

The Angle of the Sternum with the Thoracic Spine. In measuring the fetal thorax it was early found necessary to secure some formula for the essential relation between the anterior and posterior walls as to position. The relative position of the two walls is exceedingly important at all stages of growth.

The sternum and the thoracic arc of the vertebral column (as seen in mid-sagittal section) were considered as axes of the anterior and posterior walls respectively. Both of these are seen to be arcs of circles, with their concavities facing each other. The chords of these arcs are considered to be the linear axes of the anterior and posterior thoracic walls. So that a definition of the sterno-vertebral angle would be this: the angle produced by the intersection of the chord of the sternal arc with the chord of the thoracic arc when both are prolonged upward. This angle could be measured with a fair degree of accuracy during the process of locating and measuring the thoracic segment of the spine, when pins were inserted at each end of that segment. One leg of a long goniometer was held at the lateral aspect parallel with the line between the points where the pins entered the skin, and the other leg shifted until it made a chord across the sternal curve. The angle could then be read in degrees on the quadrant of the instrument.

But what is meant by the chord of the sternal arc? Simply the line passing through both ends of the sternum, excluding the xiphoid process. The sternum, being largely cartilaginous even after birth, has no absolutely definite shape in fetal life, but is best described as the segment of a circle of larger or smaller diameter. Rarely it is flat, and sometimes even concave on its anterior surface, due to pressure from the chin.

The sternal angle, visible in the adult as a prominent ridge between pre-sternum and meso-sternum, is due not so much to a change in direction between the axes of the two parts, as to a pushing out of two lip-like projections on the anterior surface of these parts just above and below the manubrio-gladiolar joint. In the adult the angle is not marked on the posterior surface of the sternum; and the angular projections on the anterior surface are much less marked in the fetus than in the adult.

So the "angulus sternalis" need not confuse the measurement if the chord of the entire arc of the sternum, down to the xiphi-sternal joint, be used. The xiphoid process has been omitted from these measurements because of its great variability in size, shape and direction; and also because it was considered a comparatively unimportant object, belonging more with the abdominal than with the thoracic wall.

The axis of the posterior wall of the thorax is taken as the chord of the thoracic arc of the vertebral column. This forms a good base-line for several reasons. Throughout nearly all of fetal life both the proportionate length and the direction of the curve of the thoracic arc remain fairly constant; although in the cervical and lumbar regions both the proportionate length and the convexity of the curve are steadily changing.

Furthermore, in the adult, when the body is erect the chord of the thoracic arc is approximately vertical, so that by locating this base-line in the fetus we have an indication of the future vertical position. The sternum is said to make an angle of about 20 degrees with the perpendicular in the adult (Thompson '14), which means the same angle with the chord of the thoracic arc.

This line has been used by Chievitz ('13) for the accurate location of the levels of intra-thoracic viscera. He says: "The position of the constituent parts of the thorax is most conveniently studied with reference to a straight line joining the central points of the two intervertebral discs which lie, the one between the thoracic/ and the cervical spine, the other between the thoracic and the lumbar spine; planes perpendicular to this line may be regarded as horizontal, and designated according to the vertebrae which they severally intersect." So the base-line of Chievitz was taken as one side of the sterno-vertebral angle.

<u>Fetal Changes in the Sterno-Vertebral Angle, and Factors in these Changes.</u>

In the embryonic stage (first two months) the topographic changes are most rapid and extensive in the thorax as elsewhere.

In the earliest stages of course there is no sternum, and it is necessary to measure the chord of the anterior thoracic wall curving out over the heart. If a line is taken through the anterior end of the septum transversum, upward through the point of contact of the mandibular arch with the thoracic wall, it was found, up to about 12 mm. crown rump to be almost parallel with the chord of the thoracic arc, although the latter curve lies at a considerably lower level. The axis of the anterior wall makes a decided angle with the cervical segment, because of the cervical curve, which at this stage is very strongly marked. The development of the heart antedates that of the liver and lung-buds. The heart at first almost monopolizes the future thoracic cavity, and the anterior wall is moulded over the heart alone. Its growth is at first fish-like, and produces a type of thorax which is pre-mammalian. The heart of a 3 week's embryo is very like that of a shark (Keith), and lies up in a subpharyngeal position.

In the human fetus the neck is differentiated in the second month. The heart gradually descends, and in the 11 mm. human embryo comes to lie opposite to the 2nd to 7th cervical segments (Jackson '09). While the upper limit of the heart lies opposite the 2nd cervical, the upper limit of the lungs is at the 7th cervical and the latter organs extend only to the 3rd thoracic vertebra. So that we have not yet the typical mammalian arrangement, but one more nearly resembling that of reptiles.

We now come to the period of sudden and rapid growth of the liver, which has a very marked influence on the sterno-vertebral angle, and upon the other proportions of the thorax.

In the 17 mm. embryo there is still no definite sternum. The ribs are growing outward but not yet meeting even cephalad. The rapid growth of the liver is checked cephalad by the large heart, and dorso-caudad by the sharp forward bend of the lumbar region of the vertebral column. So that the liver grows chiefly ventrad, and tilts the lower end of the thoracic wall before it. The pre-axial viscera all grow forward (ventrad) at this stage, until gradually the curve of the vertebral column, at first almost a complete circle, is forced open. The viscera at this early stage are so nearly fluid that pressure due to growth is probably transmitted equally in all directions. Yet the trunk, being roughly sausage-shaped, must tend to become straight as internal pressure increases; just as is the case with a sausage-shaped balloon, which is straightened by inflation.

That the heart and liver are pressing against each other at this time is shown by the fact that the heart lies in a deep groove on the upper surface of the liver. In cross-sections of the 11 mm. embryo (see Fig. 3.) the dome of the liver first appears on each side of the heart rather behind than in front. At a lower level it forms an H-shaped mass, lying between heart and lungs, and the anterior thoracic wall is stretched out very thin over the heart. In a 15 mm. embryo, the liver dome appeared in the sections first on the right side, but very soon on the left; and in succeeding sections the two sides enlarged inward till they joined behind the heart. In another 15 mm. specimen, the two sides joined in front of the heart, forming a horse-shoe-shaped mass of liver tissue between the heart and the anterior thoracic wall. These differences were probably due to a difference in the plane of the sections.

The groove for the heart on the upper surface of the liver may be due to the heart growing downward (caudad); but is more apt to be due to the liver growing upward (cephalad). At this stage the heart has passed its maximum proportionate growth (relative to the whole body); and the liver has not yet reached its maximum.

In the 31 mm. embryo, the lower segments of the vertebral column are straightening out. The liver at this stage reaches its maximum proportionate size (10.56 per cent of the total body volume, Jackson ('09)) but is now free to grow downward (caudad), as the lumbar spinal curvature straightens out. In the 32 mm. embryo, the two halves of the sternum are completely fused, according to Müller. In the 31 mm. embryo, they extend down over the heart, but not over the liver which still projects below (caudad to) the infra-sternal angle. It may serve to transmit pressure to the lumbar spine, as it reaches back to the kidneys and genital glands on both sides, the right and left lobes being almost equally developed.

This is the period of Mall's embryonal hernia into the umbilical cord, and probably of maximum intra-abdominal pressure, which seemingly cannot be without influence in straightening the curvature of the trunk.

Considerable space is given to this growth of the heart followed by the growth of the liver, because of the effect that these have upon the relation of the antero-posterior to the lateral diameter of the thorax in the lower segment, where these diameters are usually measured.

The sternum when fully formed makes with the thoracic spine almost the same angle which it is to hold all through fetal life, viz., varying close around 30 degrees. Chievitz ('99) says that the apparent shortness of the fetal sternum is due to its greater obliquity compared with the adult type. This of course varies with position. In extreme flexion of the trunk, the angle may increase to 45°, as in a frozen section of a full-term stillborn male child figured by Chievitz. In his cut showing extension, the angle is found to be less than 30°. In a mid-sagittal section figured in the collection of Prof. C. M. Jackson, of a "nearly full-term female fetus hardened in utero", the angle is 35°. Here the trunk and head are both moderately flexed.

Graph 2c, which registers the angle between the 12th ribs at the spine, also shows nearly a straight line; thus showing that the relative position of the ribs and the spine changes very little from the time they are fully formed, up to birth.

3. The three perimeters measured by Wintrich ('54) were measured on the fetus and compared in graph 3a to see if there was any significant change in shape evident during the period from the end of embryonic life up to birth. So far as the curves show anything, there appears to be none.

Graph 3b was made to try and show changes in the relative size of the superior and inferior apertures of the thorax, if any, at different periods of fetal life. In view of the theory of stenosis of the superior aperture being connected with apical tuberculosis (Freund ('59), Mendelsohn ('06)) it was thought this measurement would be useful, but nothing significant was found.

The lateral diameter at the level of the axillae was compared with the same diameter opposite to the xiphi-sternal junction, to see if any change in the inclination of the lateral walls could be detected. Apparently there is no change in the obliquity of the cone of the thorax during the period under discussion. (see graph 3c.)

This is further shown by the composite of the coronal silhouettes of plaster casts (graph 3d) made at regular intervals to show the various proportions of the trunk and their variation due to growth. When these silhouettes are super-imposed, the outlines are practically parallel for all stages of growth in utero.

4. Relation of Antero-Posterior to Lateral Diameters, and Discussion of Thoracic Index.

In early embryonic life the thoracic index, as explained in the Introduction, is very high. There is apparently a very good reason for it in the rapid forward growth of the heart at this period, which tends to elongate the antero-posterior diameter. As shown by these measurements (Graph 4a), the index very soon decreases, and in embryos over 32 mm. the contour of the thorax is nearly cylindrical, remaining so till birth. This statement is contrary to the curve plotted by Rodes ('06) and disagrees with one of his conclusions; but this phenomenon is explained by him in a footnote, better than anywhere else that I have been able to find. He says: "The tendency of the pressure of the liver is to cause the lower part of the thorax to assume that form giving the maximum capacity, i.e. circular in outline. It tends therefore to accelerate the reduction in the thoracic index until this reaches 100, but to retard any further decrease."

The embryonic type of thorax has been compared to the quadruped type, to reinforce the theory of "recapitulation". Anthropologists of the Darwinian School made many observations both on the embryo and on quadrupeds, but apparently without analysis of the constituent parts of the long antero-posterior diameter in the two cases. In those quadrupeds which were measured in the present investigation (see Table III) the highest indices found were in the ox, moose and rhinoceros. In these the vertical depth of the spinous processes alone made up 20 to 25 per cent of the depth of the chest. The enormous development of spinous processes is well seen in the bison's hump, and seems to be related to the necessity for a powerful leverage for the ligamentum nuchae to carry the heavy head at a gallop. In the human embryo under 32 mm. (the time of high index) practically no space is taken up by spinous processes. From 60 to 70 per cent of the antero-posterior diameter is taken up by viscera and the remainder by the relatively enormous spinal cord and its coverings.

Furthermore, in the embryo the viscera come forward (ventrad) directly under the anterior thoracic wall, which is thinned out over the projecting heart. In the quadruped type there is a mass of muscles, as seen in the brisket of the ox, to add to the antero-posterior diameter. This is well shown for the dog in Charnock Bradley's ('12) figure of the cross-section of a dog's thorax with an index of 121, which I have copied to compare with a human embryo of 11 mm. (see Fig. 4.). The pectoral muscles play a large part in the high thoracic index of the quadruped, but a very small one in the human embryo.

So that we have been comparing two essentially unlike types, with a superficial resemblance as to dimensions, but quite different in nature.

Wiedersheim's statement (already cited) that the "secondary thorax-type has the primary as an antecedent both ontogenetically and phylogenetically" led the writer to investigate the indices of fetal mammals other than man, and of a variety of Orders, as well as adult mammals of all the "primitive" types accessible. The results are shown in graphs 4c,d,e, and f on embryos, and in table III for the adult mammals.

The measurements on embryos (one marsupial, two ungulates, one rodent and one carnivore) tend to show that there is no primary embryonic type; except that all embryos measured (excluding the marsupial) seem to approach the cylindrical outline in an early stage, and to be modified from that barrel-shape either into lateral flattening/or antero-posterior flattening, according to the shape of their ancestors.

This shape, according to table III is apparently associated more with ancestral habits of life than with elevation in the evolutionary scale. In the table the Orders are arranged in the sequence given by Beddard ('09), and the Monotremes are seen to have an index as low as the Man. There is a wide variation in each of the Orders, which is found to correspond directly to the habits of life of the different species. There is even a variation within the species, as between the wild boar and the domestic pig, bred for pork only and not for speed. How quickly the pig reverts to his ancestral type is well seen in the razor-backed hog of the southern woods. There is also a wide variation in the dog, between the borzoi or the greyhound, and the bull-dog bred for strength only.

The conclusion from table III is that mammals to whom a rapid gallap is essential have long spinous processes, well developed pectoral muscles, a laterally compressed thorax, and high thoracic indices. Mammals which climb, or burrow, fly or swim, have low indices, and even antero-posterior flattening of the chest; due in part to the change in the lines of force applied through the muscles of the upper extremity to the walls of the thoracic cage.

V. Summary.

1. The transition from embryo to fetus with the completion of the characteristic fetal circulatory system, is accompanied by profound changes in the thoracic wall, as elsewhere in the fetus.

2. The growth changes in the thoracic wall of the human fetus are more simple than has heretofore been generally assumed.

3. After the formation of ribs and sternum is complete, the changes in the fetal thoracic wall are mainly in size and very slightly in shape.

4. No definite primary fetal type of thoracic index could be found for all mammals in the material examined.

5. The "quadruped type" of thoracic index (with lateral compression) is a modification in one plane from an approximate barrel-shape due to internal pressure; just as the "human type" txxxk (flattened dorso-ventrally) is changed in another plane.

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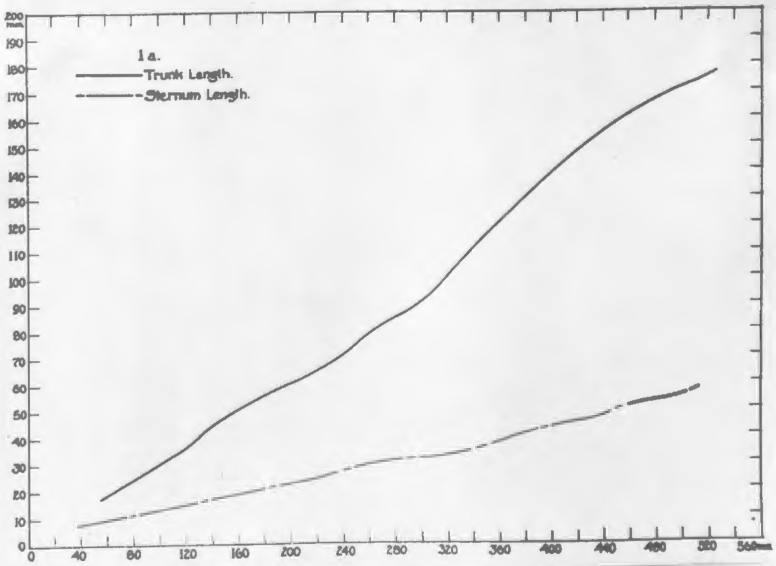
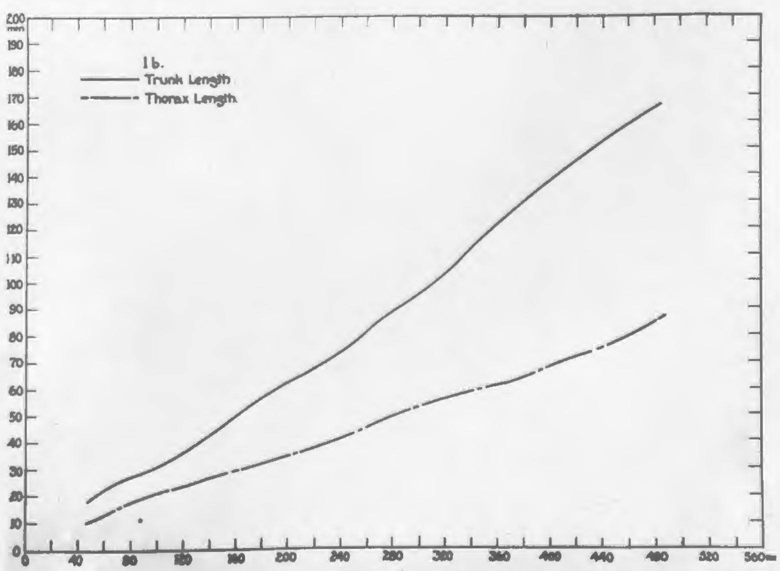
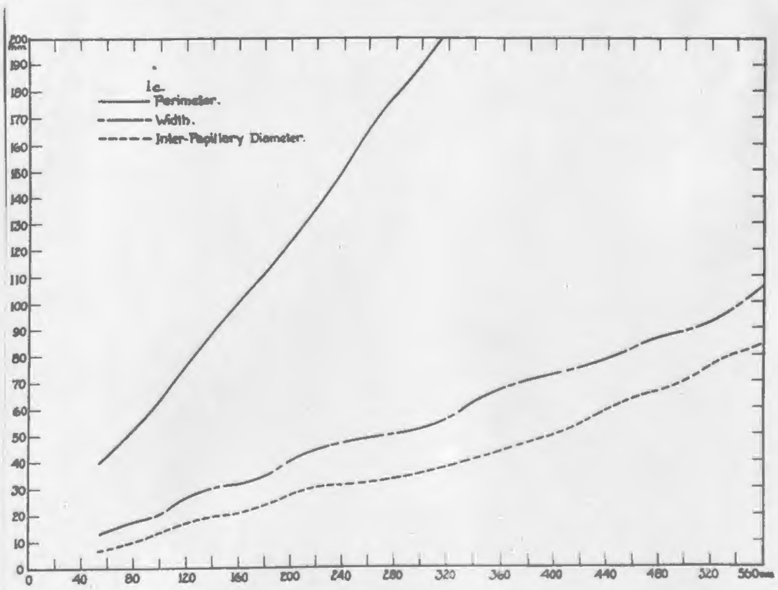
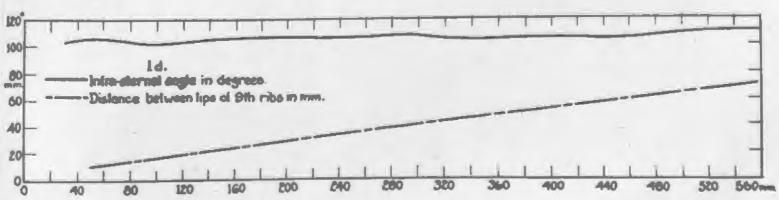
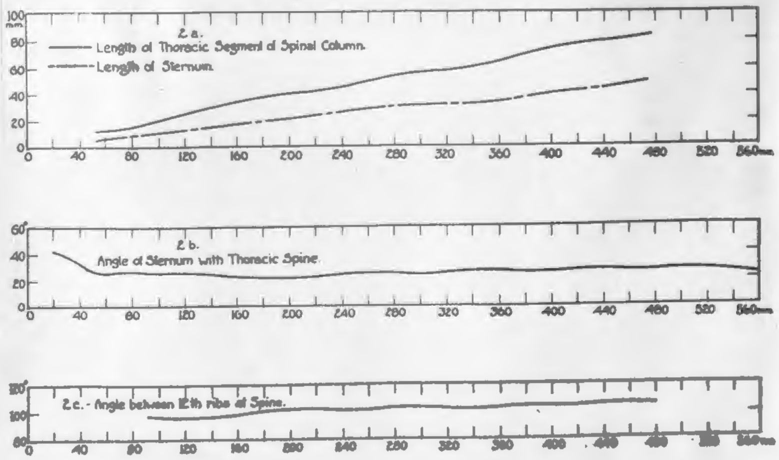

1a.
Trunk Length.
Sternum Length.
200 mm.
560 mm.

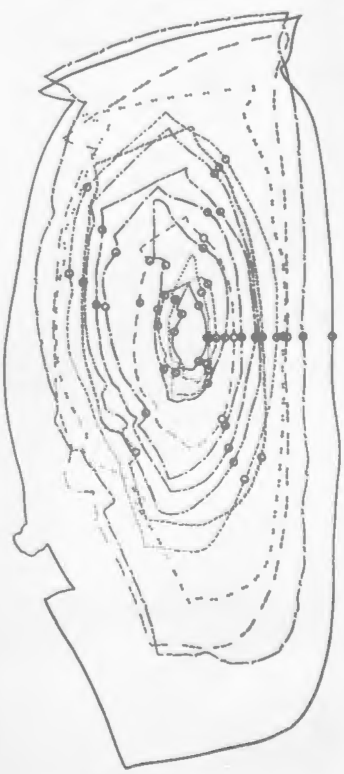

1b.
Trunk Length
Thorax Length.
200 mm.

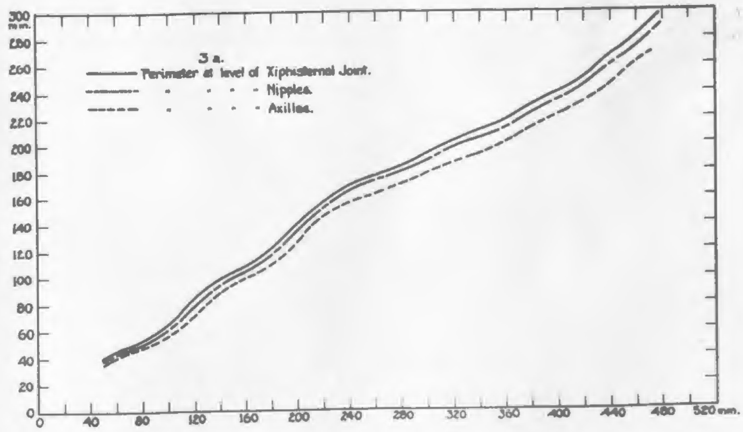

1c.
Perimeter.
Width.
Inter-Papillary Diameter.
200 mm
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
40
80
120
160
200
240
280
320
360
400
440
480
520
560 mm

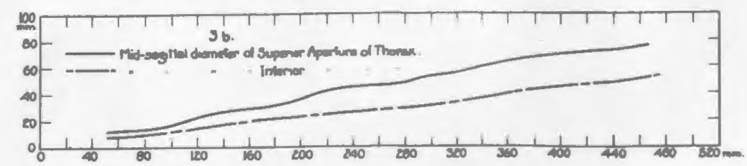

1d.
Infra-sternal angle in degrees.
Distance between tips of 9th ribs in mm.
120°
100
80
mm.
60
40
20
0
0
40
80
120
160
200
240
280
320
360
400
440
480
520
560 mm

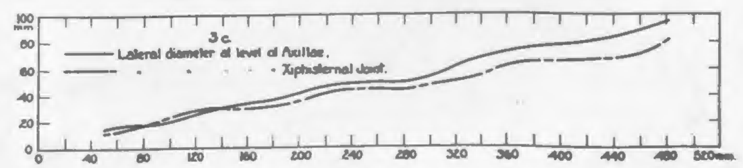

2a.
Length of Thoracic Segment of Spinal Column.
Length of Sternum.
2b.
Angle of Sternum with Thoracic Spine.
2c. - Angle between 12th ribs at Spine.

2f

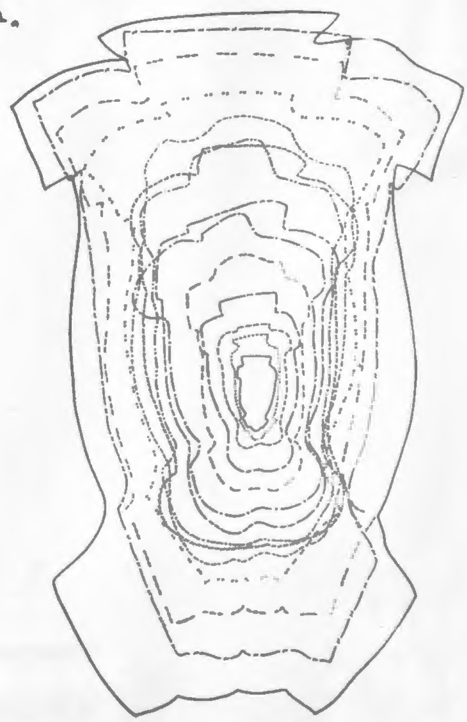


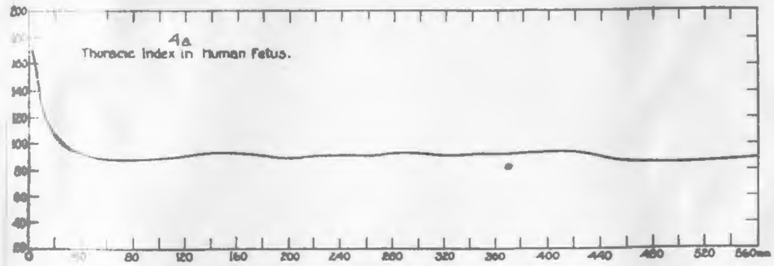

3 a.
Perimeter at level of Xiphisternal Joint.
" " " " Nipples.
" " " " Axillae.
300 mm.
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0
40
80
120
160
200
240
280
320
360
400
440
480
520 mm.

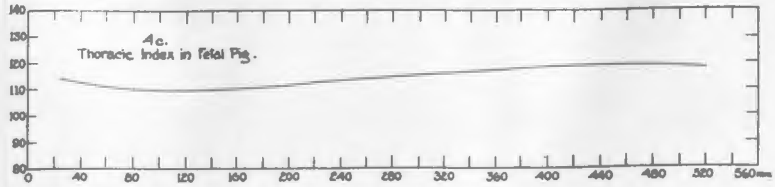

3 b.
Mid-sagittal diameter of Superior Aperture of Thorax.
" " " " Inferior " " "
100 mm
80
60
40
20
0
0
40
80
120
160
200
240
280
320
360
400
440
480
520 mm.

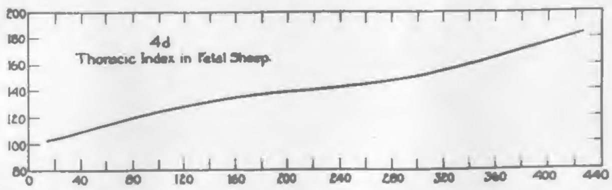

3 c.
Lateral diameter at level of Axillae.
" " " " " Xiphisternal Joint.
100 mm
80
60
40
20
0
0
40
80
120
160
200
240
280
320
360
400
440
480
520 mm.

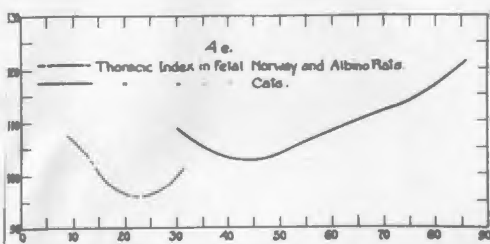
3d.

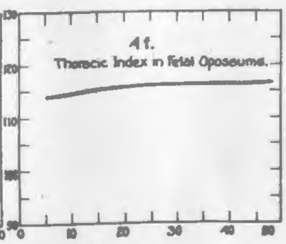



4a
Thoracic Index in Human Fetus.
200
140
120
100
80
60
40
0
80
120
160
200
240
280
320
360
400
440
480
520
560mm


4c.
Thoracic Index in Fetal Pig.
140
130
120
110
100
90
80
0
40
80
120
160
200
240
280
320
360
400
440
480
520
560mm


4d
Thoracic Index in Fetal Sheep.
200
180
160
140
120
100
80
0
40
80
120
160
200
240
280
320
360
400
440


4e.
Thoracic Index in Fetal Norway and Albino Rats.
" " " " Cats.
0
10
20
30
40
50
60
70
80
90


4f.
Thoracic Index in Fetal Oposeums.
0
10
20
30
40
50

4 b

Fig. 1.

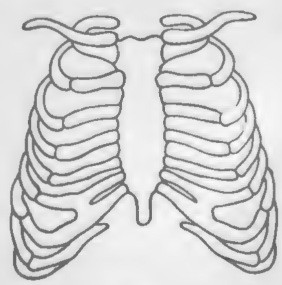


Fig. 2.
Anterior Aspect of Thoracic Cage in the Newborn.
(From Henke, 1881)

Fig. 3.

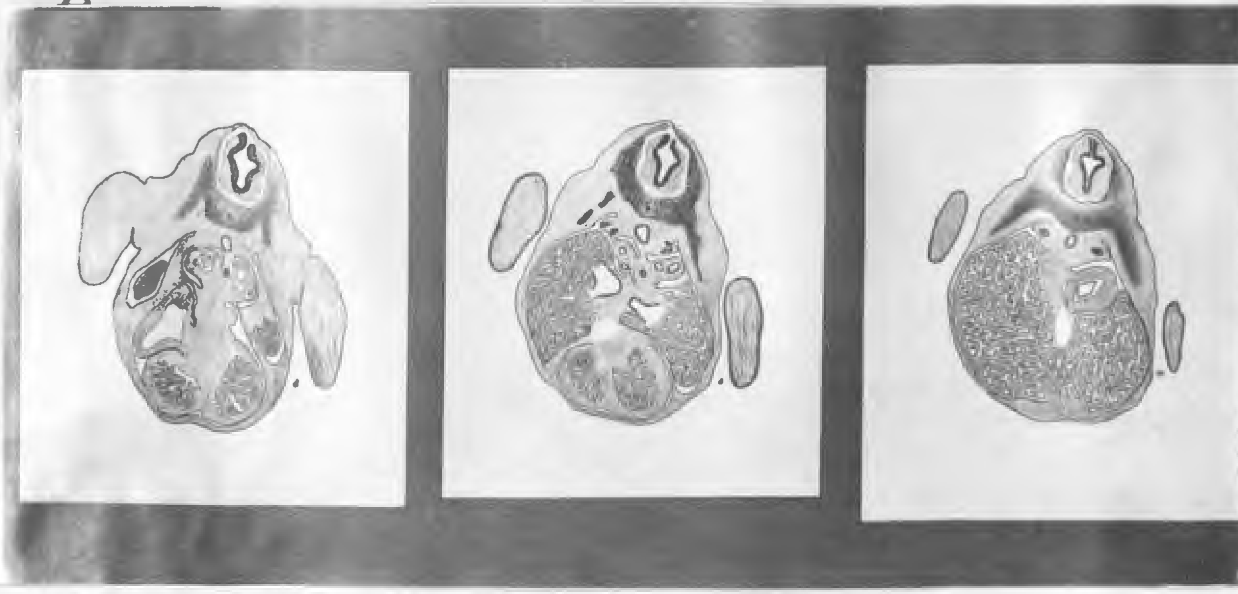


Fig. 4.

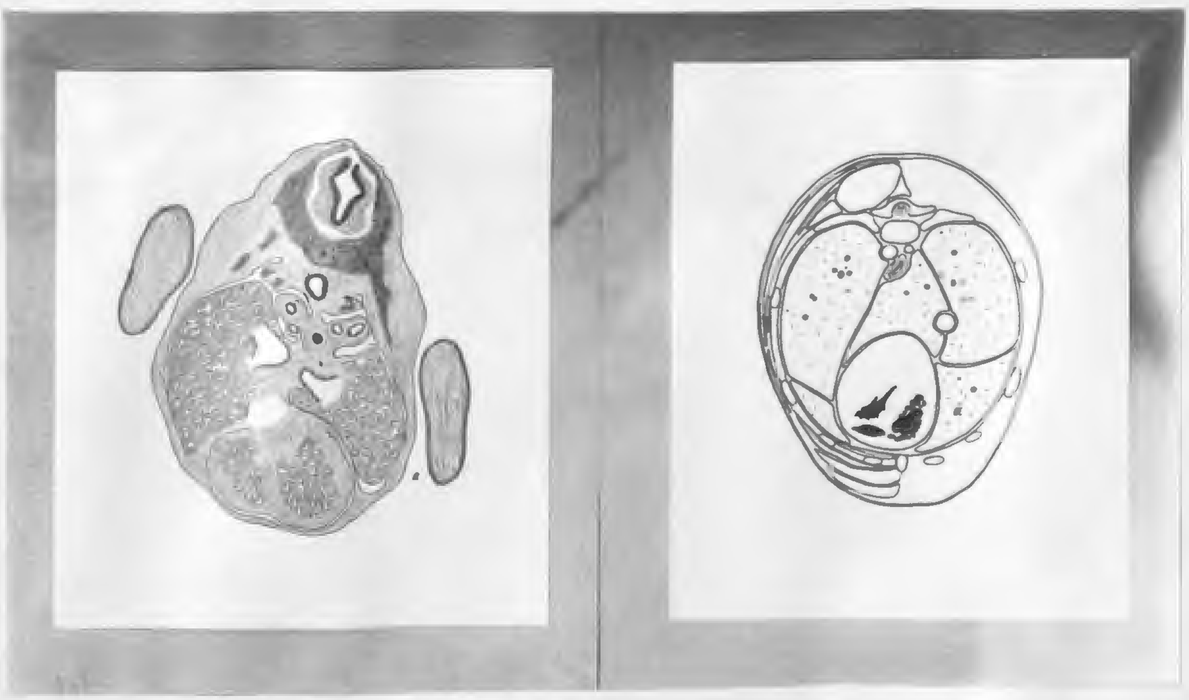


Table I.

Identification			Growth of Sternum		Location of Nipple		Growth of Infra-Sternal Angle		Growth in Midclavicular line		Changes in Post-wall of Thorax		
Case Number	Crown Heel in mm.	Sex	Length Incisura Jug. to Xiphi-stern. Junction in mm.	Incisura Jugularis to Symphasis Pubis in mm.	Opposite what rib or space?	Inter-papillary diameter in mm.	Width of angle in degrees	Distance between tip of 9th Rib in mm.	Distance mid-clavicle to costal arch in mm.	Distance mid-clavicle to Inguinal Lig. in mm	Length Thoracic Segm. of Spinal Col. in mm.	Width Sterno-Vertebr. angle in degrees	Angle between 12th rib at Spine in degrees
H388	50.	?	6	17	4S	7	105	11	12	17	13	30	
H143	52	?	6	17	4R	7.5	110	11	11	18	12	29	
H428	57	?	6.5	17	4S	8	104	11	11	19	14	27	
H414	50	?	6	17	4R	8	100	11	10	18	13	28	
H272	65	?	8.5	21	4R	9	105	11	14	22	16	26	
H429	72.5	?	8	24	5R	9.5	108	13	14	23	16	29	
G16-47	70.5	?	9	24	4S	9	106	12	15.5	24	16	30	
G16-51	82	?	10	24	4S	10	100	15	17	26	16	26	
E16-57	90	?	10	27	4R	12	103	16	19	29	16	27	
H74	91	?	12	29	4S	13	104	16	19	30	17	30	
H396	91.3	M	11.5	28	4S	11	103	15	19	27	17	24	
H503	94	M	12	29	5R	11	100	16	20	30	21	30	102
H101	105.5	M	13	31	4R	13	102	19	22	31	24	29	92
H342	97.7	F?	11	27	4S	12	105	16	19	28.5	20	30	90
G16-52	111.	M?	12	33	4R	14	98	20	25	36	25	29	92
H354	125.5	M	16	37	4S	18	100	23	27	38	27	33	85
H340	122.	F	16	38	4R	17	108	24	23	40	31	32	90
H504	151	F				22						29	
H30	153	M	18	50	5R	17	106	27	29	49	35	30	
H382	156	F	19	45	4S	20	105	27	33	51	37	28	90
H39	167	M	18	55	4R	20	108	29	28	53	37	20	
H177	168	M	19	60	4S	20	107	30	33	54	36	23	
H168	211	M	22	56	4S	29	110	29	36	60	40	25	
H90	214	F	24	65	5R	30	107	30	35	65	40	23	105
H149	210	F	23	65	4S	30	105	34	37	69	40	22	
H50	216	M	25	59	4S	31	105	40	39	67	44	20	
H186	209	M	21.5	61	4S	30	110	37	39	65	43	27	
H500	238	F	25	70	4S	32	105	39	43	70	46	28	105
H190	247	F	25	71	4S	28	108	41	42	73	41	28	
H197	254	F	29	75	4S	26	105	36	44	78	56	27	
H215	259	M	31	78	4S	37	105	44	49	86	50	32	
H202	268	M	31	79	5R	35	108	45	50	86	55	26	100
H82	261	F	30	83	4S	32	110	44	45	88	49	27	
J	250	M	30	79									
H170	289	F	34	87	4S	35	105	49	53	91	56	24	140
V	270	M	31	89									
H501	305	F	32	92	4S	37	108	52	54	97	59	25	
M	296	M	28	87									
H502	319	F	29	104	5R	39	106	58	56	107	61	30	112
V	297	F	24	85									
H220	335	M	37	110	4S	47	110	61	59	110	66	30	
T	298		29	87									
K	329	F	34	108	5R	40	95	45	63	111	56	25	115
F	350	F	40	119	4S	42	96	47	57	116	52	25	100
R	355	F	40	115									
P	357	F	34	129									
L	362	F	32	117	4S	43	100	54	59	118	66	30	112
GG	362	F	45	128	5R	56	103	63	64	132	66	25	110
W 291	364	F	37	132									
Hin. I	370	F	55	110	5R	44.5	105						
I	367	M	36	120									
B	379	F	39	126									
S	382	F	34	122									
B & D	395	F	50	145	4R	40							
2837	410	F	38	142	5R	52	100	64	71	143	79	28	115
2892	380	F	47	160		47							
A	415	F	39	134									
2480	455	M	60	165	4R	55							
2851	463	M	46	162									
2902	456	M	51	155	4R	52							
D	477	F	50	162	5R	61	110	67	83	163	80	30	120
C	488	M											
E	511	F	43	179									
2383	505	F											
N	512	F											
62973	516	F	44	167									110

Table II

Perimeters				Diameters								Index
Case No.	At level of Axillas in mm.	At level of nipples in mm.	At level of Xiphi-Sternal Junction in mm.	At level of Sup. Aperture: Sagit. Diameter in mm.	At level of Sup. Aperture: Transv. Diameter in mm.	At level of Axillas: Sagit. Diameter in mm.	At level of Axillas: Transv. Diameter in mm.	At level of nipples: Sagit. Diameter in mm.	At level of nipples: Transv. Diameter in mm.	At level of Xiphi-sternal Junction: Sagit. Diameter in mm.	At level of Xiphi-sternal Junction: Transv. Diameter in mm.	Taken at level of X-S Junction to avoid Pectoral Muscles
H388	38	41	42	7.5	8	8	11	10	12.5	12.	13	92.3
H143	37	40	40	7	7.5	9.5	10.5	10	12	11.5	12	95.8
H428	41	42	39.4	7.5	9	10	12.5	11	12.3	11.5	13.3	86.4
H414	38	40	41	8	7.5	10	12	12	12	12.5	11.8	94.4
H272	41	43	49	9	8	11	13	10.6	13	12.7	14.2	89.4
H429	45	47	50	10	9.5	12	16	13.6	15	14.7	15.5	94.8
E16-47	45	49	50	10.5	9	13	14	13.2	13	14	13.7	94.2
G16-51	52	55	55	11	10	14	17	15	17	15	16	93.7
G16-57	58	60	60	11.5	11	15	20	15.7	20	16.9	20.3	83.6
H74	55	58	60	12	10.5	15	19	17	19	18	19	94.7
H396	55	55	57	10.5	10	13	18	16	19	16	19	89.8
H503	65	65	67	14	12	18	17	18	18	19	19	100
H101	70	72	75	15	13	17	23	20	22	21.8	23	82.3
H342	56	58	58	11.5	10	15	17	17	17.7	17.5	17.8	98.
G16-52	70	72	75	13	14	19	23	21	23	22	22	100
H354	90	90	93	15	13	18	29	23	29	25	28	89
H340	89	90	94	18	16	22	29	25	29	26	28	92
H504	107	107	109	20	16	28	28.5	29	33	30	33	90
H30	108	110	112	23	20	27	32	29	32	33	35	94
H39	105	106	108	19	17	26	27	30	30	32	33	96.9
H177	90	93	97	16	16	20	24	22	26	25	29	86
H168			132					36	36	40	40	100
H 90	150	155	155	26	22	35	38	38	48	40	48	83
H149	145	155	160	25	25	34	41	43	47	43	47	91
H 50	150	155	158	28	25	36	39	39	40	40	46	86.9
H186	148	150	158	26	22	37	39	38	48	40	48	83
H500	173	177	178	29	25	44	46	48	55	49	53	92
H190	153	155	160	25	23	35	37	39	52	42	48	87.5
H197	145	150	155	27	25	38	38	42	42	43	46	93
H215	175	182	185	26	25	39	45	45	47	49	49	100
H202	165	175	185	28	25	37	42	49	46	49	49	100
H82	160	170	175	26	26	40	40	41	44	44	47	93.6
H170	175	180	185	32	30	41	41	44	45	47	48	97.9
H501	180	185	185	33	30	47	53	54	56	56	58	96
H502	195	204	202	34	34	50	52	56	58	62	63	98
H220	220	225	230	38	36	52	62	63	68	69	72	95.8
K	175	180	185	33	30	43	61	45	59	46	60	76.6
F	195	198	200	37	32	48	66	54	65	55	64	85.9
L	210	215	223	43	35	57	69	64	67	67	69	95.6
G G	245	250	250	49	44	68	81	71	74	72	74	97
Hin.I	195	205	215	37.3	35	46.5	55	54	65	59	72	81.9
B & D	200	210	215	40	32	49	54	60	67	64	69	92.7
2892	255	265	275	55	55	65	70	72	80	75	85	87
Hin.II	225	230	240	39	38	54	66	65	69	67	70	95.7
2480	270	275	285	57	50	65	75	82	77	80	85	94
2902	255	265	275	53	45	65	75	72	82	75	85	88
2855	250	260	255	47	42	61	68	66	70	75	75	100
2848	275	280	285	50	40	65	65	75	82	77	90	85.5
2854	270	275	285	52.5	47	67	79	75	86	77	96	81
2380	275	280	290	50	47	67	70	77	80	80	95	84
Ost. 2844	345	355	365	65	62	90	100	100	105	105	115	91

Table III. ADULT MAMMALS OF VARIOUS ORDERS, ARRANGED ACCORDING TO THORACIC INDEX

Index	Montremes	Marsupials	Edentates	Ungulates	Cetacea	Carnivora	Rodentia	Insectivora	Cheiroptera	Primates
200–180				Ox (293) Sheep (203) Moose Rhinoceros						Human Embryo under 32 mm.
180–160				Horse Wild Pig		Borzoi				
160–140		Dasyuridae		Hippopotamus African elephant Indian elephant	Bottle-nosed Whale					
140–120		Kangaroo Bandicoot Woodward's K. Sarcophilus		Domestic Pig		Wolf	Wild-Hare	Gymnura		
120–100		Wombat Wallaby Opossum Koala			Bowdoin's whale Blackfish Narwhal	Genet	Guinea-pig		Fruit-bat	Lemur. Anthropoid apes
100–80	Duck-bill	Dendrolagus Myrmecobius	Tamandua (ant-eater) Sloth			Kinkajou Seal Sea-lion	Woodchuck Hutch rabbit Beaver	Mole		Human Fetus
80–70	Echidua		Armadillo (53)			Badger Skunk				Human adult