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THE POST-NATAL DEVELOPMENT OF THE ANTERO-LATERAL ABDOMINAL WALL

With a Discussion of Certain Congenital Anomalies in This Region

Presented to the Faculty of Graduate Studies, McGill University, in partial fulfilment of the requirements for the Degree of Master of Science in Anatomy, in the Year 1950 A.D.

by

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PREFACE

An interest in post-natal developmental anatomy was acquired during a period of internship in surgery at the Children's Memorial Hospital in 1948. A considerable proportion of the infants and children requiring surgical treatment suffer from congenital defects; even a cursory review of the literature on this type of problem indicates the scarcity of precise data concerning anatomy in childhood, and therefore a lack of knowledge of the exact way in which these defects differ from the normal.

Admittedly, certain anatomical systems have been very thoroughly investigated, namely the cardiovascular and the osseous systems. The first of these has received much emphasis in recent years with the rapid advances in the surgery of congenital heart disease; the latter is capable of radiological study in the living subject, and has been described by specialists in this field. There are, however, a large group of defects which involve an equally important system, namely the body musculature. These are often not dangerous to life, and for this reason material for anatomic investigation is rarely available; it is with this system that this paper is primarily concerned.

The antero-lateral abdominal wall was chosen from among the many possible regions, because it is easily removed during the course of a routine autopsy, without disfiguring the external appearance of the subject. Failure of parents to claim children's bodies is rare, so that child cadavers are virtually unobtainable in this city.

I would like to express my gratitude to Professor C. P. Martin for his encouragement and help while this work was in progress. I am indebted to Dr. W. Wigglesworth for his permission to obtain material for this study from the Pathology Department of the Children's Memorial Hospital, and to the members of his department for their cooperation in this regard. To Mr, John Isaacs the credit is due for the photographic reproduction of the drawings included herein.

Montreal, July 31, 1950

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Chapter I

Comparative Anatomy

1. Comparative Anatomy of the Coelom and Abdominal Walls

If one accepts the hypothesis that in general the development of a new structure in the animal kingdom follows closely upon the demand for a new function, then the original function of a given structure can be determined by tracing it backwards in the animal scale to the point at which it first appears and noting the particular functional demand acting on the organism at that time. It will be seen that his original function need not be retained, but rather may be lost or transferred to some other structure, and the original structure adapted to some other use.

Wood Jones (72) traces the functional history of the coelom, abdominal walls, and diaphragm.

The animal stage preceding the appearance of the coelom, or body-cavity, is represented by the Coelenterata. In these organisms the archenteron of the gastrula is the only cavity in the body. The body wall is essentially of two layers, the epi-blast and endo-blast, with a poorly formed intervening meso-blast. The corals are typical of this group, the individual organisms being of small size, with enlargement by colonization.

In the higher Metazoa, the Coelomata, a second body-cavity or coelom appears, (12), either by cleavage of the meso-blast or by budding-off of closed archenteric sacs. This group includes among the lower classes the worms, arthropods and molluscs, and among the higher classes the chordates and vertebrates. The development of a coelom is apparently coincident with that of a primitive circulation, and allows increase in size of the individual. In the Annelida, the body-cavity is first definitely established and a well developed vascular system is formed, serving primarily a nutritive function.

This circulation is then further adapted for a respiratory function, or hemo-lymph system, obtaining oxygen first solely by diffusion from the body surface. As the body becomes larger, this simple system becomes inadequate; an intra-coelomic respiratory organ is formed by which aeration of a larger and more highly specialized area is possible. In the worms this takes the form of simple ectodermal sacs, and in the arthropods of elaborate superficial tracheal systems. In the vertebrates the process is essentially the same, with the formation of entodermal sacs or lungs. As will be seen, this type of aeration is dependent upon the development of the body wall; diaphragmatic respiration is a much later development.

A body wall comparable to that of man is seen in its earliest form in the dogfish. Dorsal to the lateral line the muscles run longitudinally; ventrally the muscle is single-layered and oblique, corresponding in direction to the internal oblique. The function of this layer is primarily concerned with resisting the external water pressure, and within this layer the ribs are formed. In later fish a second layer is added, corresponding to the external oblique, which functions mainly to increase body movement in locomotion; in higher animals this is further adapted in the formation of the pectoral and pelvic girdles, and in the terrestial animals in the formation of an external respiratory musculature by which intracoelomic pressure is decreased. In the amphybia a third layer is added, coincident with the assumption of a terrestial existence, and corresponding to the transversus layer. This latter layer apparently replaces the external water pressure in assisting the expulsion of excreta and in expiration.

The fibres of each of the three layers, on approaching the ventral midline, assume a vertical direction; the vertical fibres of the three layers are thought to combine in forming the rectus muscle.

Bland-Sutton (130), believes the pyramidalis muscles, a pair of small and inconstant muscles lying in front of the lower rectus muscles in man, to be homologous with similarily situated muscles in marsupials. In the latter case, however, they are large, arising from the epipubic bones, and acting on the marsupial pouch. The epipubic bones, he states, are probably represented in man by the inner pillers of the external inguinal ring and the pectineal lines.

2. The Rectus Sheath

Mijsberg (97), has studied the ways in which the flat muscles of the abdominal wall contributes to the formation of the rectus sheath in the primates. In addition to the three flat muscles mentioned above, he describes a fourth layer, intermediate in position between the external and internal obliques, and present in all the monkeys, which he terms the "membrana abdominis intermedia". This layer is believed to be homologous with a layer of muscle in the Urodele Amphybia and in reptiles, termed the "M. obliq. ext. profundus", lying deep to the layer of most superficial muscle described by Wood Jones.

The primary condition of the rectus sheath, he believes, is for the transversus, internal oblique, and membrana intermedia layers to lie entirely deep to the rectus muscle, as found in the Urodiles and Reptiles. In the monkeys, this original condition was found to be least changed in Ateles paniscus, in which the transverse and internal oblique layers lie entirely deep to the rectus, the external oblique lies in front of it, and the caudal half of the membrana intermedia blends into the lateral border of the rectus. In Semnopithecus, the membrana intermedia and internal oblique both lie anterior to the rectus throughout its length, with the transversus anterior in the lower abdomen only. Man is intermediate between these two extremes, the internal oblique being entirely anterior to the rectus in the lower abdomen, but splitting to enclose the rectus in the upper abdomen.

Thus there seems to be a gradual piercing process by which the rectus attains a progressively deeper position relative to the flat muscles. The arcuate lines, marking the lower limit of the posterior rectus sheath, result from this process. Mijsberg attempts no explanation for such a change occurring.

3. Comparative Anatomy of the Diaphragm

It is pertinent to discuss this structure in conjunction with the anterior abdominal wall, since they are intimately related in both development and function. Although the human diaphragm is generally thought of as being primarily a respiratory organ, an efficient pulmonary respiration was developed far in advance of any structure dividing the body cavity into pleural and peritoneal parts. Wood Jones (72), shows that this organ develops first to fill the need for increased intra-coelomic pressure, and is only secondarily adapted as an internal respiratory mechanism.

Vestiges of a diaphragm are first seen in the amphybia and reptiles, and are formed from fibres of the transversus muscle layer. In the birds this takes the form of a non-contractile membrane. Even in an animal as large as the ostrich (82), respiration is adequately carried on by means of the external musculature alone. A true diaphragm is found in the mammalia alone, and appears coincident with an increasing complexity of the pelvic floor and the innovation of giving birth to living young. In the lower animals, ova and excreta are extruded through a single cloaca, a procedure requiring no great expulsive effort. In the mammals, however, the excreta are not semifluid, but rather bulky formed stool, and urine which must be forced through the complex sphincters of the pelvic floor; in addition the female must be capable of parturition. The diaphragm is then a means of increasing intra-abdominal pressure, and it seems logical that it be formed from the transverse muscle layer, which was developed originally for this purpose as described above.

The original transversus layer extending from the cervical to the caudal regions of the organism, is represented in the higher animals by four structures (35). Its cervical portion forms the diaphragm, which during its ontological development will be seen to migrate to a position between the thorax and abdomen. The thoracic and abdominal portions form the transversus abdominis and transversus thoracis muscles respectively. The caudal portion is believed to form part of the inner musculature of the pelvic floor.

Location of the heart and lungs above the diaphragm is apparently secondary to the increased intra-abdominal pressure, in that it spares these vital organs from the deleterious effect of such pressure. In the quadripeds, diaphragmatic action is not essential to respiration, reliance being placed on the external musculature, the external intercostal muscles and those of the pectoral girdle. Lemon (83), states that bilateral staged phrenic avulsion in the dog, followed by complete excision of the diaphragm, is well tolerated, and compatable with over three years of activity.

Relatively great reliance on the diaphragm for efficient respiration is found in the primates, and is believed to result from loss of fixation of the upper limb, and therefore loss of efficiency of the external mechanism. Cetacea also exhibit a well developed diaphragm, and these mammals also lose the fixation of their pectoral girdle by virtue of their aquatic existence.

Chapter II

Embryology

1. Embryology of the Abdominal Wall

Little work had been done on the gross development of the vertebrate musculature until 1900, when Bardeen (4), and Bardeen and Lewis (5), described the development of the body wall of the pig and the human.

The body wall of the mammalian embryo is first composed of the "membrana reuniens", a thin transparent membrane continuous with the umbilical cord, and enclosing the pericardial, pleural and peritoneal coeloms. The somatic structures arise first in the dorsal region, on either side of the neural tube. The first stage of development of the musculature is the appearance of individual segmental myotomes, persisting up to the 12-14 mm. stage. Neuromuscular attachment is believed to occur at this time, so that in the adult the nerve supply of a given muscle gives an accurate indication of its segmental derivation.

In the second stage, 12-23 mm., adult muscle groups are formed from the myotomes. This occurs by the ingrowth of vascular mesenchyme splitting the original myotomes, and by fusion of adjacent myotomes to form longitudinal muscle masses. At the end of this stage the individual muscles can be dissected out.

Figure 1 shows a diagrammatic cross-section of a pig embryo near the end of this stage.

The third and final stage consists of forward growth of the muscles into the membrana reuniens, until finally the recti meet in the ventral midline. Once a muscle is formed, it may alter its relation to the embryo in three ways:

1) By expansion in breadth and width, it may occupy a much greater relative area.
2) Passive shifting by growth of underlying skeletal or other structures. This is illustrated by the forward shifting of

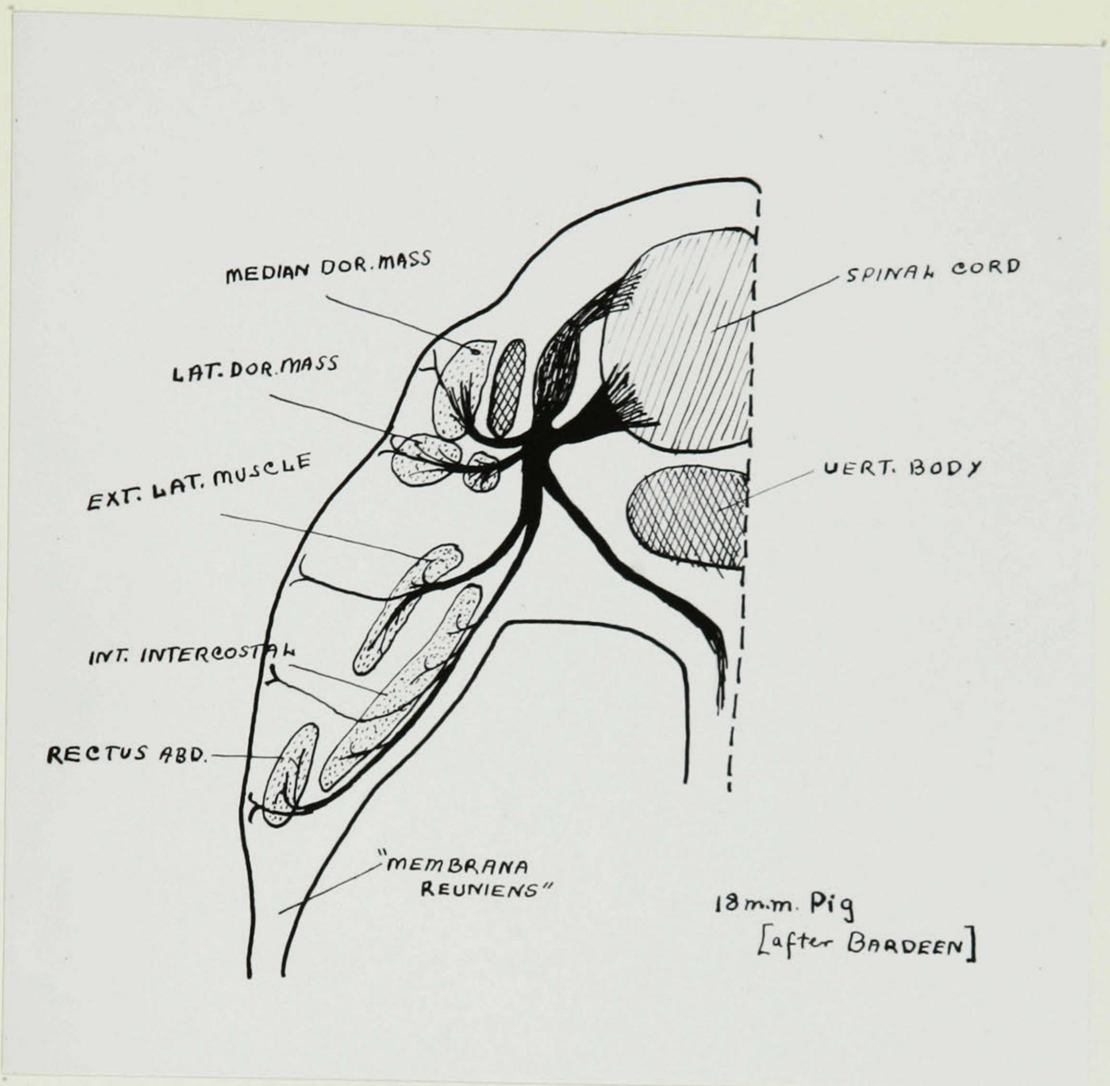

Fig. 1. Transverse section of an 18 mm. pig embryo in the zone of the developing rectus muscle. Muscle masses are stippled, nerves are dense black, and skeletal anlage cross-hatched. After Bardeen, (   ).

the rectus muscle by growth of the chest wall and pubis towards the ventral midline.

3) New muscle may be formed from pre-existing muscle, but having a new relationship to other structures. This is illustrated by the formation of the innermost intercostal from the internal intercostal, on a plane deep to the intercostal nerve.

Closure of the ventral midline takes place first in the regions of the upper sternum and the pubis. The region of the umbilical cord and epigastrium is thus the last to close. The ingrowing muscular body-wall closes up against the umbilical area by the tenth week in the human, and at this time the intestine is normally withdrawn from the cord and returns to the peritoneal cavity. The coelomic extension into the cord is obliterated by the end of the twelfth week.

Growth of the somatic musculature, in size and degree of differentiation, continues through birth until the individual reaches maturity. Bardeen quotes Morpurgo, in 1898, as saying that new striate muscle cells are formed in the rat until shortly after birth. Whether this is also true in the human is not certain.

2. Embryology of the Diaphragm

Mall (87, 88), in discussing the development of this organ, states that it is one of the most difficult problems in embryology, due to the constantly changing level of the diaphragm relative to the embryonic segments, and due to its constantly changing inclination, as the curvature of the embryo straightens out and the heart changes from a ventral to a cephalic position relative to the abdominal region.

Figure 2 gives a diagrammatic representation of this process. After Wood Jones (72).

His (35, 65) recognized the anlage of the diaphragm in a mass of tissue in the head region of the embryo, which included the liver anlage and the venous end of the heart, and termed this mass the "septum transversum". Uskow (140), in 1883, described two additional structures, which he termed "pillars", extending from the dorsal aspect of the septum transversum. Brachet called these latter the "pleuro-peritoneal" and "pleuro-pericardial" membranes, the latter containing the ingrowing phrenic nerve.

Mall considers these two pillars or membranes as arising from a common structure, the "pulmonary ridge", extending from the septum transversum dorsally to the dorsal attachment of the mesocardium. It lies in a transverse plane, and has cephalic and caudal horns, corresponding to the pillars or membranes of the earlier writers, between which lie the ductus Cuvieri on each side.

In the early embryo (87, 135), nearly the entire coelom lies in the head region, forming a space around the ventral and lateral surfaces of the heart, with tubular extensions dorsally and then caudally on each side lateral to the dorsal mesentery. The septum transversum forms a reference point allowing division of this single cavity into the median

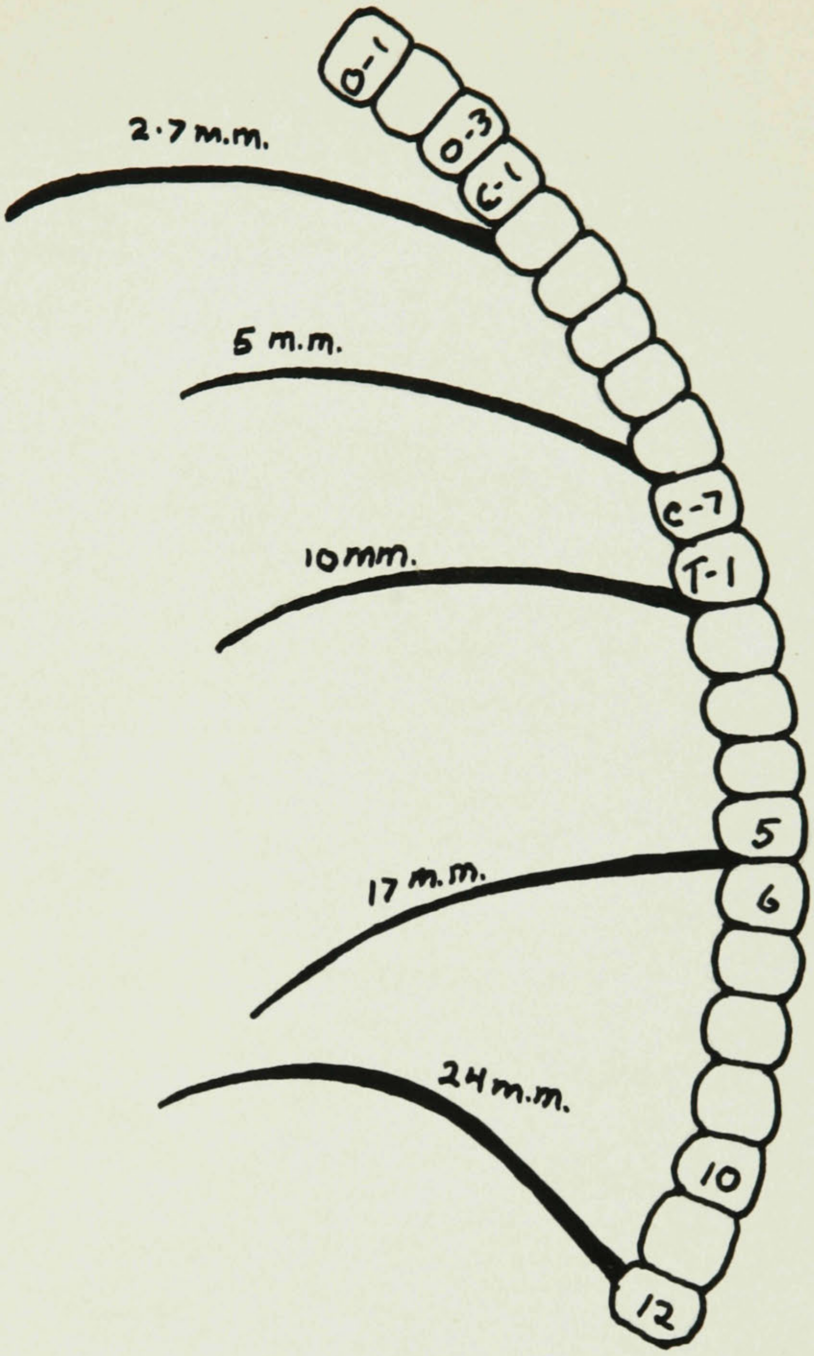

Fig. 2 Changing level and inclination of the diaphragm in the embryo relative to the spinal segments. O-, C-, T-, indicate occipital, cervical, and thoracic segments respectively; embryo size is shown in mm. at each level. After Wood Jones, ( ).

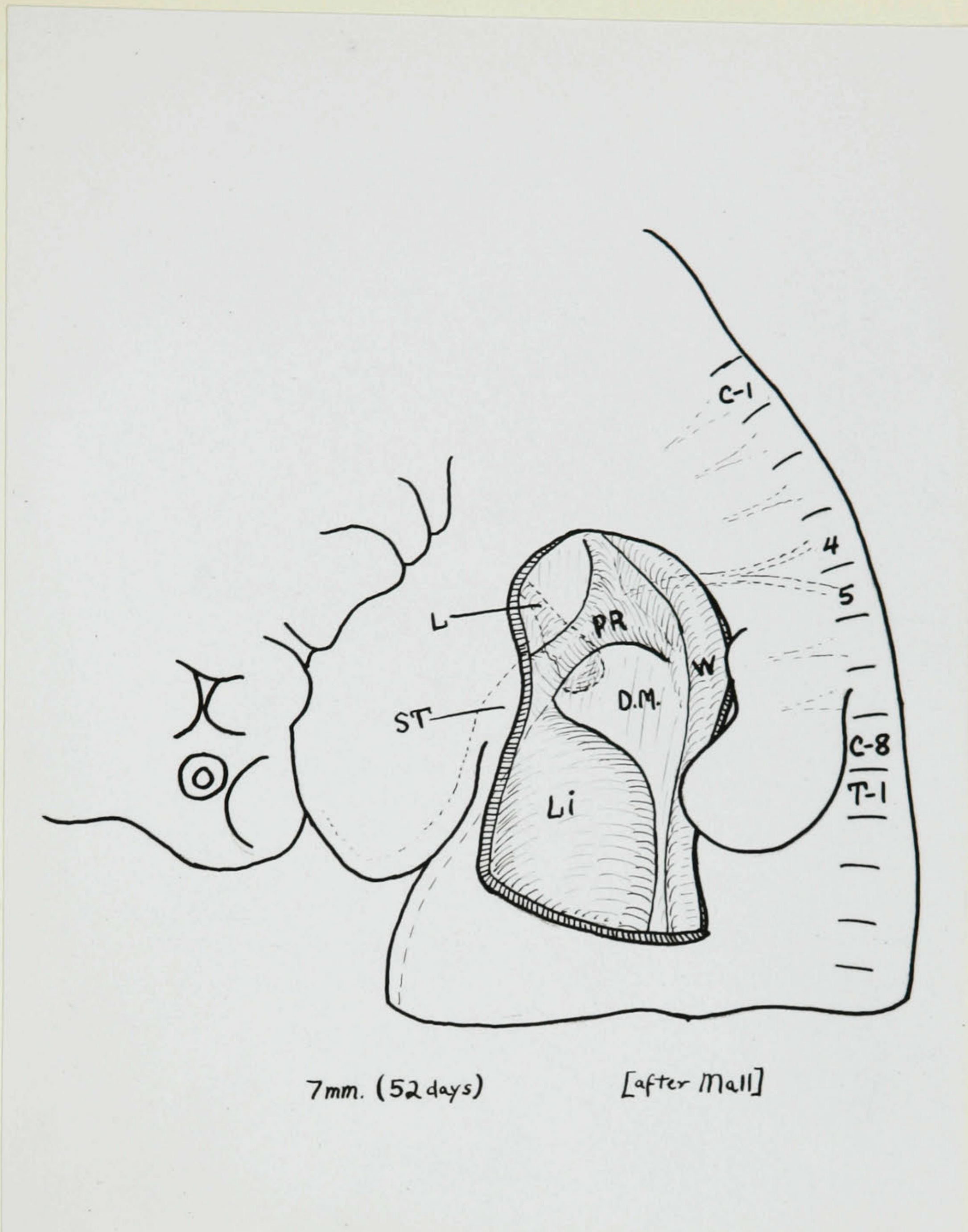

Fig. 3. Lateral view of the pulmonary ridge, (PR), in a 7 mm. embryo. L, lung bud; ST, septum transversum; Li, liver anlage; DM, dorsal mes-entery; W, Wolffian ridge. Ingrowing phrenic nerve represented by dotted lines opposite 4th and 5th cervical segments. After Mall, ( ).

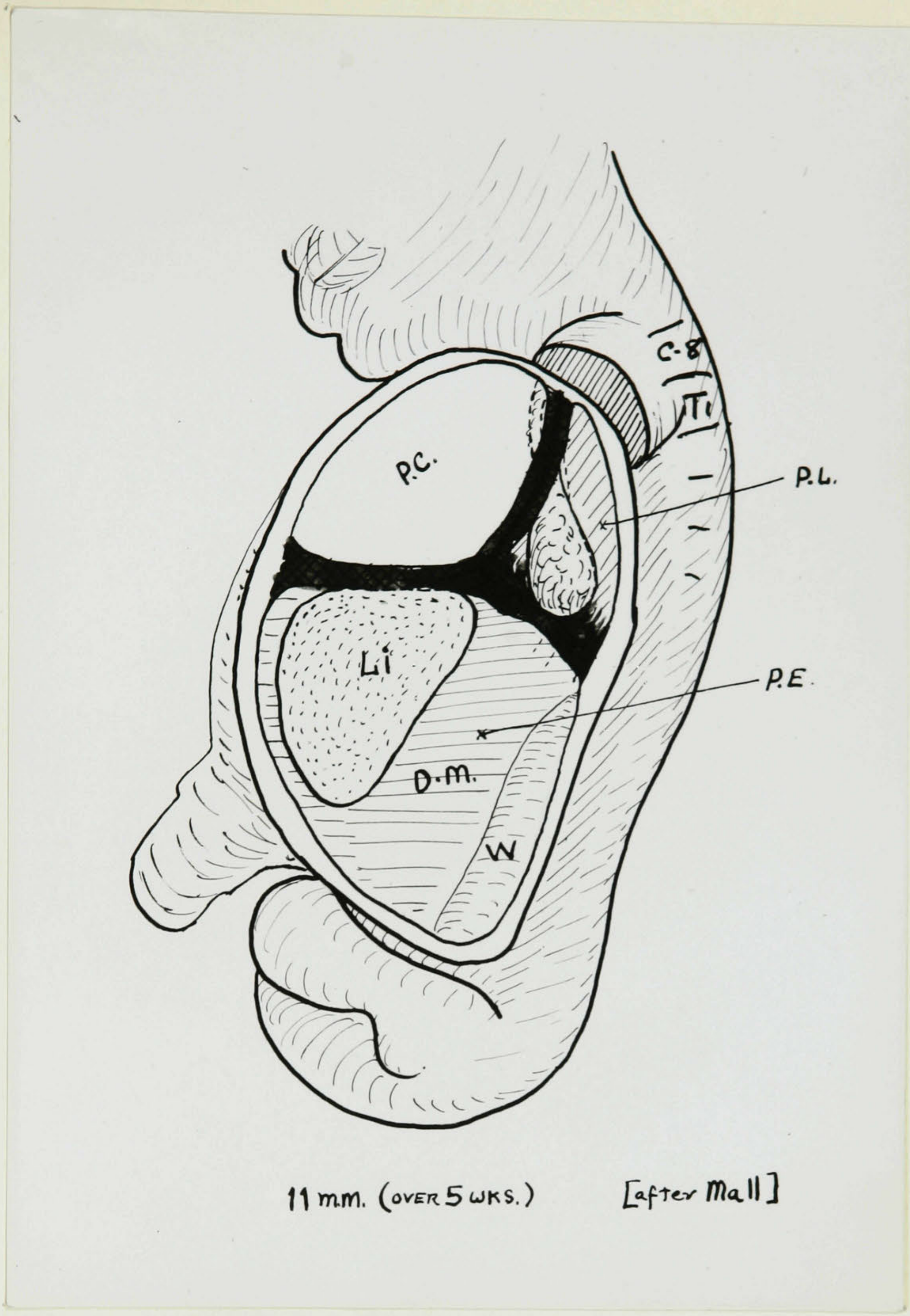

Fig. 4. Lateral view of the septum transversum, (black), in the 11 mm. embryo. Note cephalic and caudal horns. PC, PL, AND PE, pericardial, pleural, and peritoneal cavities; Li, liver; DM, dorsal mesentery; W, Wolffian ridge. The lung bud is being everted into the pleuro-peritoneal cavity. Intestinal tract not shown. After Mall, ( ).

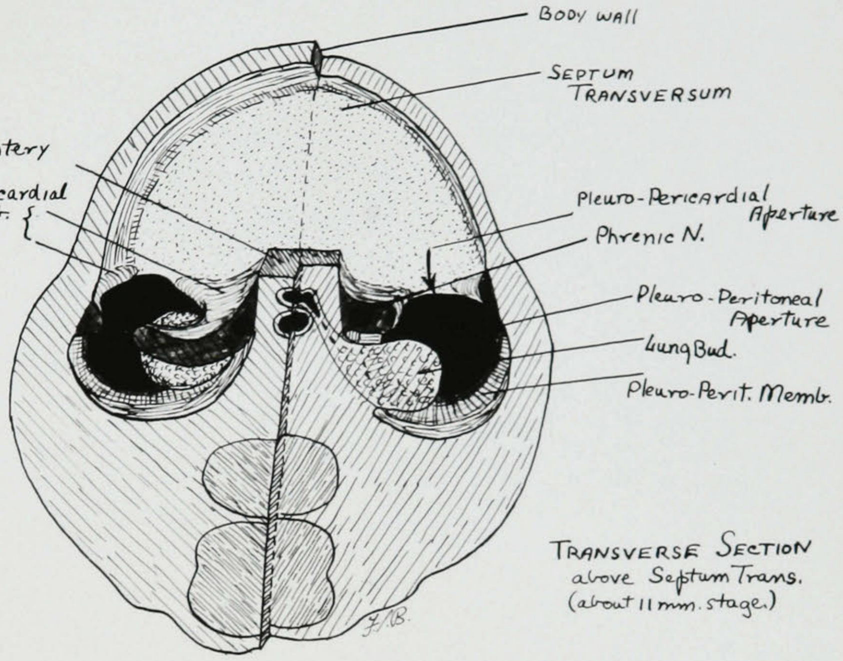

Fig. 5. Diagrammatic reconstruction of transverse sections at two levels just above the septum transversum. The heart and great vessels are not shown. After Mall, ( ).

pericardial coelom and two paired pleuro-peritoneal coeloms. The pericardial coelom recedes from the head region in consequence of the development of the branchial region and the limb buds.

The pulmonary ridge is not definitely established until about the 7 mm. stage (Fig. 3). At this time the cephalic horn is present, as a bulging in the wall, or a constriction in the cavity, of the coelom, between the pericardial and pleural regions. The pleural region is indicated by the appearance of the lung buds, projecting forward and laterally from the fore-gut. The lungs, liver, and stomach develop within the dorsal mesentery until, by reason of increasing size, they are turned out or evaginated into the coelomic space. The pelrual region thus becomes established and expanded by the growing lung buds.

By the 11 mm. stahe (Figs. 4 and 5), the cephalic and caudal extensions of the pulmonary ridge are well formed, with the phrenic nerve extending through the former to the septum transversum. The pleuro-pericardial apertures close first, by the 20 mm. stage, the pleuro-peritoneal aperture remaining open with the rapidly growing lungs projecting into the peritoneal region.

The diaphragm becomes an intact structure by the end of the second month. Closure of the pleuro-peritoneal canal occurs first on the right side; this may be due to a more rapid growth on this side due to its greater vascularity, in consequence of the persistence of the ductus Cuvieri on this side, and the preponderence of the liver on the right (35).

The adult derivatives of the various embryonic precursors of the diaphragm have been fairly well established. Broman (18), by a diagram which is frequently reproduced in the texts, indicates four origins:

1) The pericardial part of the central tendon and the anterior muscle fibres are derived from the septum transversum.
2) The crura and tendon around the aorta, oesophagus and vena cava are from the dorsal mesentery.
3) The right and left domes are from the pleuro-peritoneal membranes.
4) Finally, a peripheral region is said to be derived from the musculature of the chest wall by its being added to the circumference of the diaphragm after its descent from the neck region.

This latter origin has been disputed by later authors, since if such were the case, the peripheral muscle should be supplied by motor nerves from thoracic segments. Experimental section of the phrenic in the dog, and post-mortem studies in man after accidental phrenic section, have shown that this is the only motor nerve supply (83). Nerve fibres seen entering peripheral muscle from the lower intercostals histologically, are purely sensory in character.

3. Embryology of the Sternum

Whitehead and Waddell (143), studied the formation of this structure in the pig, cat, and human. Ruge, in 1880, said the sternum was formed by the fusion of two longitudinal cartilaginous bars, derived by fusion of the ventral ends of the embryonic ribs. In 1900, Patterson (111), claimed its formation as a single median cell mass. In the pig and cat, the first evidence of a sternum is the appearance of two cellular bands in the anterior thorax, which are not derived from the ribs. As the heart sinks into the thorax with growth of the latter, these bands fuse, first at their cephalic ends. At this time, a single median cell mass appears above and fuses with this upper end. In the human the process is essentially the same, except that the clavicle enters into closer relationship to the median cell mass. The median structure, they believe, is homologous with the episternum of the lower vertebrates or the prosternum of the monotremes.

Hanson (62), agrees with these authors, and adds that after fusion in the midline, the sternum is secondarily divided transversely into sternebrae. These sternebrae are always intercostal, and therefore do not correspond to the original segmentation of the ribs. He states that the origin of the sternum is homologous for all vertebrates, the originally paired meso- and xiphi-sternum uniting in the midline, as in the mammalia, or persisting as separate horns, as in some amphibia and reptiles.

Chapter III

Post-Natal and Adult Anatomy

1. Introduction

This report is concerned with the gross anatomical findings after dissection of twenty specimens. These include portions of the abdominal walls of sixteen children, obtained at autopsy; of these, eleven consist of complete anterior abdominal walls, including a generous portion of the flat muscles of the lateral wall on either side, with the lower anterior chest wall from the third costo-sternal junction down, a shaving of the crest of the pubis comprising the insertion of the recti, and that part of the anterior diaphragm attached to the chest wall as far dorsally as the inferior vena cava. The remaining four children's specimens are incomplete, comprising only the rectus muscle of one side and part of the linea alba, detached from the chest wall and pubis. Two complete adult abdominal walls were dissected; these agreed in detail with the descriptions in the anatomy texts, and were used to obtain particular measurements for comparison with those of the children.

In addition, the chest, abdominal wall and diaphragm of a fetus of 6 1/2 to 7 months were dissected. The abdominal and chest wall of a stillborn child with a large midline defect or omphalocele was obtained from the Pathology Department, and will be described in detail.

All specimens, with the exception of the fetus and the two adults, which had been embalmed, were obtained from fresh autopsy material within twelve to eighteen hours of death. The first four taken were incomplete, attention being focussed primarily on the recti and linea alba, and an attempt being made to take as little adjacent tissue as possible. This procedure was, however, found to be inadequate to allow accurate measurements to be made, and in addition, the scope of the investigation was expanded to include the diaphragm and lower chest wall in relation to the congenital deformities, "pigeon chest" and "funnel chest".

Once removed from the body, there was considerable variation in the measurements obtained, depending on the degree of tension on the tissues. For this reason, the specimens were placed in a formalin solution as soon as possible, and not dissected until completely fixed. Under these conditions, the various measurements are thought to be comparable from one case to another.

The pertinent vital statistics of each case were obtained from its hospital report, together with the presumed cause of death. Since all of these children had been very ill, usually for some time prior to death, there was a considerable discrepency between their ages and weights as compared to the expected normal. Thus a comparison of the degree of development of soft tissues in different cases, based on either one of these factors, must necessarily be inaccurate. In this report, the measurements have been tabulated according to age.

In the following description, each structure will be dealt with individually, giving the pertinent measurements and observations taken from the various specimens, together with a brief description of the adult anatomy of the part. The individual subjects are referred to by age and number; a general description of each subject is given in Appendix I.

2. Superficial and Deep Relationships of the Muscular Abdominal Wall

The superficial relationships of the abdominal wall consist of the skin and subcutaneous tissues overlying this region. Congdon (31), uses the term "tela subcutanea" in discussing this area. The thickness varies with the amount of adipose tissue; the "panniculus adiposus" is made up of shell-like plates of fibrous tissue forming incomplete walls for the intervening spaces or alveoli, containing lobules of fat. In the thin subject, this panniculus may be only two alveoli thick, with the septae running parallel to the surface; in fat subjects it is up to six alveoli thick and the septae enclose globular or even vertically alligned spaces. In the anterior midline, "retinacula" have been described between the skin and linea alba; these are incomplete allignments of alveolar walls, and never form a complete septum between one side and the other.

In the children examined, incomplete fibrous septae running from the skin to the linea alba were found to be most easily defined near the umbilicus, extending upwards and downwards in the midline from the umbilical cuff for as much as one inch.

Congdon describes the superficial fascia, or "Camper's" fascia, as sheets of fibro-elastic tissue formed by the allignment of alveolar walls, lying parallel to the surface. This fascia is usually made up of a number of sheets of varying size, often incomplete, whose adjacent edges may overlap so that two layers are found in some places.

At operation, this layer is usually easily defined and sutured in children; in the fixed specimen it may be seen easily in cross-section where the abdominal wall is quite fat, but if dissection is attempted a clear plane of cleavage cannot be found.

In the lower abdomen, two layers of superficial fascia are described (85), one superficial as above, and a deeper layer to which the name of Scarpa has been affixed. This second layer is said to fuse with the more superficial in the upper abdomen, to be attached to the deep fascia of the thigh below the inguinal ligament laterally, and to follow the spermatic cord into the scrotum medially. Congdon considers this layer to be similar to Camper's fascia, and a reduplication thereof in the lower abdomen; he refers to Roux, who in 1883 explained the formation of such sheets of fascia in animals as due to the condensation of intralobular septae in regions of stress. A second panniculus adipose may be found deep to this layer. The true deep fascia of the abdomen is the perimysium of the abdominal muscles, comparable to that elsewhere in the body.

The deep relationships of the abdominal wall, from within outwards, are the peritoneum and the properitoneal connective tissues. Davies (37), visualizes the abdominal wall as a cylinder of voluntary muscle surrounded by a connective tissue sheath; the superficial layer is the deep fascia of the abdomen, while the inner layer is the "Transversalis fascia". Between this latter fascia and the peritoneum is the sub-peritoneal fibro-areolar layer containing a variable amount of fat. Lockhart (85), defines the transversalis fascia as that covering the deep surface of the transversus muscle. In the lower and lateral abdomen it is continuous with the inner sheaths of the transversus abdominus, quadratus lumborum, iliopsoas, obturator internus and levator ani muscles (95). In the upper abdomen it is more distinct and fuses with the fascia of the undersurface of the diaphragm; in the anterior median area, it is distinct from the posterior rectus sheath and linea alba, but attached to the inner aspect of the umbilical scar. Moschcowitz (101), describes the attachment of this fascia to the linea alba at the sites of perforation by vessels, forming potentially weak spots where spontaneous herniae may occur.

In the cases studied, the above description was confirmed insofar as the anterior wall was concerned. A space exists between the sternal and costal origins of the diaphragm; this is not a real space in the normal subject, and is only made so by the removal of the transversalis fascia and subdiaphragmatic fascia. In the lower anterior abdomen the transversalis fascia is very thin, and in the undernourished subject is separated with difficulty from the peritoneum; below the arcuate lines these layers form an inner covering for the lower rectus muscle.

Classically, from within outwards, four layers are mentioned, the serous peritoneum, the fibrous layer of the peritoneum, the extra-peritoneal connective tissue, and the transversalis fascia. Browne (21), believes the confusion to result from the use of the term "fascia" to describe connective tissue planes of very different consistencies and in many locations. He suggests the term "abdominal connective tissue", to describe an investing layer between the osteo-muscular box and the serosal peritoneum, including the transversalis fascia, the tela sub-serosa, the fibrous layer of the peritoneum, the visceral layer of the pelvic fascia, the renal fascia, the extra-peritoneal fat, and all other indefinite terms. Any structure passing out of the abdomen during its development, such as the testis, femoral vessels, or an external hernia, will carry with it a sheath of this tissue. Condensations of fibrous tissue will occur wherever strains occur, forming the so-called suspensory ligaments, and large amounts of fat are found where a "packing material" is required. The easiest plane of cleavage is found between the muscles and this layer, the so-called "extra-peritoneal" space.

3. The Linea Alba and Umbilicus

Lockhart (85), describes the linea alba in the adult as a band of interlacing fibres of the musculo-fascial abdominal wall, located in the ventral midline, pierced by the umbilicus, and forming the greater part of the ultimate insertion of all the lateral abdominal muscles. He states that it is narrow below the umbilicus but increases in width to about half an inch in its upper part.

Waterston (142) has described the manner in which the fibres of the two rectus sheathes interlace in the midline, producing a thick membrane which is quite elastic in a vertical direction, but relatively inelastic transversely. This is essential, in that the linea must adapt to variations in length with changes in posture, whereas it is subject to a fairly constant pull transversely by the flat muscles; this latter amounts to a pull of 30-50 pounds under light anaesthesia (7).

Brown has recently described the linea alba as a continuation of the posterior perichondrium of the sternum, or "membrana sterni", distal to the xiphoid process (19). In none of the specimens dissected was this found to be the case. The linea alba at its extreme upper end is composed essentially of the anterior rectus sheath, the medial extension of the external oblique fascia. This blends with the perichondrium of the front of the xiphoid and lower sternum between the origins of the recti. The tip of the xiphoid is always free in the areolar tissue deep to the upper rectus; that is, the linea alba attaches to the anterior surface of the xiphoid as much as half an inch above the tip.

Figure 6, illustrating the immediate relationships of the xiphisternal area, demonstrates this point.

The width and shape of the linea alba varied considerably at

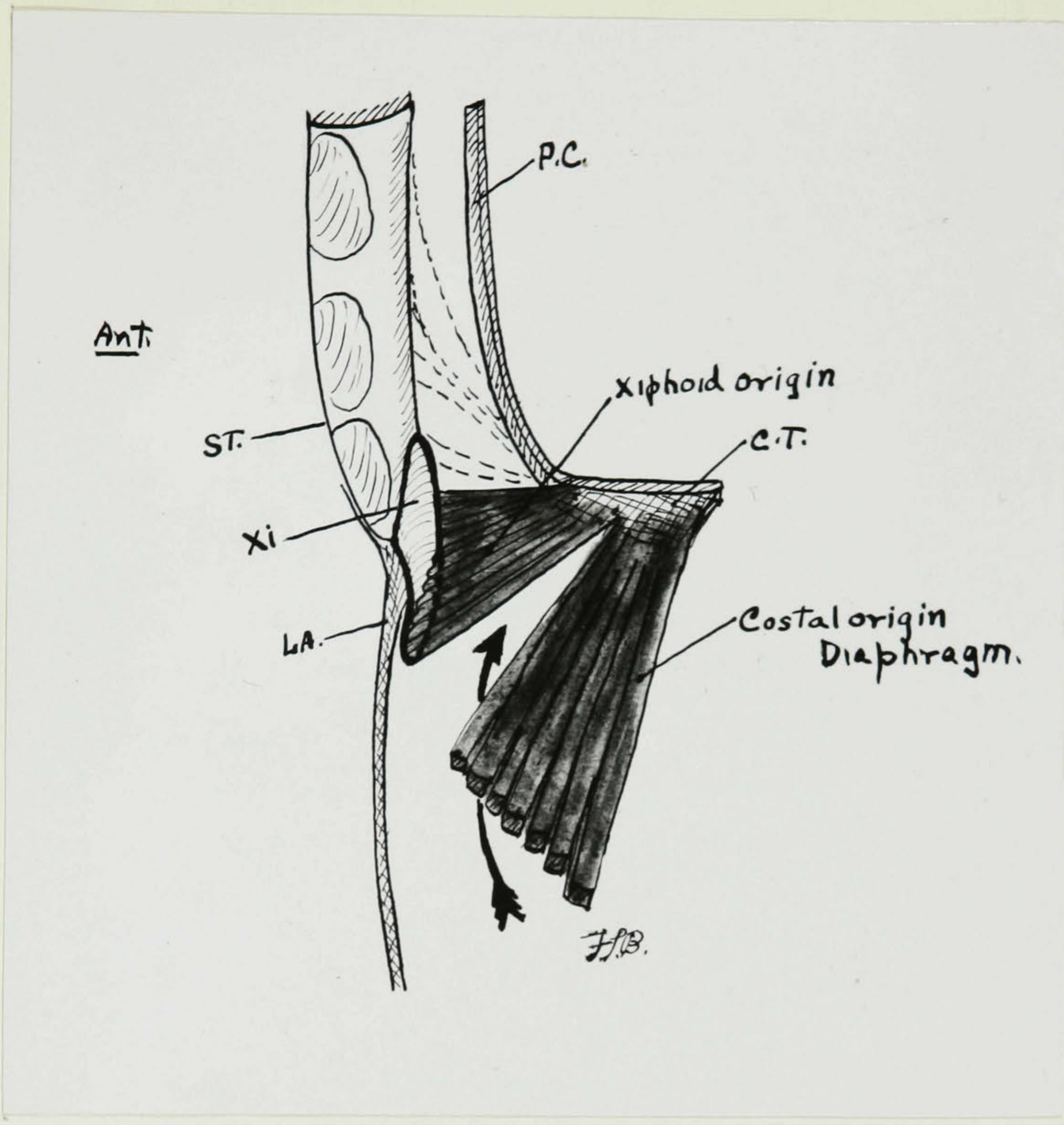

Fig. 6. Relationships of the xiphi-sternal area. ST, sternum; Xi, xiphoid; La, linea alba; PC, pericardium; CT, central tendon. The arrow indicates the sub-costo-sternal diaphragmatic aperture. Dotted lines indicate variable weak sterno-pericardial "ligaments".

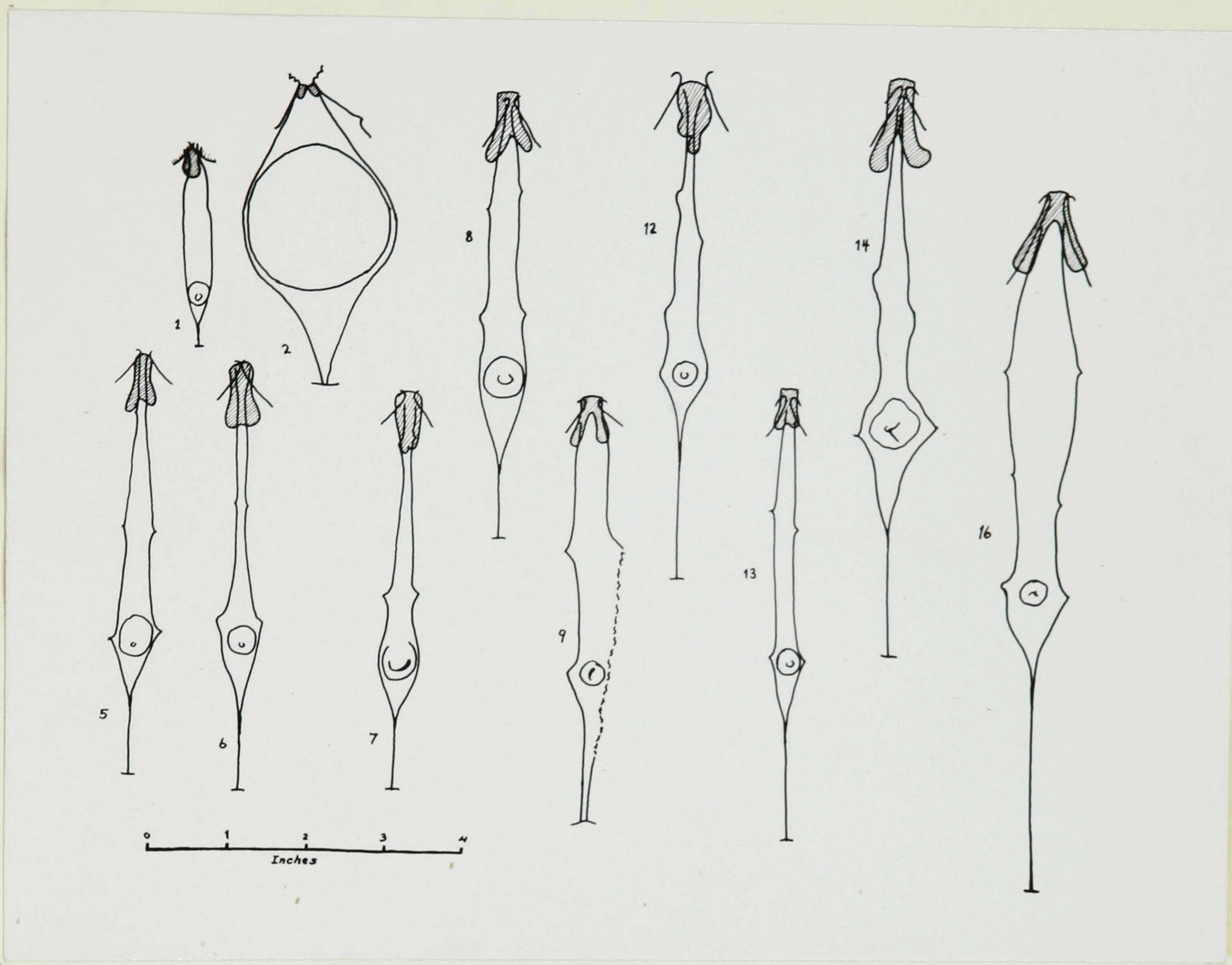

Fig. 7. Comparison of the outlines of 11 of the linea alba in this series, drawn to scale. The numerals refer to the lists given in the text. Variations in the sizes and shapes of the xiphoid processes are shown; the positions of the cutaneous umbilici are indicated.

different levels and in different specimens. In general it became linear, or about 1/16 inch wide, from one half to one inch below the mid-point of the umbilicus. The widest point was opposite the umbilicus in all but one case, and varied from 5/16 inch in the fetus to 7/8 inch at the umbilicus of one adult, and at three inches above the umbilicus in the seven year old child. This latter was the only case in which a degree of diastasis recti might be said to have esisted. Margulies (90), quotes Tandler (Lehrbuch der Anatomie, Wien, 1922), who claimed that diastasis of the upper recti is physiologic in newborn and young children.

Figure 7 is a diagrammatic comparison of eleven of the specimens, drawn in scale, and showing the variations encountered. In a number of these, especially specimen number 14, the width of the linea alba at the umbilicus was due principally to identations of the medial borders of the recti by the lowermost intersections of those muscles.

The umbilicus is uniformly located at the centre of a cross formed by the linea alba and this lowermost tendinous intersection. In this area the fibrous strands of the linea, having a transverse or oblique direction elsewhere, attain a circular arrangement surrounding the umbilical defect. This fibrous structure is well marked centrifugally, but centrally it becomes amorphous, and fused with the fibrous tissue of those structures which traverse the umbilical defect.

See Fig. 8 part III. Table I gives the measurements found in thirteen cases.

In specimen No. 6, age 25 days, the linea alba was thinned out to a considerable degree in the umbilical region, and the circular arrangement of the fibres was very well marked. The umbilicus could be pushed outward so that a cul-de-sac 3/8 inch deep was formed, closely resembling the small umbilical hernias seen clinically. This case was also unusual in that the

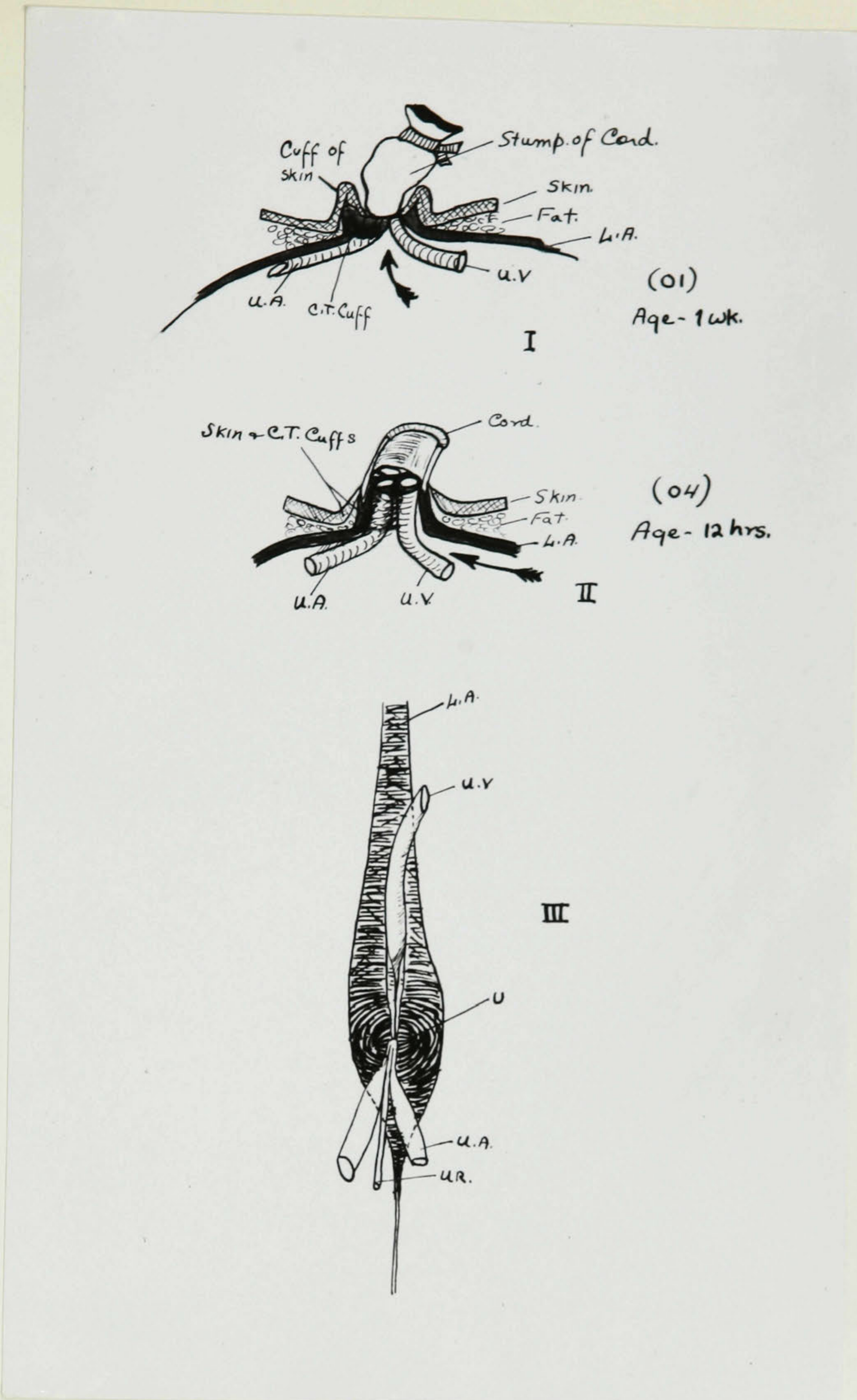

Fig. 8. I. Sagittal section through the umbilicus of an infant of 1 week, case 4; II. Section in case 3, age 12 hrs. ; III. Deep surface of the linea alba to show the circular arrangement of the fibrous tissue at the umbilicus. L.A., linea alba; u.a., umbilical artery; u.v., umbilical vein; ur., urachus. Arrows indicate the defects around the vein.

The Linea Alba.

No.	Age	X-S to Pubis A. *	Umb. to Pubis B.	$\frac{B}{A}$x 100 **	Width X-S	Width Umb.	Meet below Umb.	Width at Pubis
1	Fetus	5.0	1.7	31.2	0.3	0.8	0.9	0.1
5	13 d.	13.3	4.2	30.9	0.3	1.7	1.8	0.1
6	25 d.	13.0	4.2	31.6	0.3	1.4	2.5	0.1
7	1 m.	12.7	4.2	32.5	0.3	1.9	2.4	0.1
8	6 wk.	15.2	5.7	37.5	0.3	1.7	2.9	0.1
9	8 wk.	13.6	4.5	32.5	0.6	1.3	1.7	0.3
12	1 yr.	15.9	6.4	40.0	0.3	1.4	2.5	0.1
13	19 m.	15.9	7.0	44.0	0.3	1.3	1.9	0.1
14	25 m.	18.7	7.6	40.6	0.1	1.9	2.5	0.1
16	7 yr.	22.8	9.5	41.6	0.5	1.7	2.7	0.1
17	13 yr.	35.5	15.9	44.6	0.3	1.4	3.2	0.1
18	Adult	33.1	14.6	43.3	0.1	2.2	3.8	0.2
19	Adult	35.7	16.5	44.0	0.1	1.4	2.2	0.1

* All measurements are given in centimeters.

** This index, $\frac{B}{A}$ x 100, gives the percent of the total length of the linea alba, (A), which is made up by the lower segment, (B), from the umbilicus to the pubis.

The column marked, "Meet below Umb.", refers to the distance below the umbilicus at which the converging recti come together, so that the linea alba becomes linear.

stump of the umbilical cord had not yet separated, an event normally occurring before two weeks of age.

A gradual change can be followed in the umbilical region with increasing age. In the fetus, there is a central defect transmitting the omphalo-mesenteric duct, vitelline arteries and veins, the allantoic stalk, the paired umbilical arteries and the umbilical vein (56, 73, 96).

After birth, but before the umbilical cord has separated off, the central defect persists. (Specimen Nos. 3, 4, and 6, ages 12 hours, one week, and 25 days respectively). Figure 8 illustrates the findings in the first two cases. The umbilical vein, arteries and the non-patent allantoic stalk inserted separately on the inner aspect of the umbilicus; the vessels at 12 hours were still patent and filled with fresh blood clot. Externally these structures were already necrotic. The linea alba surrounding the vessels extended outward as a dense cuff projecting for 1/4 inch beyond the linea alba itself; the coverings of the umbilical cord extended into the cuff and fused with it, while the abdominal skin extended to this junction of the cord and cuff. The umbilical arteries, entering the cuff from below, were densely attached to the fibrous cuff; the umbilical vein, however, was surrounded by loose areolar tissue, and was easily extracted from the ring.

At one week of age, the frankly gangrenous cord was easily detached, leaving the outer aspect of the protruding umbilical cuff covered by thin skin except for a central granular area 1/8 inch in diameter. There had not as yet been any retraction to give the lobulated appearance of the healed umbilical scar. The cuff was still well defined, with the individual structures traversing it easily defined. The vessels were occluded by yellowish connective tissue; the arteries as before were densely attached, but the vein entered the inner aspect of the cuff by a funnel-like depression, and was only attached in the depths of this pit.

At 25 days the situation was much the same as at one week, except that the cuff was now only 1/8 inch high. The arteries were now only fibrous cords, but the vein was patent and contained red thrombus. The funnel-like insertion of the vein was again well marked, especially at its upper aspect; below the arteries and vein were closely attached. The crescentic defect so formed above the vein corresponded to the circular direction of the fibres in the thinned-out linea alba previously mentioned, so that perforation of the fibrous tissue in this area was particularly easy.

Du Bose (44), mentions the infundibular defect around the umbilical vein, penetrating the umbilical, or "Richet's", fascia. Jaffe (70), attributed the failure of the umbilical vein and umbilical cuff to fuse to lack of an adventitial coat comparable to that of the arteries.

Following separation of the umbilical cord, the umbilicus is rapidly covered with skin. This skin is strongly attached to the centre of the umbilical region, and retracts with decrease in the umbilical cuff; this cuff gradually recedes until the umbilical zone of the linea alba is on a level with the rest of that structure. The umbilical zone is easily defined in the older children and in adults by the direction of its connective tissue fibres; whereas in the rest of the linea alba these fibres run from side to side transversely or obliquely, in this zone they also run in a circular direction and outwards into the corium of the umbilical skin; these latter fibres are responsible for the retraction and wrinkling of this skin. A crescentic defect in close relation to the umbilical vein has been noted prior to separation of the cord; A similar defect was also apparent in cases 5 and 7, aged 13 days and one month, respectively.

In the first of these cases, the umbilical vein was still patent and contained red clot as far distally as the umbilical skin. A crescentic groove above the vein was converted into a slit in the linea alba when the umbilical skin was separated off. In the second case the vein and arteries were completely obliterated. The umbilical region was lax and could accomodate the tip of a little finger to a depth of 3/8 inch. On removal of the umbilical skin, the distal ends of the umbilical arteries and vein could still be defined on the outer surface of the scar, with a crescentic defect similar to that noted before, but located below the insertion of the arteries and urachus.

With increase in age, there is also a change in the manner of attachment of the structures inserting on the inner aspect of the umbilical scar. These structures recede from the umbilicus, so that only thin strands of fibrous tissue run to the umbilicus from their distal ends. The umbilical vein lying in the free margin of the falciform ligament of the liver ends, in the older cases, from 1/4 to 1 1/2 inches from the umbilicus. In the older cases, the lower structures have the appearance of an inverted trident, the paired umbilical arteries and the intermediate cord-like urachus joining 3/8 to 2 or more inches below the umbilicus, and continuing upwards to insert as a single fibrous cord of diminishing calibre. This single cord has been termed the "ligamentum commune" (11).

In the adults, the umbilical zone is of the same thickness and consistency of the remainder of the linea alba, being marked by the more densely attached skin externally and the fibres of the ligamentum commune and umbilical vein, or round ligament of the liver, internally.

The surface anatomy of the umbilicus has been the subject of a number of studies. Stiles (127), states that the umbilicus lies just below the mid-point of a line from the infra-sternal notch to the symphysis pubis, opposite the fourth lumbar vertebra in the adult. The position relative to the mid-point of the body is known to vary with age. Johnson (71), quites Charpy as saying that the umbilicus is below the mid-point in the newborn, at this point at two years of age, and above it in the adult; this tendency to rise parallels the increasing growth of the legs relative to the upper trunk. Giovanni is quoted as saying that the xiphi-umbilical distance varies with the volume of the stomach, liver, spleen and pancreas, while the umbilico-pubic distance varies with the volume of the intestines. Johnson (71), studied 1000 young adults, and found that the umbilicus is approximately two thirds of the distance from the supra-sternal notch to the pubis, but admits that these measurements vary considerably with posture.

Since the linea alba is firmly fixed to the recti by the fibrous intersections of these muscles attaching to the anterior rectus sheathes, it was felt that a study of the position of the umbilicus relative to the linea alba, or the distance between the xiphi-sternal joint and the crest of the pubis, might indicate any difference in growth between the upper and lower portions of these muscles. Table I gives the length of the linea alba, the distance of the umbilicus from the pubis, and percentage which this second measurement comprises of the first. This percentage is seen to rise with increasing age, from approximately 31 in the infant to 43-44 in the adults. Although there is considerable variation in the different cases, there would seem to be a greater relative growth of the infra-umbilical rectus segment compared to the supra-umbilical segment. This corresponds to the change taking place relative to the length of the body as a whole.

4. The Rectus Abdominis Muscle

The rectus muscles are paired muscles lying on either side of the linea alba, and extending from the lower chest wall to the pubis. Grant (56), and Lockhart (85), give the origin as a medial head from the ligaments in front of the symphysis pubis and a lateral head from the crest of the pubis. The muscle widens as it passes upwards, inserting as a broad sash onto the superficial surfaces of the xiphoid process and the fifth, sixth, and seventh costal cartilages. The origin is approximately one inch wide and tendinous in its lower inch; the insertion is wholly muscular, relatively thin, and about three inches wide in the adult. The medial border is fairly straight, conforming in shape to the outline of the linea alba; the lateral border forms a shallow curve convex laterally.

Dobson (41), states that in most mammalia a single muscle, the "rectus abdominalis et sternalis", extends upwards as far as the first rib, lying between the pectoralis major and the ribs. Patterson (112), reports cases in the human in which the rectus abdominis is prolonged upwards and laterally to the upper intercostal spaces.

Figures 9-18, showing the abdominal walls of the children dissected, indicate the shape and position of the rectus in different cases.

It will be seen that in most cases the insertion on the chest wall is roughly horizontal, and corresponds to that in the adult; its relation to the sternum and to the inner end of the fifth intercostal space is quite constant at different ages. This suggests that growth in width of this portion of the muscle is dependent on expansion in area of this part of the thoracic cage, rather than to a tendency to spread

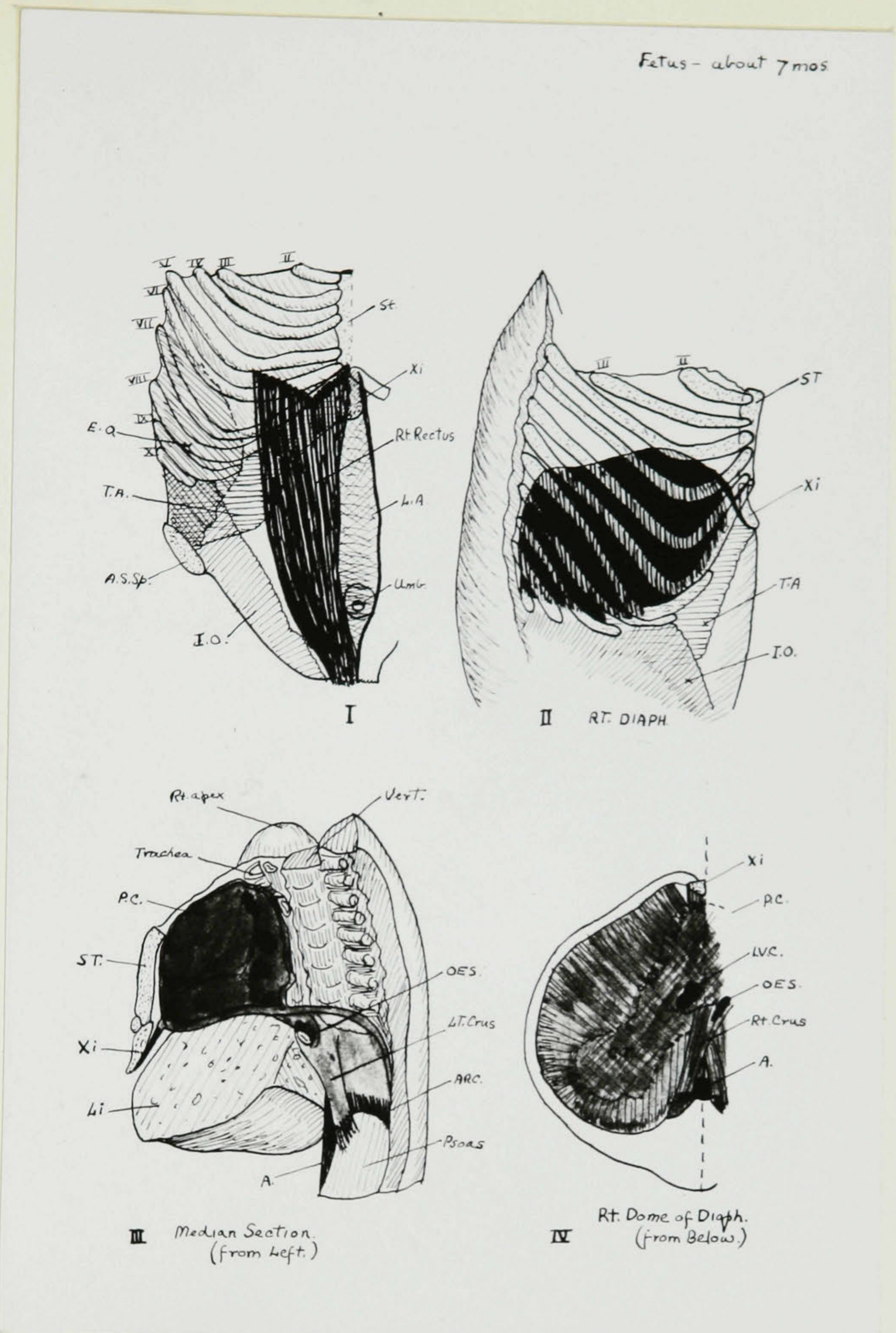

Fig. 9. I. The abdominal wall, showing the Rt. rectus, dark, and the lateral muscles, with their musculo-aponeurotic junctions indicated. II. and III., lateral views of the Rt. diaphragm. IV. Rt. diaphragm from below. Case 1, fetus. Roman numerals indicate ribs; St., sternum; Xi, xiphoid; La, linea alba; E.O., external oblique; T.A., transversus abdominis; I.O., internal oblique; A. S. Sp., anterior superior iliac spine; P.C., pericardium; Li., liver; OES., oesophagus; Arc., medial arcuate lig..

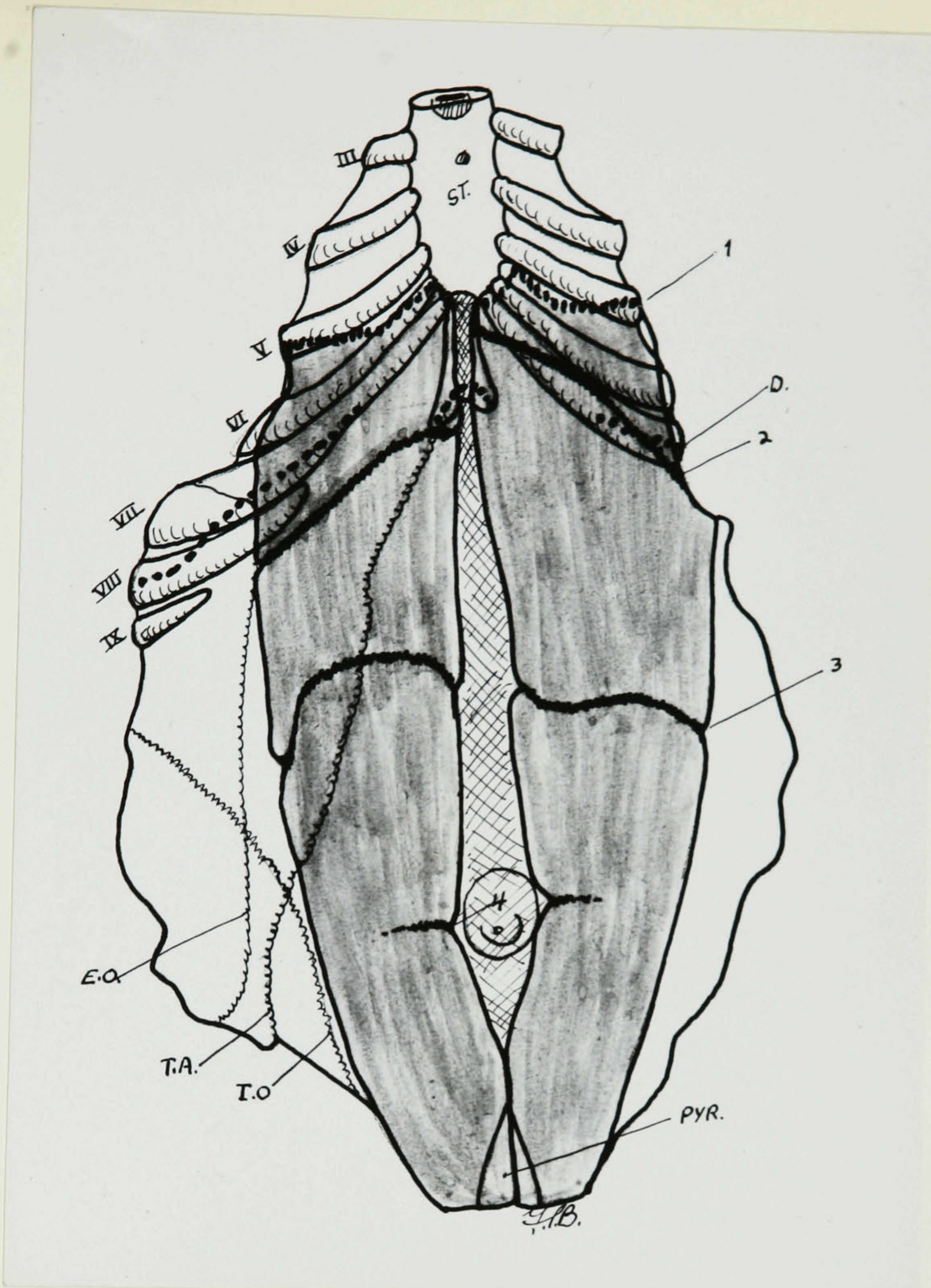

Fig. 10. Abdominal wall, case 5, age 13 days. Recti shaded, with insertion on the chest and the three intersections numbered 1 to 4. The musculo-tendinous junctions of the flat muscles, E.O., I.O., and T.A., are indicated on the Rt. side. The underlying origin of the diaphragm is indicated by heavy dotted lines, D.. The linea alba is cross-hatched. PYR., pyramidalis muscles.

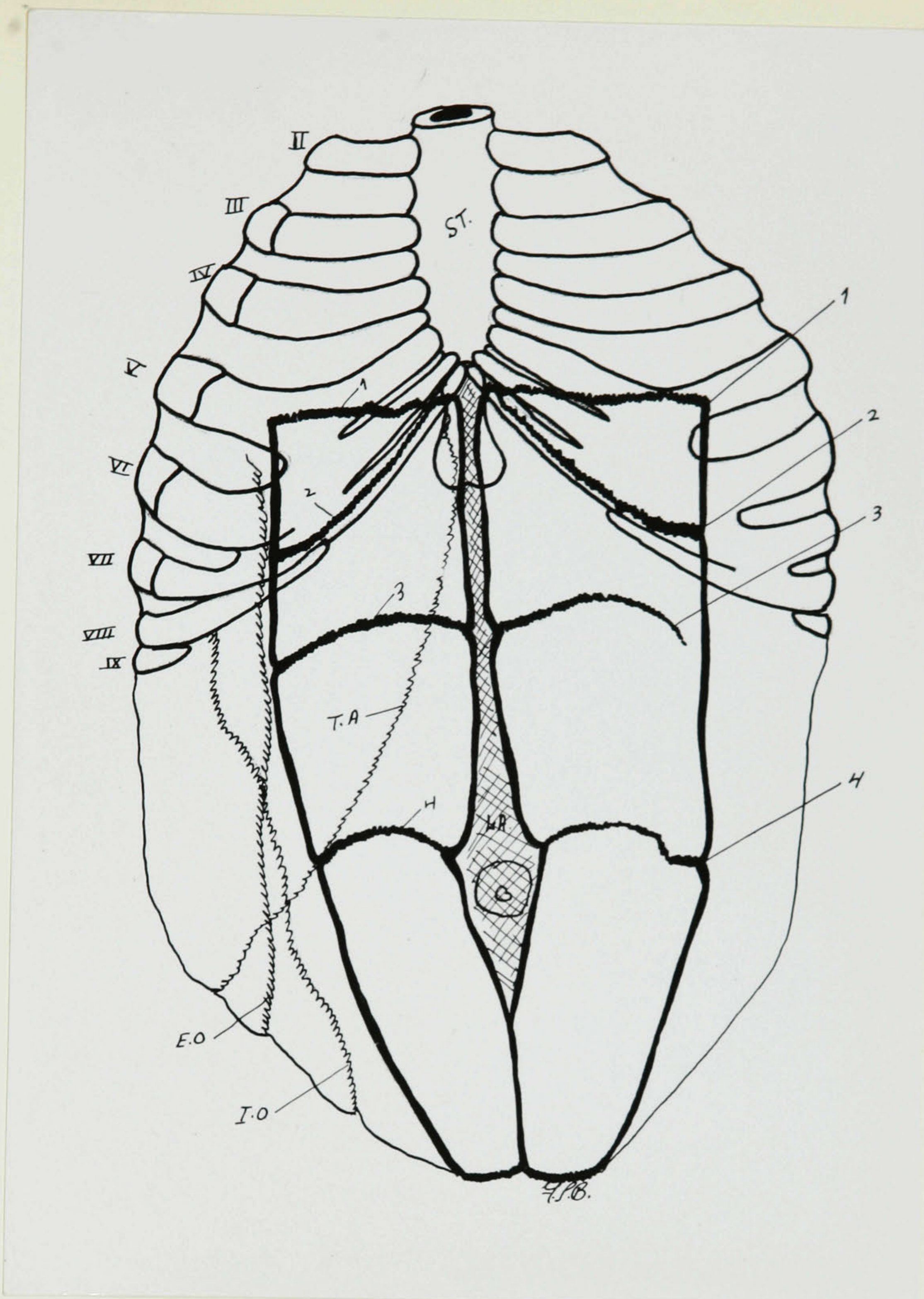

Fig. 11. Abdominal wall, case 6, age 25 days. Labels correspond to those of fig. 10. The lateral extremities of the ribs on the Rt. side show the increasing bony replacement of the cartilage.

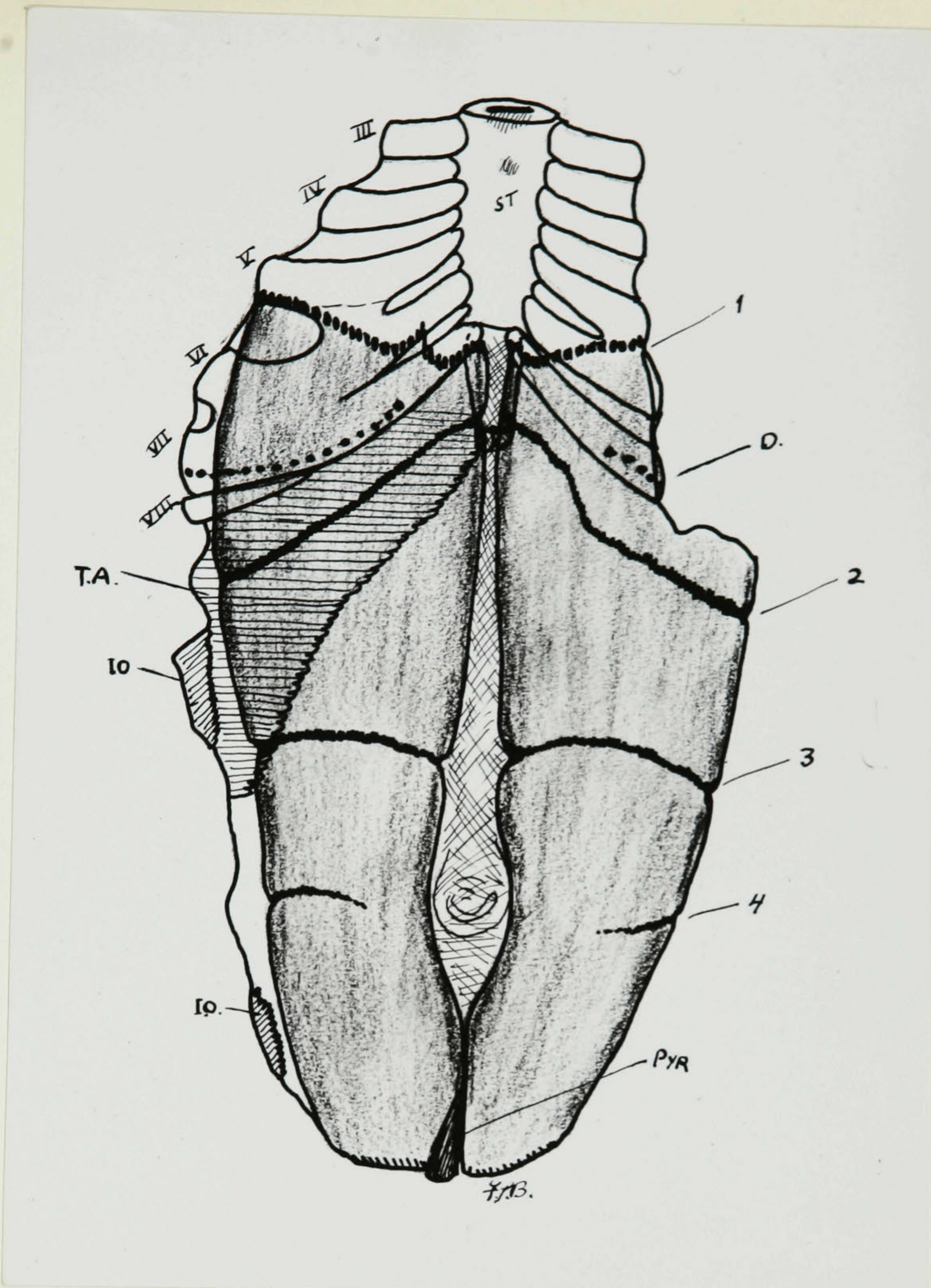

Fig. 12. Abdominal wall, case 7, age 1 month. Recti shaded. The upper transversus muscle is shown by ruled lines. Small portions of the Rt. internal oblique is seen. The muscular part of the external oblique was not included in the original specimen. The pyramidalis was present on the Rt. side only.

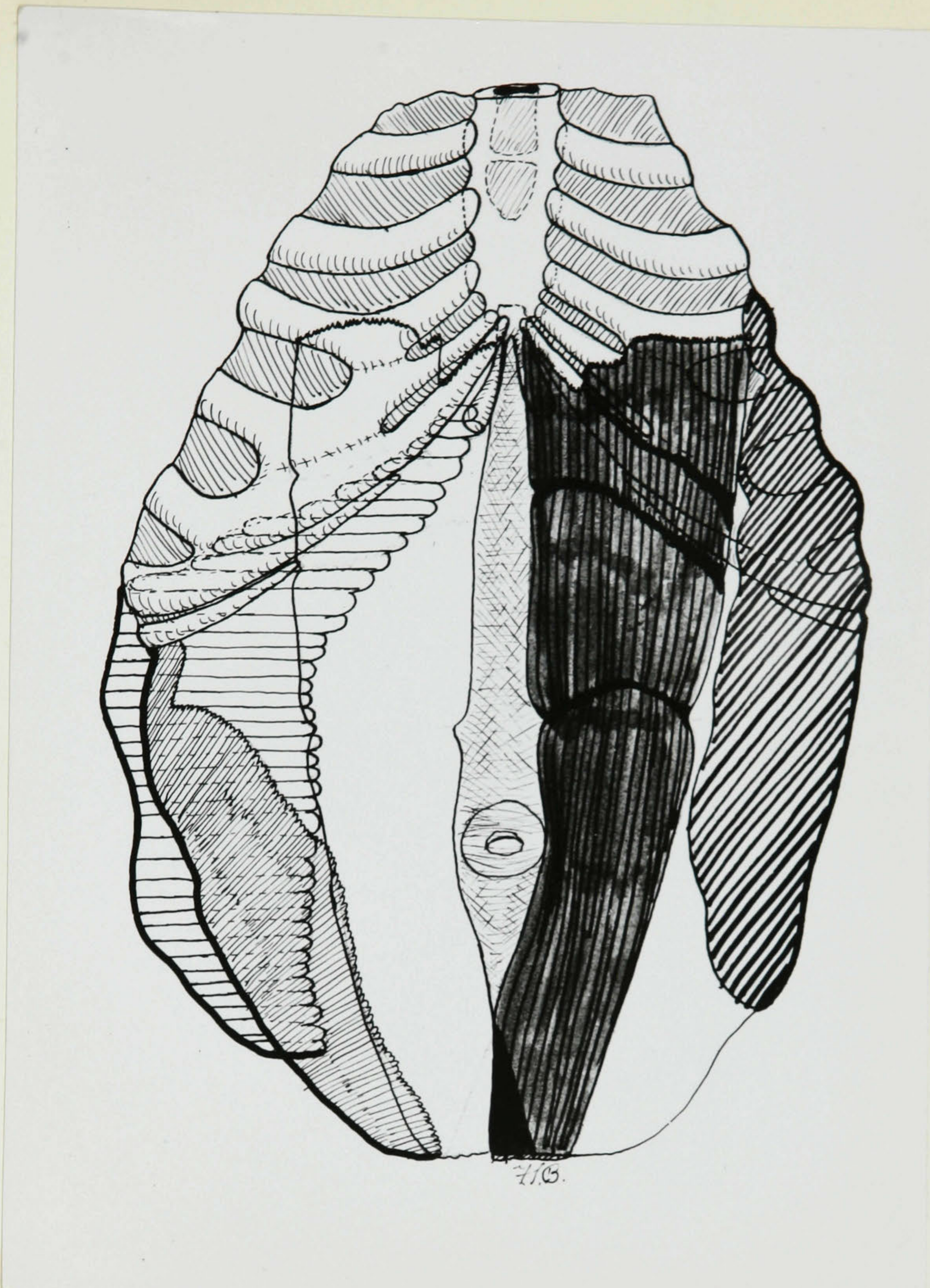

Fig. 13. Abdominal wall, case 8, age 6 weeks. The Lt. rectus is shaded. The muscular portions of the internal oblique and transversus on the Rt. side are shown by horizontal and oblique lines respectively. The external oblique is shown on the left.

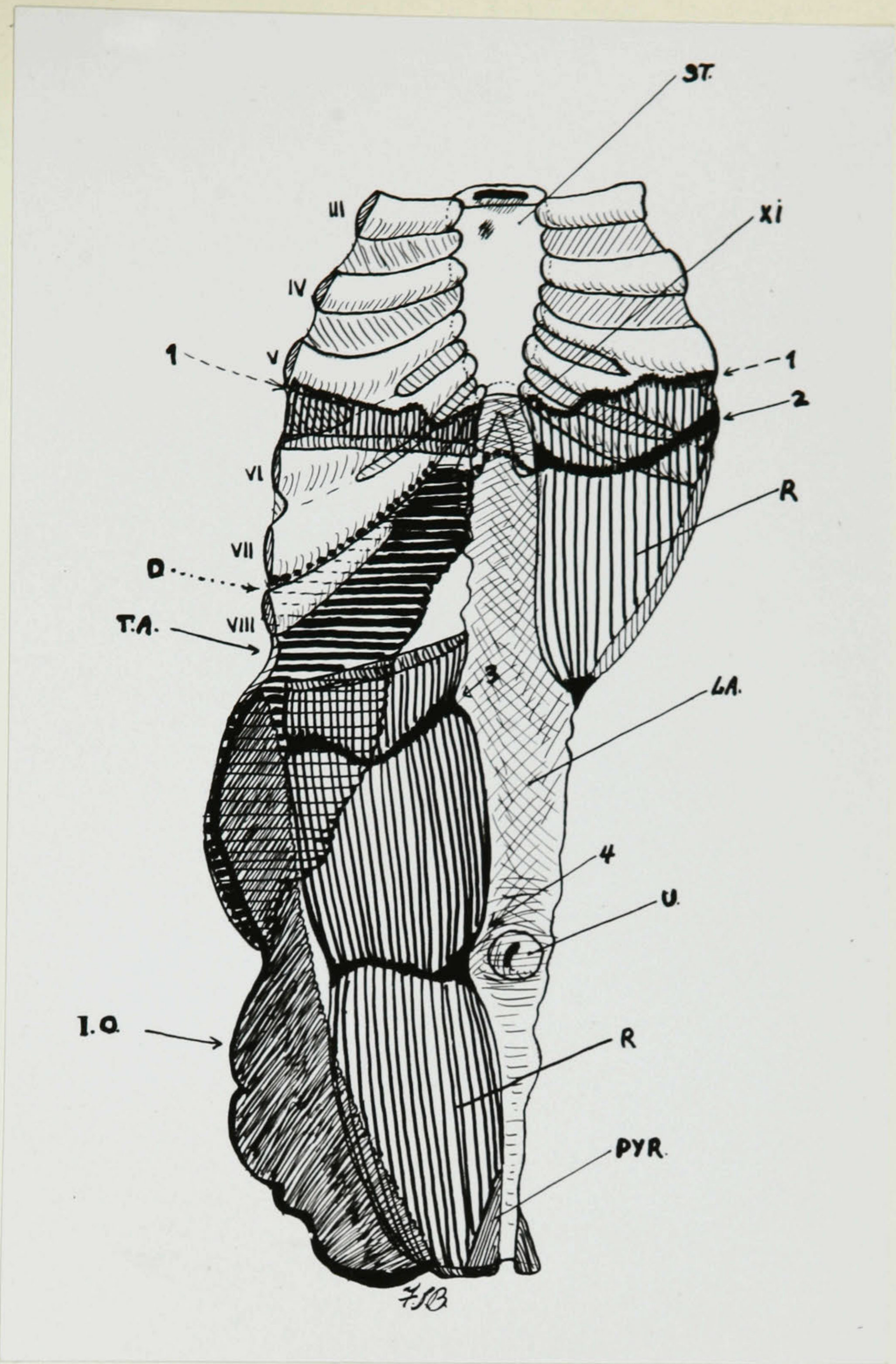

Fig. 14. Abdominal wall, case 9, age 8 weeks. The left side of the original specimen was incomplete. The internal oblique and transversus are shown on the right. A section of the Rt. rectus has been removed over the costal margin, to show the manner in which the upper transversus overlaps the posterior rectus sheath.

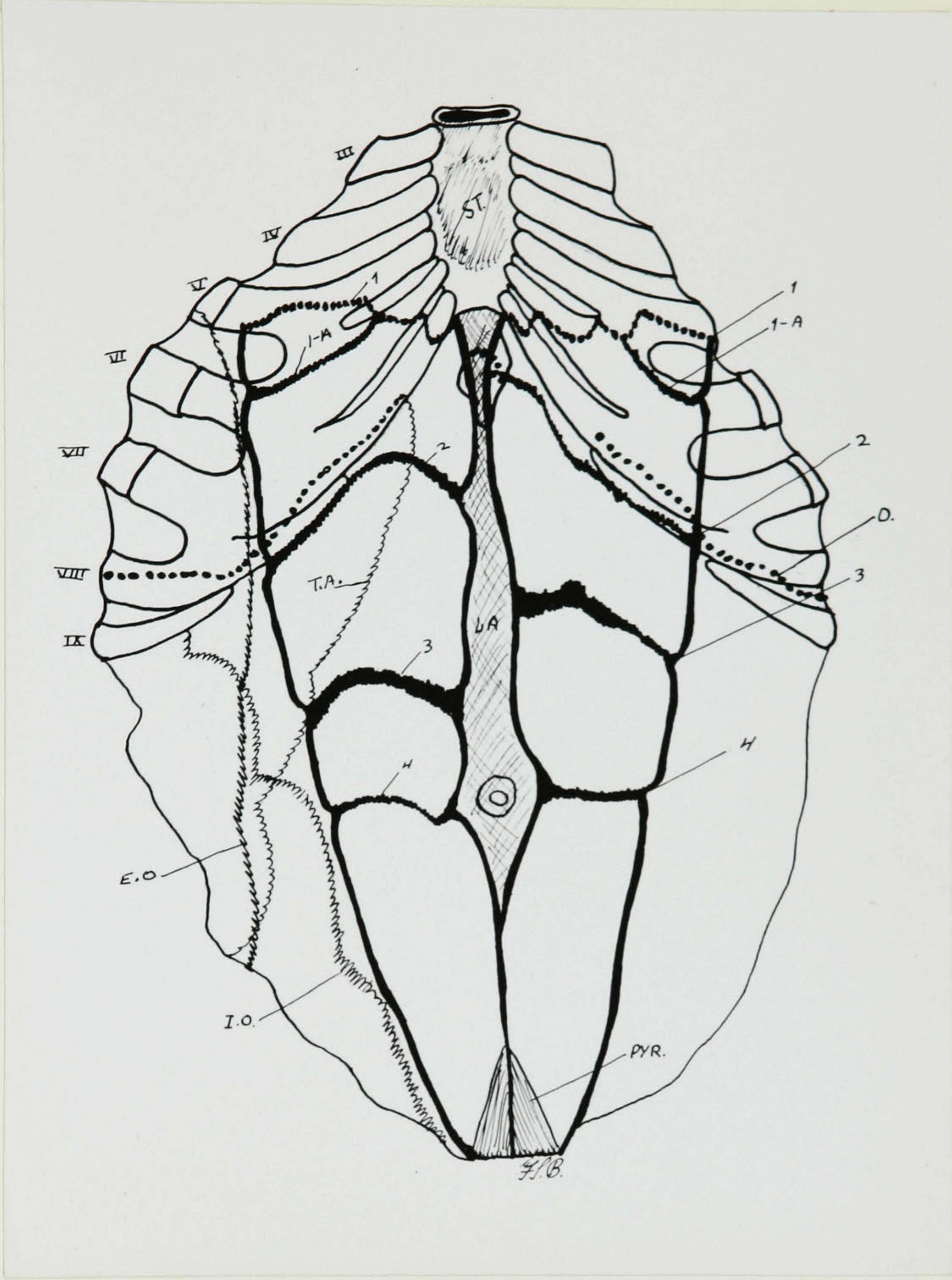

Fig. 15. Abdominal wall, case 12, age 1 year. The narrowing of the recti toward the pubis is more uniform than usual in this case. Note the irregularity and lack of coincidence of the tendinous intersections of the two recti.

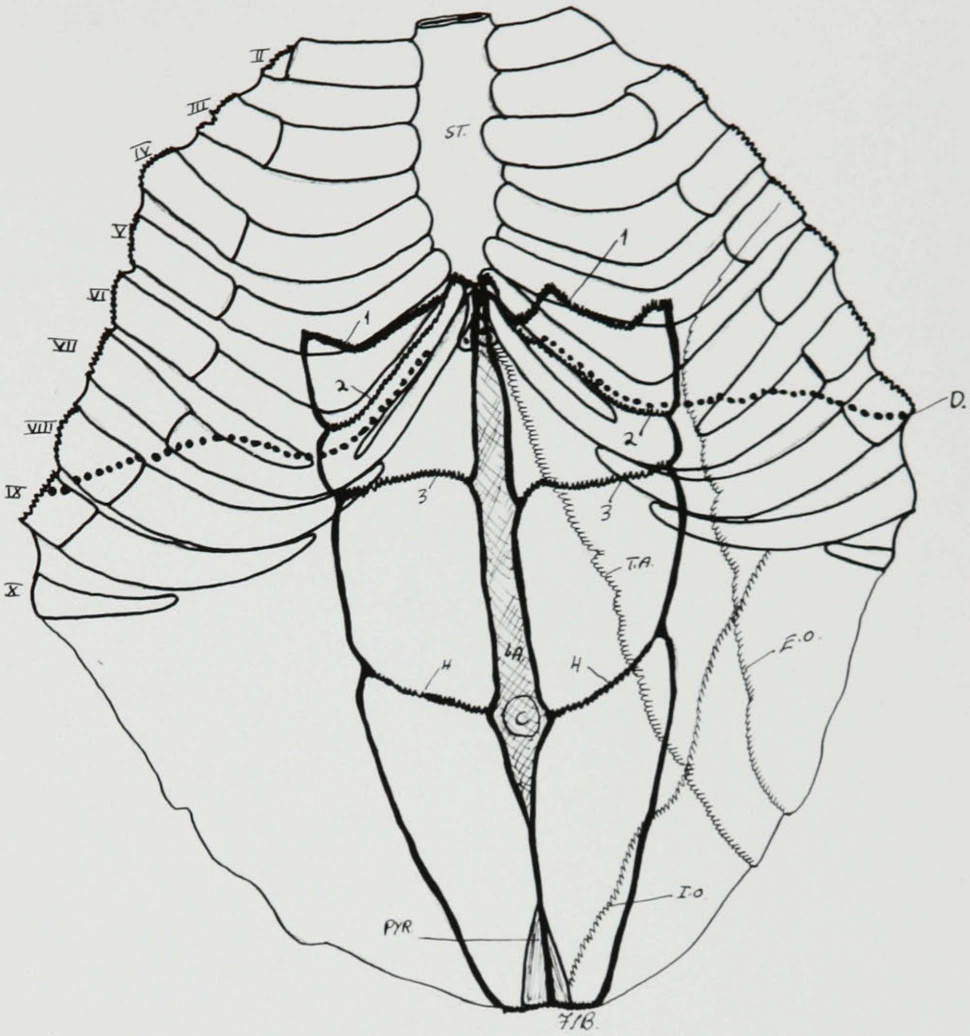

Fig. 16. Abdominal wall, case 13, age 19 months. The musculo-tendinous junctions of the flat muscles are here shown on the left side.

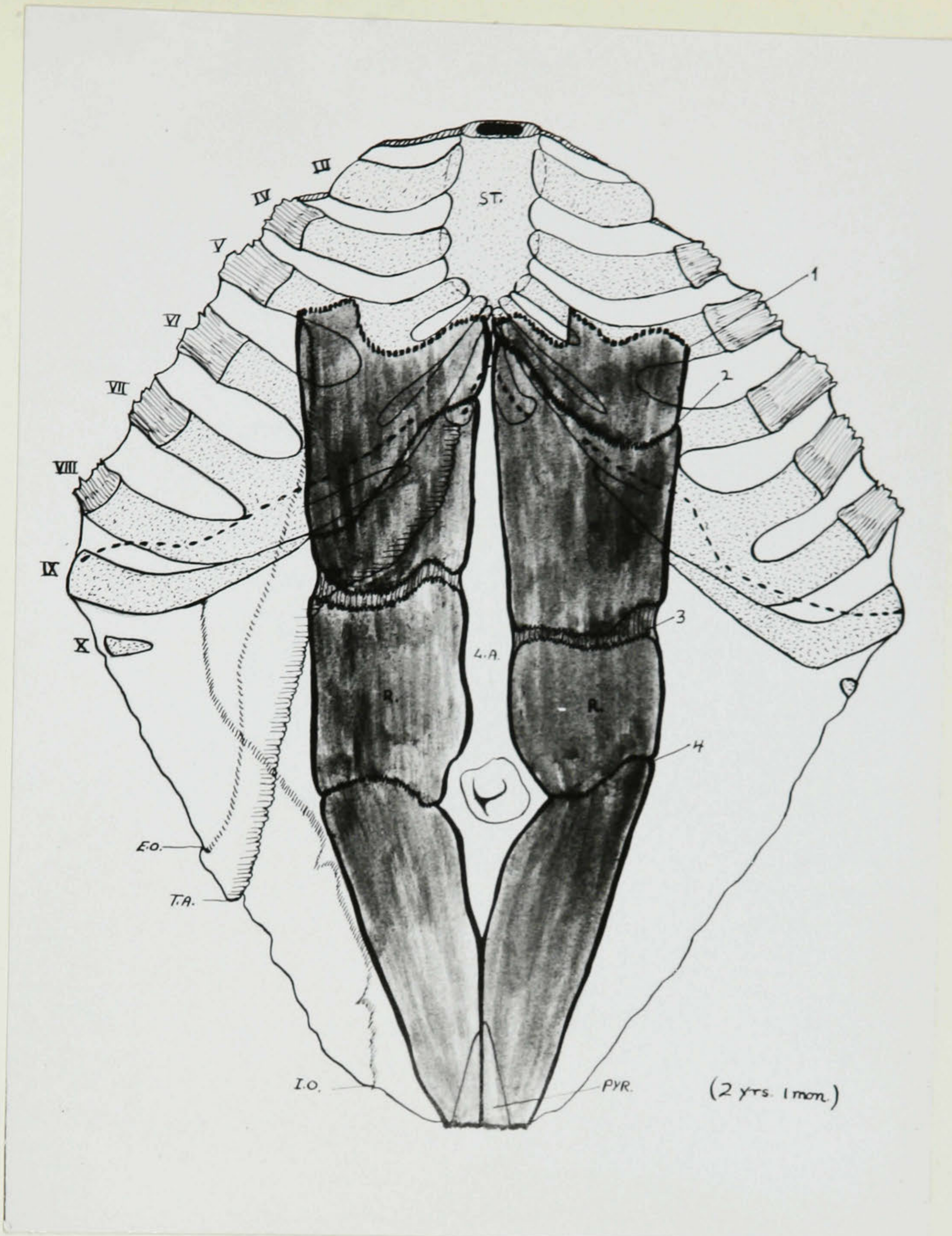

Fig. 17. Abdominal wall, case 14, age 25 months. The recti are shaded. Note the width of the intermediate tendinous intersections, (3), which formed bands of fibrous tissue penetrating the full thickness of the muscle.

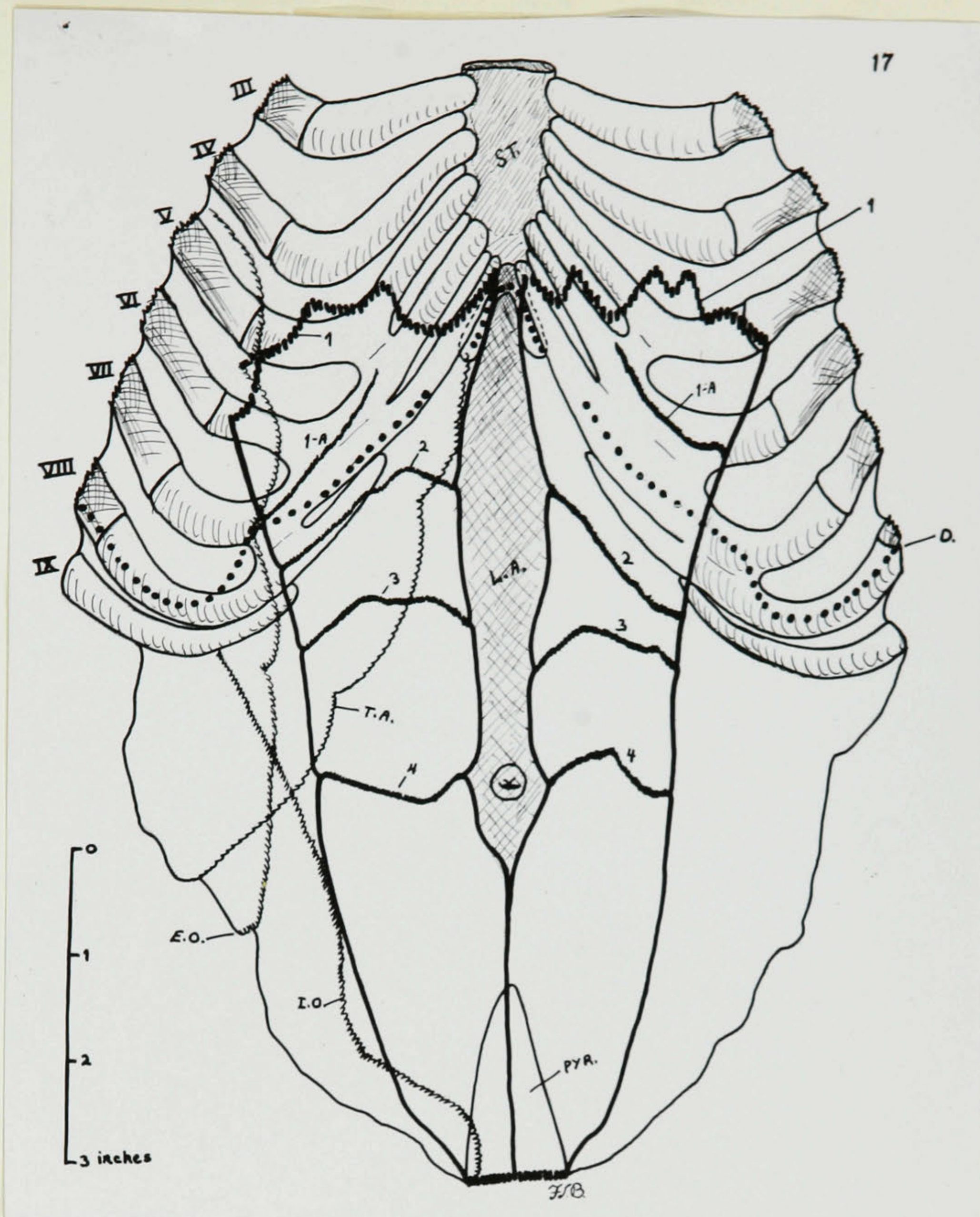

Fig. 18. Abdominal wall, case 16, age 7 years. There is an unusual separation of the recti in the epigastrium and om the chest wall. An extra intersection occupies the upper and lateral segment of the muscle, (1-A). Drawings shown in figures 10 to 18 were made full-size after tracing the actual specimen; These are reduced to varying degrees in the reproduction. The scale of inches in fig. 18 is not applicable to the other drawings.

of the muscle per se. The degree of separation of the two recti at their upper extremities would then be expected to depend on that of the medial ends of the seventh ribs where they join the lower end of the body of the sternum. In each of the cases examined, this was apparently true. In cases 9 and 12 the ends of the seventh ribs were about 3/8 inch apart, with a corresponding separation of the recti; in case 14, the ends of these ribs were in contact, as were the two recti at this point. In case 2, despite the wide separation of the recti around the epigastric omphalocele, their upper ends were close together, as were the ends of the seventh ribs, the chest wall being intact.

Table II presents the data pertaining to the recti gained from this study. The number of tendinous intersections encountered is given in those cases in which the complete rectus was present. In all cases the lowest of these was opposite or slightly above the umbilicus; this intersection is nearly horizontal. Another intersection is found close to the cartilage of the seventh rib, running downwards and outwards at an angle corresponding to that of the costal cartilage. A third intersection is located about midway between these two; it may run obliquely paralleling that above, or may run a curving course concave below. In case 12, the fourth intersection was the uppermost, running obliquely to segregate the upper and outer corner of the rectus on each side from the remainder of the muscle. In the two youngest cases, the fetus and the newborn, intersections could not be made out. In the rest, the intersections were linear, and extended through about two thirds the anterior thickness of the muscle; in cases 12 and 14, they were wider, particularly that in the middle, reaching a quarter inch in width, and extending through the whole thickness of the muscle. The muscle belly tended to narrow on approaching an intersection, producing an indentation of the margin at

Rectus Abdominis Muscle.

No.	Age	X-S to Pubis *	Width of Rectus			Thick-ness at Umb.	No. of Inter.
			Pubis	Umb.	Thorax		
1	Fet.	5.0	0.6	1.1	1.9	0.1	0
2	N.B.	10.1	0.6	1.3	0.9	0.3	0
3	12 hr.	?	0.6	2.2	?	0.3	?
4	1 wk.	?	0.6	1.9	?	0.2	?
5	13 d.	13.3	0.9	2.0	3.3	0.3	3
6	25 d.	13.0	0.8	2.5	3.5	0.5	3
7	1 m.	12.7	?	2.7	3.8	0.3	3
8	6 wk.	15.2	1.3	2.5	3.8	0.4	3
9	8 wk.	13.6	1.3	2.4	3.2	0.5	?
10	8 wk.	?	1.3	2.1	?	0.5	?
11	6 m.	?	?	2.4	3.3	0.3	?
12	1 yr.	15.9	0.9	2.9	4.5	0.5	4
13	19 m.	15.9	1.1	3.2	3.8	0.6	3
14	25 m.	18.7	1.1	3.0	3.8	0.6	3
15	4½ yr.	?	?	3.8	5.4	0.6	?
16	7 yr.	22.8	1.7	3.8	6.4	0.6	3
17	13 yr.	35.5	2.2	4.2	5.4	0.5	3
18	Adult	33.1	2.2	6.3	7.9	0.5	3
19	Adult	35.7	1.9	4.8	9.5	0.4	3

* All measurements are given in centimeters.

this point; this is more marked on the medial aspect, and especially opposite the umbilicus.

Pyramidalis muscles were present in all of the 11 cases which permitted accurate examination of the lower recti. In two cases, 6 and 7, only one was present, on the right side. These small muscles lie within the rectus sheath on the anterior surface of the rectus muscle; they arise from the medial end of the crest of the pubis and run upwards and medially to insert into the lower linea alba, the more medial fibres having the lower insertion. In this series they varied in size from 3/16 inch at the base and 3/8 inch high in case 6, to 3/4 inch at the base and 5 inches high in an adult, case 19.

5. The Lateral Abdominal Muscles

The lateral abdominal muscles are three flat muscular sheets enclosing the antero-lateral abdominal wall, the external and internal obliques and the transversus abdominis.

The external oblique arises from the lower eight ribs of the lateral chest wall, interdigitating with the lower portion of the serratus anterior and the costal origin of latissimus dorsi. Its muscular fibres sweep downwards and forwards, the lowermost inserting into the anterior half of the crest of the ilium of the same side, while the central and upper fibres fuse with the medial aponeurotic portion of the muscle. In its superior part, this aponeurosis forms the fibrous sheath of the rectus muscle origin, blending with the periostium of the sternum in the anterior midline, and giving origin to the lowermost fibres of the pectoralis major muscle. The inferior part of the aponeurosis forms a free border stretched between the anterior superior iliac spine and the pubic tubercle. Between the xiphoid process and the pubis, the greater portion of this fibrous sheet forms, with the anterior layer of the internal oblique aponeurosis, the anterior rectus sheath, its fibres blending with those from the opposite side in the linea alba.

The internal oblique is encountered with removal of the external oblique. There is an intervening layer of areolar tissue which forms the adjacent perimysium of the two muscles, but one would hesitate to dignify this tissue with the term "membrana intermedia", as described by Mijsberg (97), in other primates. This second oblique muscle layer arises from the outer half of the inguinal ligament and the anterior two thirds of the crest of the ilium (24, 56); its fibres run upwards and forwards, inserting into the costal cartilages of the lower four ribs above, into the crest of the pubis and pubic tubercle below, and in between forms an aponeurotic sheet by which it gains insertion into the linea alba. The aponeurotic portion of the internal oblique, in its upper two thirds, splits into two layers which enclose the rectus muscle; the anterior layer blends with the fibrous portion of the external oblique just medial to the lateral margin of the rectus, below the level of the tip of the ninth rib. Above this point the internal oblique is poorly defined. Opposite the lower quarter of the rectus the aponeurosis fails to divide and passes entirely in front of the rectus muscle.

The transversus abdominis muscle is the deepest of the three flat muscles, arising by fleshy strips from the inner surfaces of the lower six costal cartilages, and interdigitating with the costal origin or the diaphragm. Above the diaphragm, the transversus thoracis muscle arises from the costal cartilages of the sixth, fifth and fourth or higher ribs, and is essentially an upwards continuation of the abdominal muscle. The upper fibres run transversely forwards and medially to insert into the deep surface of the sternum above the diaphragm, into the lateral border of the xiphoid process, and onto the deep surface of the posterior rectus sheath in the upper abdomen. In the lower abdomen, the transversus blends with the fibres of the internal oblique inserting into the pubic crest and tubercle to form the conjoined tendon. Above this, the muscular fibres become tendinous, blend with those of the internal oblique, and contribute to the formation of the rectus sheath.

In general, the transformation from a muscular to a tendinous structure, which occurs as each of these flat muscles approaches the anterior midline, occurs in a more or less vertical zone near the mid-clavicular line. Although this line differs for each layer, it is quite characteristic for a particular layer. Special attention was paid to the relationship of these musculo-tendinous junctions to the lateral border of the rectus muscle in the cases in this study. Lines are shown on each figure of the specimens (Figs. 9-18). It will be seen that there is little if any change in the relationship with increasing age, the newborn and the adult abdominal walls having very similar appearances in this respect.

Bland-Sutton (130), describes the phylogenetic origin of tendons in general, or the regression of the muscular tissue, as being due to disuse. The absence of muscle other than the strong rectus in the mid-abdomen might be explainable on this basis. He states that in the human the tendinous portion of the muscle tends to increase with maturation during fetal life and childhood; this may account for failure to find tendinous intersections in the recti of the fetus and the newborn dissected. In the case of the aponeurotic portions of the three flat muscles, however, the increase in extent of the fibrous part would seem to be proportionate to the growth in width of the rectus muscle, and probably to the increase in girth of the muscular abdominal wall as a whole. The proportion of fibrous to muscular tissue making up these muscles would appear to be fairly constant with maturation.

Zimmerman (149), has studied 250 adult abdominal walls in relation to the occurrence of certain spontaneous herniae in the lateral abdominal wall above the inguinal regions. He describes a condition which he terms "banding", in the internal oblique and transverse muscle layers, most marked in the zone of transition from muscle to aponeurosis. This consists of a banding or grouping together of the medial ends of the muscular fibres to form digitations, with intervening fascia between, instead of the almost linear transition described above. A potential weak spot thus occurs lateral to the rectus sheath and bounded above and below by adjacent muscle bundles. Of the 500 hemi-abdominal walls examined, one or more defects of this type was found in either the internal oblique or the transversus in 21.8%; defects were found in both layers in 10%, and in 6% of these the defects were superimposed. It is in these latter cases that hernias would be likely to occur. Defects of this nature were not found in any of the children, the musculature in all cases being closely packed and having an abrupt transition to aponeurotic tissue.

Beck (10), describes a separation of the fibres of the external oblique aponeurosis in the lower abdomen, but above the external inguinal ring, which he calls "diastasis of the external oblique". In thin people the separation may reach one half inch in width, with a bulging of the deeper muscles that simulates a direct inguinal hernia. He believes this condition to be present in 60-70% of subjects; the author has seen such a condition during the course of herniorraphy in adults, but did not encounter it in the children studied in this series.

6. The Rectus Sheath

The rectus sheath is formed by the medial fibrous portions of the three flat muscles, and has been described in the course of describing these muscles. The anterior sheath is formed by the external oblique throughout its length, with the addition of the anterior layer of the internal oblique in its lower three quarters or so; in its lower fourth the aponeurosis of the transversus muscle is also added. The posterior sheath is formed in its upper three fourths by the posterior layer of the internal oblique aponeurosis and the transversus; this part of the sheath is deficient above the costal margin, where the rectus is in contact with the properitoneal connective tissue and the transversalis fascia. The lower limit of the posterior sheath forms a falciform edge concave downwards, called the arcuate line, which marks the zone at which the internal oblique and transversus muscles change from a posterior to an anterior position relative to the rectus; mention has already been made of Mijsberg's view of this as evidence that the rectus has perforated these layers in a backward direction.

Figure 19 indicates the composition of the rectus sheath at three levels.

The rectus muscle is firmly fixed to the anterior sheath above the umbilicus at its tendinous intersections. Posteriorly and on either side of the rectus lies quite loosely in its sheath. Medially the interior of the sheath presents a rounded margin; laterally the margin is a cleft extending outwards to the point of separation of the two layers of the internal oblique aponeurosis. The external oblique anteriorly and the transversus posteriorly, fuse with these two layers medial to their origin, so that when the various layers are dissected out the lateral limit of the sheath is not strictly speaking linear. The term, "linea semilunaris",

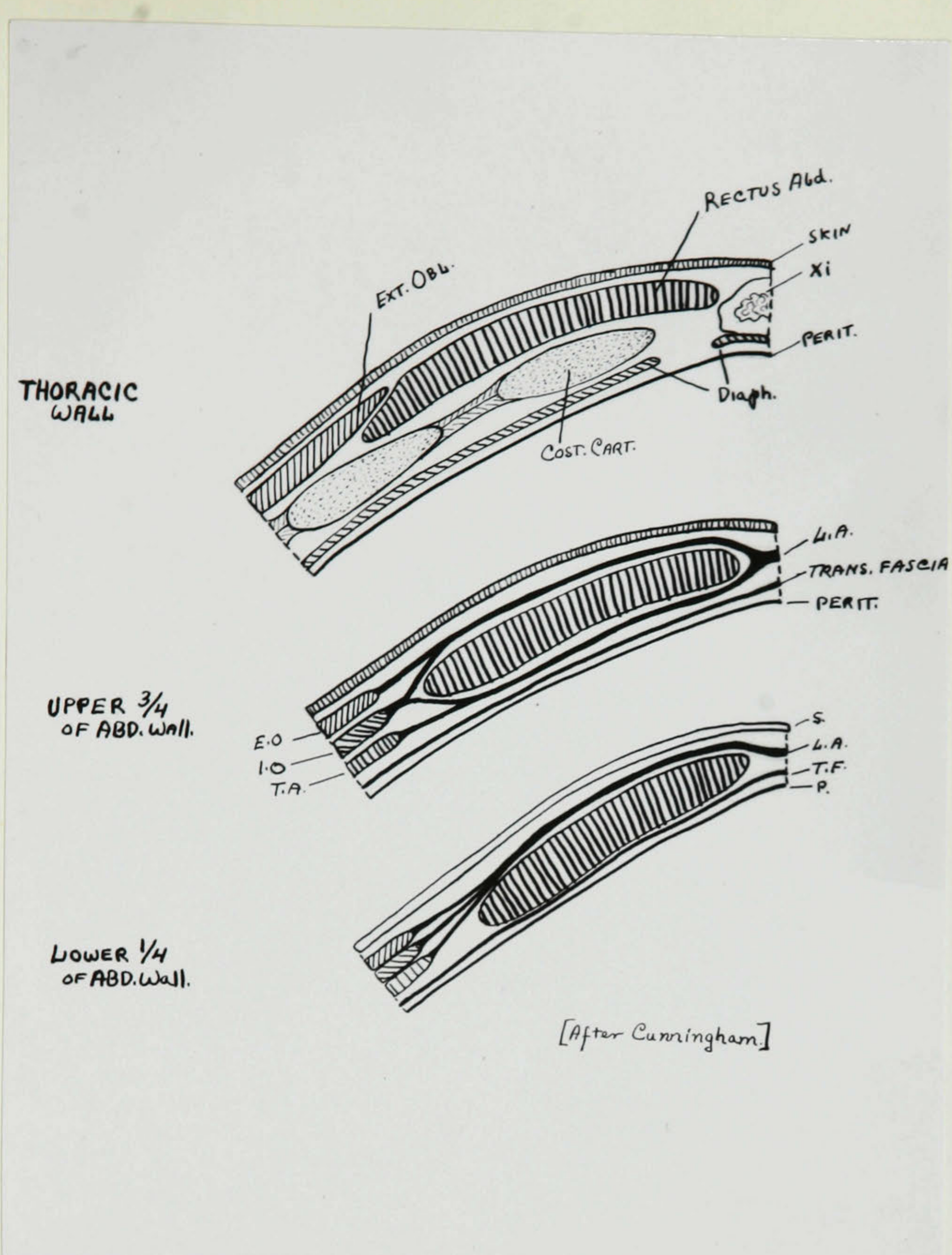

Fig. 19. Relationships of the rectus muscle at three levels. Xi, xiphoid; L.A., linea alba; T.F., transversalis fascia; P., peritoneum; S., skin; E.O., external oblique; I.O., internal oblique; T.A., transversus abdominis.

applied to this zone is therefore not quite accurate; this region is generally considered an area of weakness and the site of spontaneous herniae, but as pointed out by Zimmerman, this is rather an area of strength, and the defects described by him are the more likely cause of herniae in this region.

7. Relationships of the Antero-Inferior Thoracic Cage

The part of the thoracic cage with which we are here concerned is made up of the lower extremity of the body of the sternum and the xiphoid process in the midline, and the costal cartilages of the fifth, sixth and seventh ribs as they course upwards and forwards to attach to the sternum.

The sternum, composed of the manubrium, the body made up of four sternebrae, and the xiphoid process, forms a stable insertion for the ribs in the ventral midline of the thorax. The fifth costal cartilage meets the body of the sternum opposite the junction of the third and fourth sternebra, while the sixth and seventh cartilages fuse with its tapering lateral border. The xiphoid process lies on a slightly deeper plane than does the body of the sternum, so that it fuses with the postero-inferior margin of the last sternebra. The medial ends of the costal cartilages, on the other hand, lie on a more superficial plane than the sternum, and fuse with the antero-lateral border of that structure. The xiphoid process is thus normally quite deeply situated in the infra-sternal angle formed by the converging seventh costal cartilages, an appearance similar to that seen in an exaggerated degree in pectus excavatum.

The xiphoid is usually shown as a single structure, perforated near its tip. In the cases examined its shape and size varied considerably as seen in the diagrams (Fig. 7). In most cases, it begins as a single structure which divides into two diverging prongs of one quarter to three quarters inch in length. A typical case is shown in Fig. 20, which also shows the region being discussed and the shape of the rectus muscle origin.

The superficial relationships of this region have already been described in connection with the muscles of the abdominal wall; the origins

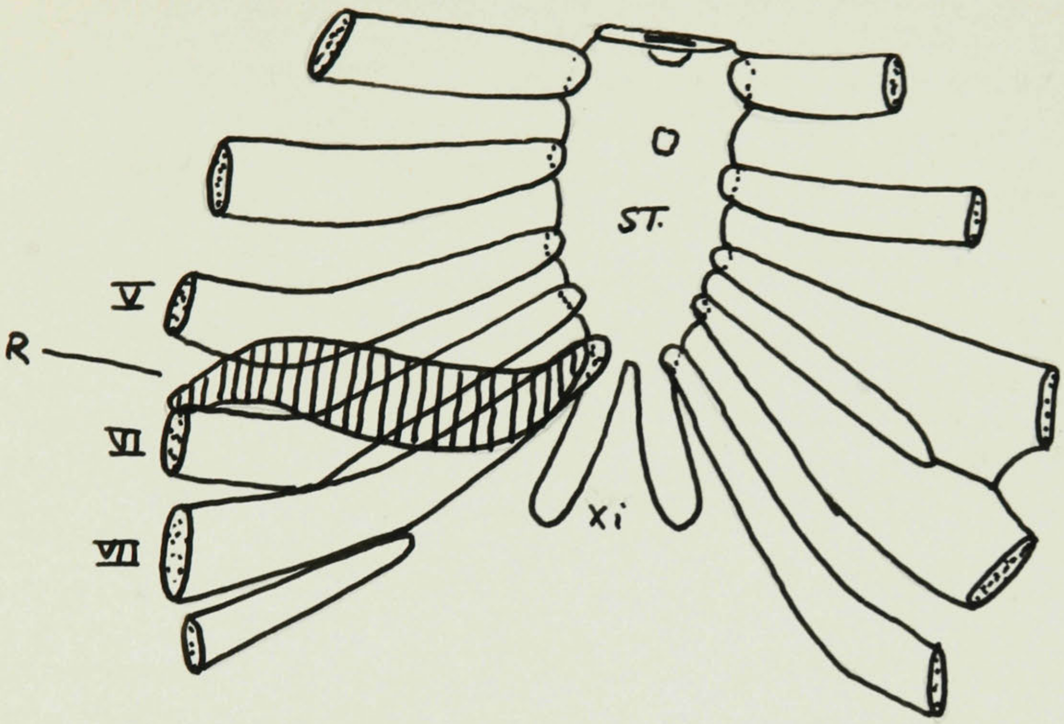

Fig. 20. Diagrammatic representation of the usual insertion of the rectus muscle on the child's chest wall. The common bifurcate xiphoid process, found in this series of cases, is shown.

of the two recti and the attachment of the linea alba are the most noteworthy structures. The uppermost bundles of the transversus abdominis muscle have been noted to insert into the lateral edges of the xiphoid process. The superior epigastric artery runs downwards on the deep surfaces of the medial extremities of the costal cartilages; behind the lower ribs it is covered internally by the transversus thoracis muscle, and it thus crosses the inferior margin of the seventh cartilage lying on the upper transversus abdominis, entering the rectus sheath deep to the rectus muscle.

The diaphragm has an antero-lateral origin from the deep surfaces of the lower six ribs; in the area under discussion, this involves the seventh cartilage where it is turning upwards at an acute angle to reach the sternum. This part of the origin reaches to within three quarters to one inch of the xiphi-sternal junction. The deep surface of the xiphoid gives rise to two bundles of muscular fibres inserting into the anterior leaf of the central tendon of the diaphragm. Between the xiphoid and costal origins, there is thus a triangular gap with its base on the medial extremity of the seventh cartilage. Since the diaphragm normally passes almost directly upwards from its origin, close to the posterior surface of the sternum, this triangular space is in an almost coronal plane.

The fibrous pericardium is reflected from the upper surface of the diaphragm one to one and a half inches posterior to the anterior origin, but due to the upward inclination at this point, the pericardium is very close to the sternum. In the midline it is separated from this latter structure by loose areolar tissue, which comprises the anterior mediastinum; on either side, the peritoneal cavity intervenes as an anterior recess.

Figure 6 shows this region, with the diaphragm pulled backwards and somewhat downwards to separate the various structures. Dotted lines indicate variable weak strings of fibrous tissue running between the deep surface of the sternum and the lower pericardium or anterior diaphragm. These have been termed the sterno-pericardial ligaments by Luschka.

Mention has been made of the sub-sternal ligament described by Brown. In the cases examined, the posterior perichondrium of the childhood sternum shows no thickening which might be called a ligament; in the two adults the periosteum was not unusual.

Blair (14), studied the development of the central tendon of the diaphragm from fetal life through childhood. This is in the form of a three leaved sheet of fibrous tissue, the anterior leaf of which receives the muscle fibres arising from the antero-inferior chest wall. The tendon maintains its shape and relative extent from fetus to adult, but with an increasing amount and complexity of fibrous strands. He noted similar features in monkeys. As far as the part of the tendon anterior to the inferior vena cava is concerned, the above description was confirmed in this study. Figure 9, showing the diaphragm in the fetus, is typical of all the children in this series.

Truesdale (138), describes the diaphragm of the adult from various points of view. His diagram from one side shows the close relationships of the origins of this muscle and the transversus abdominis from the deep surfaces of the lower ribs; the two muscles lie in the same plane, and in the region of the eleventh and twelfth ribs, their muscle fibres run in the same direction with an intersection of aponeurotic tissue intervening. The thorax and upper abdomen of a child of twelve years was dissected to demonstrate this point. Figs. 21 and 22.

Fig. 21. Photograph of the dissection of the left diaphragm and upper transversus muscle, case 20, age 12-13 years. Note the allignment of the muscle bundles of the two sheets posteriorly, separated by aponeurotic bands between the ends of the ninth to 12th ribs. See fig. 22.

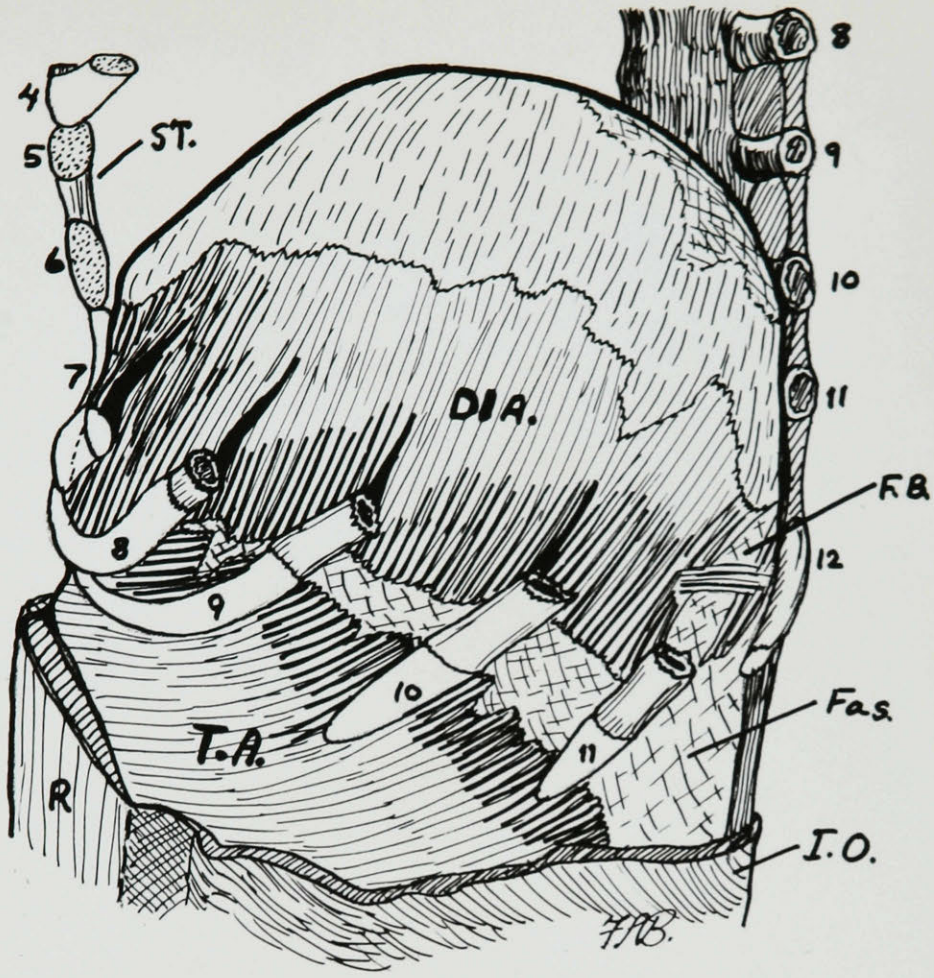

Fig. 22. Diagram based on a tracing of the photograph shown in fig. 21. The interdigitations of the diaphragm and transversus muscles are shown anteriorly, where their muscle bundles are at right angles to one another. Posteriorly, the two muscles form a single sheet, whose muscle bundles are interrupted by the interposed aponeurosis. St., sternum; T.A., transversus abdominis; Dia., diaphragm; I.O., internal oblique; Fas., fascia; F.B., foramen between costal and vertebral origins of the diaphragm, here crossed by crossed muscle bundles.

8. The Neuro-Vascular Supply of the Abdominal Wall

Only one child cadaver, age 13 years (No. 17), was available in its entirety so that the nerves could be accurately identified, and the arteries injected with latex.

Figure 23 shows the conditions encountered in this case, with particular emphasis on the rectus muscle.

Lockhart gives the nerve supply of the external oblique and rectus as the anterior rami of the lower five intercostals (T, 7-11), the internal oblique and the transversus as the lower five intercostals, the subcostal and the ilio-hypogastric and ilio-inguinal (T. 7-12 and L-1). Grant (56), gives that of the rectus as the lower five thoracic nerves (T. 7-12), while Bartlett (7), gives it as the lower eight thoracic (T. 5-12).

All agree that these nerves travel forwards in the abdominal wall between the internal oblique and the transversus muscles and, with the exception of the branches of the first lumber, pierce the posterior rectus sheath near its lateral border. Le Gros Clark (81), states that the terminal branches divide within the sheath; the larger supplies the medial part of the rectus and sends a branch forwards to the skin; the smaller division ends in the lateral part of the muscle. Davis (39), warns that a longitudinal rectus muscle incision may weaken the area by denervating the medial portion of that muscle.

With the exception of the specific nerves supplying the rectus, the specimen studied was in agreement with the above statements. The rectus was found to be supplied by the 7-12 thoracic nerves; the manner of their distribution is evident in the diagram. Although the insertion of the rectus overlies the anterior ends of the fifth and sixth interspaces, fibres of these intercostal nerves could not be found to penetrate the

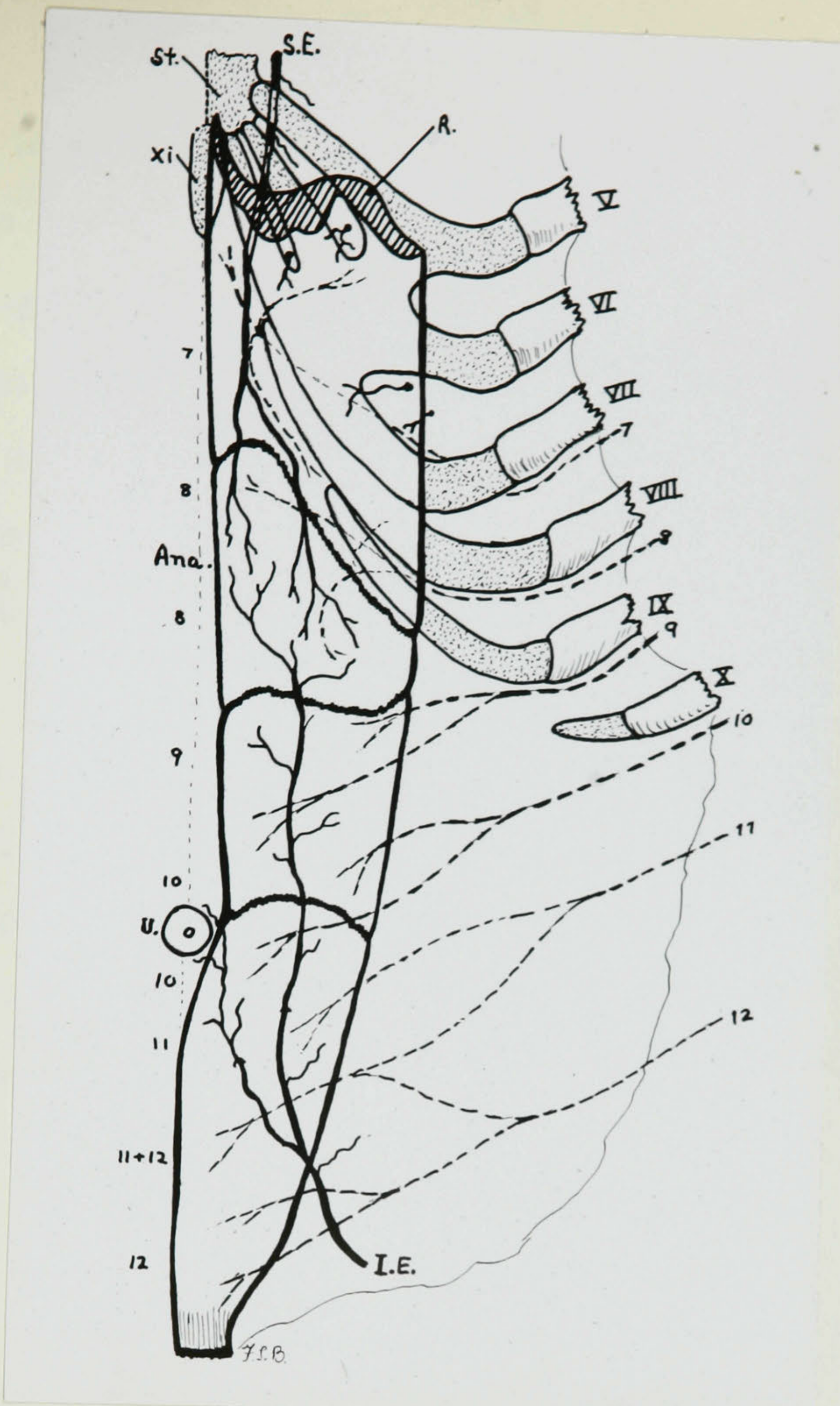

Fig. 23. Nerve and blood supply of the left rectus muscle, case 17, age 13 years. The ribs and costal cartilages are shown by Roman numerals, while dotted lines and Arabic numerals indicate the intercostal and subcostal nerves. Arteries are shown in wavy and branching black lines. St., sternum; Xi, xiphoid; S.E., superior epigastric artery; R., rectus muscle insertion; Ana., region of arterial anastamosis; U., umbilicus; I.E., inferior epigastric artery.

intercostal muscles in this area. Distribution of the nerves relative to the segments of the rectus were noted; the seventh intercostal supplies the upper segment between the insertion on the chest and the upper intersection; the eighth supplies the next lower segment. The segment between the middle and lower intersections is supplied by the ninth and a branch of the tenth intercostal, and thus the tenth is distributed to the region adjacent to the umbilicus, both above and below the lower intersection. The lowest intercostal and the subcostal are distributed to the remainder of the rectus below the umbilicus, with an intermediate terminal branch which receives communications from both of these nerves.

The vascular supply of the abdominal wall, with the exception of the rectus sheath, follows the nerves and is derived from the lower seven intercostal arteries and the upper lumbar vessels. These follow the nerves into the rectus sheath, and supply the lateral border of that muscle. In addition, the epigastric arteries provide the major part of the blood supply of the antero-medial abdominal wall. The superior epigastric, one of the terminal branches of the internal mammary artery, arises opposite the fifth interspace and enters the posterior rectus sheath between the rectus and the transversus muscles as described previously. Soon after emerging from beneath the costal margin it divides into two branches which enter the medial and lateral portions of the muscle. In addition the upper rectus receives branches of the fifth and sixth intercostal arteries entering its insertion from the medial ends of these spaces. The inferior epigastric, arising from the external iliac artery just medial to the internal inguinal ring, enters the posterior rectus sheath by crossing the arcuate line. It also divides into two branches; the medial is the smaller, and runs in the rectus muscle towards the umbilicus and finally supplies the

Chapter IV

Congenital Anomalies

1. The Problem

Ladd (77), in a recent editorial, has outlined the problem confronting the surgeon who has to deal with a congenital anomaly. He urges optimism in this regard, saying that there are thousands of individuals leading happy useful lives who were born with congenital anomalies. One might not go as far as Kite (75), who, in speaking of congenital absence of the clavicles, says, "It is important to reassure the affected person that, far from being physically inferior to his fellows, he possesses a unique faculty for escape from a strait jacket, through a ship's scuttle or down a drainpipe." A large proportion of these cases can be restored to normal function and improved cosmetically, as a result of the great advances made in paediatric surgery in the past twenty-five years. Ladd states that the surgeon must now be well trained in embryology and anatomy in order that he be able to recognize the exact way in which the condition differs from the normal, and prescribe the best form of corrective treatment.

In reviewing the literature on a number of anomalies, one is soon made aware of a lack of knowledge of the precise morphology of the defect, and of the exact anatomy to be expected in children at various ages. In the older literature especially, much effort was expended in theorizing as to the etiology of the various defects, and although the greater part of the various theories was pure speculation, they are still repeated in modern text-books.

The question of the etiology of a particular defect is probably insoluble, and indeed need not concern us, since the agent will have acted in embryonic or early fetal life, and so cannot be attacked directly in the manner of such agents as bacteria. The agent once having acted, we are left with a "lesion", the tissues of which are essentially normal in the sense that the tissues about a traumatic lesion are normal. This does not apply to those so-called congenital lesions, such as certain of the hemangiomata, in which there is present an abnormal type of tissue which is closely allied to a neoplastic growth. A sharp distinction should probably be made between the two types of anomaly; the former, in which the tissues of which the defect is composed are normal in their manner of growth, with the defect resulting from a lack of some normal stimulus at an early age; the latter, in which the tissue shows an abnormal growth tendency, is really not a defect, but rather a new growth or "hamartoma". The first type may be approached surgically by techniques useful in the treatments of wounds; the second may be better understood with further advance against the problem of cancer.

Kiskadden (74), has reviewed the various theories of etiology. Of each 100,000 pregnancies, there are about 80,000 normal births. Of the remainder, there will be 615 monsters born, and 7,048 abortions of abnormal embryos. Of the normal births, one in every 132 have an anatomical defect of some type. He claims the oldest statement on the subject to be that of Pliny (23-79 A.D.), "Nature creates monsters for the purpose of astonishing us and amusing herself". Maternal impressions received earnest consideration from the early writers; this was true as late as 1888 in England (47, 80); in one case the author conceded that the impression may have aggravated a small defect antedating it, since the impression occurred in late pregnancy. Injury to the mother, vitamin deficiencies, hormonal imbalance, drugs, etc., have all been implicated at one time or another. The part that heredity plays is difficult to define, but a few well documented family trees are available to prove that the tendency to form a given abnormality may be transmitted to the offspring in a manner similar to the transmission of normal characteristics; knowing this still does not shed any light on the cause of the abnormality in the first member of the family to be affected, except to say that the cause acted on the genotype, rather than on a given group of somatic cells alone.

Gruenwald (60), has written an extensive series of papers on the mechanisms of abnormal development. He differentiates between genetic and environmental types of etiology. The former results from a change in the genotype, by spontaneous or secondary mutation of the germ cells, and results in a hereditary malformation. To detect the initial cause of a particular defect would require tracing it back through all generations until the external factor causing the first gene mutation was found. The second acts in a single individual, by a change in phenotype, from the mutation of a somatic cell. The result is most striking when it occurs at the first cell division, affecting all of one side of the body.

Genes are thought to act by determining the presence of enzymes, which in turn regulate cell metabolism. If one cell becomes abnormal it will affect all of its descendents, and the structures developing in the neighborhood of these descendents. Experimentally, many deformities have been produced by the application of external agents to embryos, causing both genetic and somatic mutations. These agents closely resemble, and in some cases are the same as, those used in the experimental production of cancer. Application of such an agent will result in different changes in growth and form, depending on the manner in which it is applied, the area to which it is applied, and the age of the individual in which it is used. Study of the defect itself can indicate the age at which the agent acted, but gives no idea of what the agent actually was.

The fundamental difference between a developmental anomaly and a cancer is that in the former the teratogenic factor acts during a short period of development and produces certain changes; subsequently normal development proceeds on the abnormal foundation. In the latter, the abnormal mechanism is perpetually active.

2. Omphalocele

Omphalocele, a terme derived from the Greek, meaning "hernia of the navel", is now the most widely used term for a group of defects of the ventral midline of the abdomen present at birth, and lacking cutaneous covering. Ambroise Paré is credited with first describing the condition in 1634 (46). In the past these defects were included in the general term, "umbilical hernia", which is also applied to the small hernias of the umbilical cord in the newborn, the very common infantile umbilical hernias, and the hernias in this region in the adult; indeed, most of the literature under this title refers to the severe congenital defects. Rysch, in 1691, is quoted as having said, "No hernia can be called umbilical before the umbilicus exists". The hernia contents in these cases have never been entirely within the abdomen.

Ogilvie (106), states that, "The human fetus, when first recognizable, has an umbilical hernia so large that it would be more accurate to describe the whole as a hernia with a small embryo attached."

Other terms used have been "gastroschisis", "exomphalos", "amniocele", "ectopia viscerum", "schistasis", "fissure abdominalis", "congenital eventration at the umbilicus", etc. Early authors (61, 120), quote the classification of St. Hilaire, in his "Histoire des Anomalies", wherein he divides the monsters with eventration into groups depending on the extent of the cleft and its location; it may involve the pubis and abdomen below the umbilicus with lower genito-urinary anomalies, the mid-abdomen, the epigastrium and lower chest wall, the chest itself with ectopia cordis, or the whole ventral midline from manubrium to pubis. As in most severe congenital defects, there are commonly associated defects of internal organs, limbs, etc. Mills and Walpert (99), report a case with a complete cleft of the ventral midline extending to the cranium and the sacrum, so that the fetus was everted and the parietes joined in the midline only in the region of the thoraco-lumbar spine.

We are here concerned with those less severe defects which permit of the birth of a viable infant, and which are confined to the muscular abdominal wall and not complicated by the presence of an ectopic heart or bladder. At birth, the skin of the abdomen is deficient over a defect in the musculo-fascial abdominal wall, so that the intestines in the midline region are covered by a translucent membrane resembling and continuous with the covering of the umbilical cord; this latter structure attaches to this thin hernial sac to left or right of the midline. Such a defect is found in from one in 5,000-6,000 deliveries (27, 90, 114, 125, 148), to one in 10,000-11,000 (46, 68). The majority of the large and small bowel may be contained in a fragile tumor the size of a grapefruit, but inclusion of the liver is said to be very rare; Nora and Carr (103), were able to find only seven valid cases in the literature up to 1946.

Recently two cases were encountered at the Children's Memorial Hospital in which the majority of the liver was contained in the upper portion of a large sac; in the first of these (121), surgical repair has been successful. In the second, the child died within one hour of birth at another hospital, and the body was thus available for autopsy before changes due to secondary infection had occurred; this case (No. 2), is described here.

Figure 24 shows a diagragmatic picture of the external appearance of the hernia, and the anatomy of the abdominal wall after dissection.

The sac, having a volume of 100 cc. contained most of the small bowel and over two-thirds of the liver; the liver was attached to the dome of the sac, and by a cord containing the hepatic vein, to the diaphragm

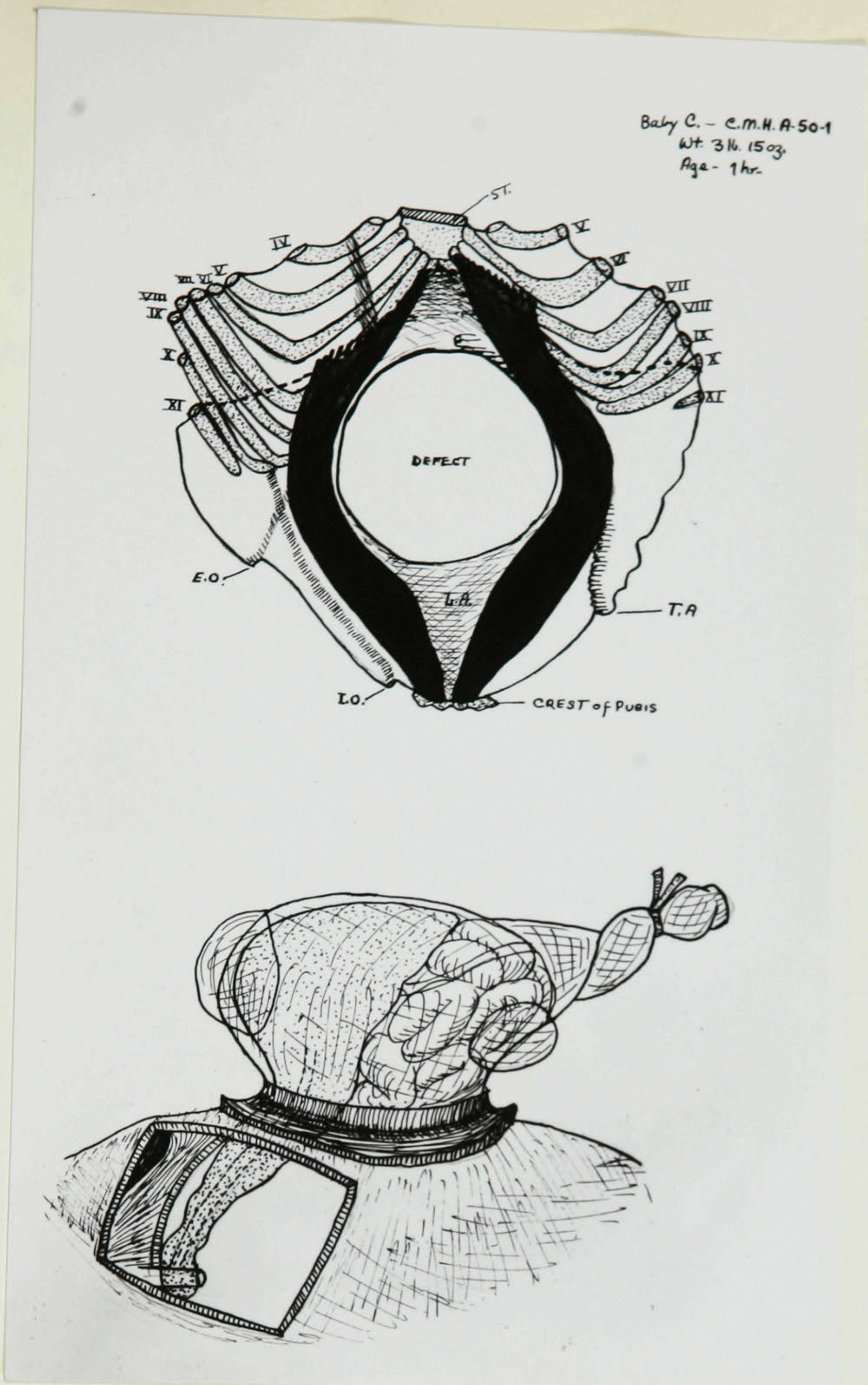

Fig. 24. Abdominal wall, case 2, age 1 hour. Omphalocele. The recti are shown in black, with the remains of the linea alba cross-hatched. The lower drawing shows the conditions before dissection, in a lateral view. A cuff of skin has been left around the neck of the sac, which contains small bowel and liver, (speckled). A window in the abdominal wall shows the level of the diaphragm and the inner attachment of the liver.

around the inferior vena cava. The abdominal skin ended along a sharp line on the neck of the sac, and corresponded to the limit inside to which the peritoneum could be separated-off the abdominal wall in the usual manner. The sac wall was of tissue closely resembling that of the cord, and in places there were bullae of jelly-like material. The defect in the abdominal wall had a sharp margin formed by the remains of the linea alba above and below, and the medial edges of the rectus sheathes laterally. The recti were about half the size expected in the upper abdomen, but more nearly normal in size on approaching the pubis; the chest wall and pubis were intact and the origins and insertions of the recti were close together as in the normal, the muscles diverging around the circular defect which measured 4.5 cm. in diameter. The relationship of the musculo-aponeurotic junction of the flat muscles to the lateral border of the rectus was normal, and these muscles were of a normal thickness compared to the other abdominal walls studied.

Although the size of the defects, composition of the sacs, and disposition of the abdominal contents are noted in a number of reports in this condition, no anatomical studies of the abdominal walls were found. Surgical reports note the presence of recti surrounding the defects, and speak of suturing the various layers of the abdominal wall wherever possible, but make no mention of the degree of development of the wall (22, 36, 40, 43, 53, 54, 61, 64, 94, 110, 115, 119, 120, 144, 145). The difficulty of closure of the parietes at operation is due to a discrepancy in size between the abdominal cavity and the viscera; although the circumference of the musculo-fascial abdominal wall is probably less than normal in all cases, it is not certain whether this is a primary hypoplasia or secondary to some factor to some factor preventing normal ingrowth of the wall. The latter seems the more likely, in that normal development of the wall proceeds when the hernia is successfully reduced, and in view of the findings in the case here described. In cases in which there is hypoplasia of the muscles (see Section 4), rather than a constricted abdomen there is a flaccid and distended cavity. In addition to the deficiency of the abdominal wall, the cavity is further reduced in a number of cases by the unusually low position of the diaphragm, which was present in this case, and by a degree of lumbar kyphosis frequently noted in the reports. Both of these conditions are quite possibly the result of the unsupported abdominal wall.

A number of theories have been advanced to explain the mechanism of formation of the defect. Early writers explained many defects on the basis of intra-uterine inflammatory adhesions, and this is no exception; St. Hilaire (61), is sais to have produced eventration in chicks by producing such adhesions in the embryos, but they were not accompanied by associated anomalies. The more recent theories are divisable into two groups, placing the fault on the abdominal wall or on a failure of withdrawal of the intestines. Normally, at about nine weeks, the bulk of the intestines enter the base of the umbilical cord, presumably due to a greater rate of growth of the viscera than of the abdominal wall; return of the gut to the abdominal cavity occurs when the abdominal wall "catches up", and is supposed to be effected by a relatively negative intra-abdominal pressure, traction of the omphalo-mesenteric artery and the mesentery, or attachment of the intestine to the posterior body wall (46, 125). Failure of one of these factors, malrotation of the gut, or persistence of the omphalo-mesenteric duct, are supposed to prevent retraction of the gut and cause eventration (27, 46, 114, 125). Margulies (90), quotes Pernkoff (Ztschr. f. Anat., v. 77, 1925), as saying that diastasis of the recti is present in the upper abdomen of the fetus long after retraction of the intestines, and he does not think that the recti play an active part in the midline closure. If this is so, failure of normal development of these muscles should not be blamed for the defects, as a number of authors do (25, 59, 68, 148). Kermauner, in a monograph on anomalies (Jena, 1909), is quoted by Margulies (90), as saying that the recti are prevented from reaching the midline by an absence of the intermediate mesenchymal layer of the membrana reuniens, into which these muscles must grow.

In the case described, the general appearance of the abdominal wall suggested to the author that the muscles probably had a normal growth tendency; the size of the abdomen, the low diaphragm and the common association of kyphosis, suggests that the reduced capacity is secondary to the defect and not its cause. There was no abnormality of the intestinal or umbilical vessels or ducts, which might prevent retraction of the intestine. The essential fault is believed, therefore, to reside in the embryonal midline tissues, or membrana reuniens. This may be a connective tissue disorder, responsible for the associated anomalies as well as the one under consideration. No explanation is available for the extra-abdominal position of the liver, a condition which never occurs in normal development.

3. Umbilical Hernia

Although the cutaneous umbilicus is not formed at birth, the umbilical region is definitely defined by the convergence of the midline structures on its deep surface, and by the fibrous umbilical ring in the linea alba; for this reason it is legitimate to speak of umbilical hernia of the newborn as well as that of infancy and childhood.

The former type is present at birth, and consists of a peritoneal sac projecting for a variable distance into the base of the umbilical cord between the vessels, the neck of the sac constricted by the fibrous umbilical ring. This is essentially a persistence of the coelomic extension into the cord normally present in the embryo before the twelfth week; in some cases the failure of this extension to be obliterated is due to a short persistent omphalo-mesenteric duct which prevents retraction of the attached knuckle of ilium (33, 70, 90). These herniae usually contain a loop of bowel which may be obstructed by the tie used to ligate the umbilical cord at birth (13, 128).

Ladd and Gross state that umbilical hernia in infancy is an extremely common occurrence, and report 1500 cases in the 25 years from 1915 to 1935 (78). Jaffe (70), found 50 percent of all types of hernia near the umbilicus to occur in infants and children; only 13 percent of these children suffered from specific disorders, including rickets, mixidiosy, cretinism, mongolianism, and amaurotic family idiosy. He states that the majority were undernourished, and many had a family history in one or both parents and grandparents. Umbilical herniae occur twice as frequently in female as in male infants. The incidence of umbilical hernia in adult life is higher in those people with a history of childhood hernia (70), but the overall incidence in adults is much lower than in children; Schroeder (123), found only 0.73 percent of hernias in adults to be umbilical. This suggests that a large proportion must resolve spontaneously in childhood (48); Ladd and Gross suggest a rate of 50% spontaneous cure.

Ogilvie (106) and Jaffe (70), attribute the development of these herniae to weakness of the umbilical scar normally present in the first six months of life; during this time the umbilical zone is susceptible to any chronic increase in intra-abdominal pressure attendant on coughing, straining, etc. The undernourished child is especially susceptible to respiratory infections, and in addition has a poorly developed muscular system, both of which predispose to hernia anywhere. Ladd and Gross agree that there is normally a weakness after birth, but say that in the cases with umbilical hernia there is a separation of the recti around the defect, which is often continued upwards to the xiphoid as diastasis recti. While Ogilvie, and Barrington Ward (6), attribute spontaneous cure to the consolidation of the fibrous tissue of the umbilical cuff with age, Ladd and Gross attribute it to the constricting effect of the recti. Coe (30), also describes a supra-umbilical type occurring in infancy, separated from the umbilicus by a thin band of fascia, and unlikely to heal spontaneously; most authors do not mention this last type, but consider the hernia to occur through the funicular defect around the umbilical vein described in an earlier section.

Herniae occur not uncommonly in animals, and are of various types. Umbilical hernia can occur in mammalia only; in the lower animals viscera may be extruded through the pharyngeal or cloacal orifices, while in reptiles ventral herniae occur by tearing of the circular muscle layer, but are rapidly repaired by muscle regeneration. Umbilical hernia are described in fish, due to a persistence of yolk sac structures within the ventral abdominal wall. In birds, although there is a great increase of intra-abdominal pressure over that found in the more sluggish lower animals, the abdomen is well protected by the projecting sternum and the well developed musculature associated with flight. Andrews and Bissell (2), note four factors predisposing to abdominal hernia in mammals; 1) Descent of the tunica vaginalis preceeding the testis; 2) Presence of the umbilicus in placentalia, so that a weak spot persists while intra-abdominal pressure increases with the advent of digestion and increased motor activity; 3) Ability to assume the upright posture with added stress on the lower abdominal wall, and the greater size of the femoral artery over the sciatic in the blood supply of the leg predisposing to femoral hernia; 4) Increased importance and range of the diaphragm, so that hernia are likely to involve that organ.

These authors state that umbilical hernia are very common in the young of many domestic animals, and are so frequent in foals as to be considered normal. The hereditary nature is marked in dogs, especially the Pekinese and St. Bernard. There is a strong tendency to spontaneous cure, as in man. The incidence of hernia of all types is highest in man, at 3-4 percent; the pig is the most susceptible of animals, at 1.16 percent, mostly umbilical and in the female of the species; other domestic animals approximate 0.5 percent; the monkeys are lower still at 0.37 percent.

The material studied in this report bears out the view that a weakness is present in the umbilical area for at least the first six months after birth, and that the most likely site for the hernial sac to begin its protrusion is the region surrounding the obliterated umbilical vein. The gradual consolidation of the umbilical ring during the first year would seem to be responsible for obliteration of the defect, providing that the intra-abdominal pressure is not unduly elevated during most of this time. If, due to persistently high pressure, the gut is prevented from retracting until the fibrous tissues surrounding the defect have matured, then the potential towards spontaneous cure will no longer be active, and the hernia will be likely to persist.

Adhesive or other types of retentive strapping have been recommended to encourage spontaneous cure (42). The use of a button over the umbilicus is probably contra-indicated on the grounds that it also exerts centrifugal pressure on the defect thus defeating the purpose of the bandage. Ladd and Gross attribute the effectiveness of strapping to the holding together of the recti; any action of the recti to constrict the umbilical zone would seem to operate at a considerable mechanical disadvantage, and from this study the author is of the opinion that there is probably little relationship between the degree of separation of the recti and the occurrence of these herniae. After one year of age, most authors recommend operation for any case having a defect over one centimeter in diameter; subcutaneous ligature (55), and various types of overlapping fascial repairs (44, 93, 117), are advocated.

4. Other Lesions of the Abdominal Wall

Deficiency of one or more of the abdominal muscles is a rare lesion; Osler (108), reported a case in 1902, and credited Guthrie with the first report in 1896. Mollison (100), collected eleven cases up to 1908, and Baxter found 24 cases by 1932 (8). The majority of the reports describe a completely lax and pendulous abdominal wall lacking any response to electrical stimulation, and through which the viscera are easily palpated. The umbilicus in these cases is marked by a vertical furrow. There is usually retantion of feces and a distended bladder and ureters, while the children are very susceptible to pulmonary infection; these features are thought to be secondary to absence of the expulsive and expiratory functions of the abdominal wall. Cases reported by Osler and by Smith (124), showed an unnatural protrusion of the lower anterior chest wall. Baxter states that the deficiency involves the two oblique muscles most frequently, with the recti least often affected; Smith reported a case in which the recti were represented by fibrous bands lying in the normal position but devoid of muscle. Ikeda and Stoesser (69), report the histological examination of the abdominal wall in one case in which fascial planes were found representing the various muscle layers, but in which only a few scattered muscle fibres could be found. Bolton (15), reports a case in which the lateral flat muscles were absent but the recti appeared to be normal.

Congenital shortening of one rectus muscle was reported by Clarke in 1902, and was the only case found in this review of the literature (28). The condition was associated with kyphosis, which was corrected by division of the rectus muscle; in the corrected position a three inch gap was left between the muscle ends. The author explained the condition as arising on the same basis as congenital torticollis.

Herniæ occur in the abdominal midline other than at the umbilicus; these are infrequent in children, increasing with age, and lie above the umbilicus. Moschcowitz (101), has explained these herniae as due to the protrusion of properitoneal fat through normal vascular perforations of the transversalis fascia and linea alba; the fat may in time be followed by a peritoneal sac and a true hernia occur. Most of these herniae probably begin in later life and are thus not truly congenital; Davis (38), reported a case present for many years and possibly at birth, and the author has seen a case in a child of four or five years in which there was a coexistent diastasis recti.

Separation of the recti is normally present up to a three quarter inch width in younger children, and probably should not be included in the term "diastasis recti". This latter term is taken to mean an abnormal separation, usually of over an inch, in which there is a longitudinal bulging in the epigastric midline suggesting hernia. In a case seen recently at the Children's Memorial Hospital, the separation of about two inches extended upwards to include the insertion of the recti on the chest wall, and so could be legitimately called congenital. In adults, the condition may involve the rectus muscle bellies while their attachments above and below the normal; Stark (126), describes such a condition in a woman with myxoedema, and the separation may well be secondary to pathological changes in the musculo-fascial tissues.

Congenital herniae and other anomalies occurring in relation to the inguinal canals and the structures passing through them have been omitted from this discussion since they constitute a lengthy problem in themselves. Mention has been made of the work of Zimmerman showing the banding which may involve the internal oblique and transversus muscles in the lower abdomen, giving rise to ventral hernia in later life. Woliver and Scott (146), have reported such cases recently. Murray (102), Oliver (107), and more recent authors have reported herniae of the lower abdomen having a similar appearance, but due to the turning upwards of inguinal herniae so that the fundus of the sac lies between the muscle planes lateral to the rectus sheath.

Trimingham (137), has compiled a list of the various congenital anomalies which may involve the umbilicus alone or in association with umbilical herniae. These include various degrees of patency or persistence of embryonal structures, the omphalo-mesenteric duct, urachus, umbilical vessels or omphalo-mesenteric vessels. Pack and Ehrlich (109), discuss 470 tumors of the abdominal wall, of which 391 were neoplasms; of these latter 51.5 percent were benign and 13.4 percent were primary malignancies. Grieg (58), describes certain fibromata, termed "desmoid tumors", which are supposed to be congenital; 90 percent occur in the female and may be noticed as early as eight months of age, arising from the fascial planes or the tendinous intersections of the rectus muscles.

5. Pectus Excavatum

Pectus excavatum, or funnel chest, has been the subject of renewed interest in the surgical literature of the past few years. Other terms are used to describe an abnormal degree of depression of the lower sternum and adjacent costal cartilages, including koilosternia, trichterbrust, chonechondrosternum, and thorax en entonnoir.

Sutton (131), found the condition in 0.04 percent of 30,000 school children examined, and noted a family history of the defect in 38 percent. Brodkin (16), found 0.059 percent of 46,705 adults to show the condition. Ochsner and De Bakey (105), collected 268 cases, 31 of which gave a family history in which the anomaly was transmitted as a dominant characteristic; they noted a ratio of four males to each female in the series. These authors consider it to be a congenital anomaly, with its onset in childhood, and rarely acquired; Kuhns (76), considers it developmental rather than congenital, saying that it tends to occur in slender types, and is always associated with faulty posture. He states that a gradual transition from flat to funnel chest can be seen in this type of child followed for a number of years. The hereditary factor is undeniable in some cases; Sainsbury (122), described six cases occurring in four generations of one family. Figure 25 shows the family tree in these cases. Arneill (3), reports five cases with defects from 2.5 to 6.5 cm. in depth, occurring in two brothers, their father and two paternal uncles, all of whom were heavy labourers without any physical disability.

Ochsner and De Bakey quote earlier authors who felt that the defect was a persistence of a physiological funnel chest said to occur in the fetus, or was due to pressure on the fetal chest; in this latter regard cases are cited which at birth showed a depression into which the chin, heel, knee,

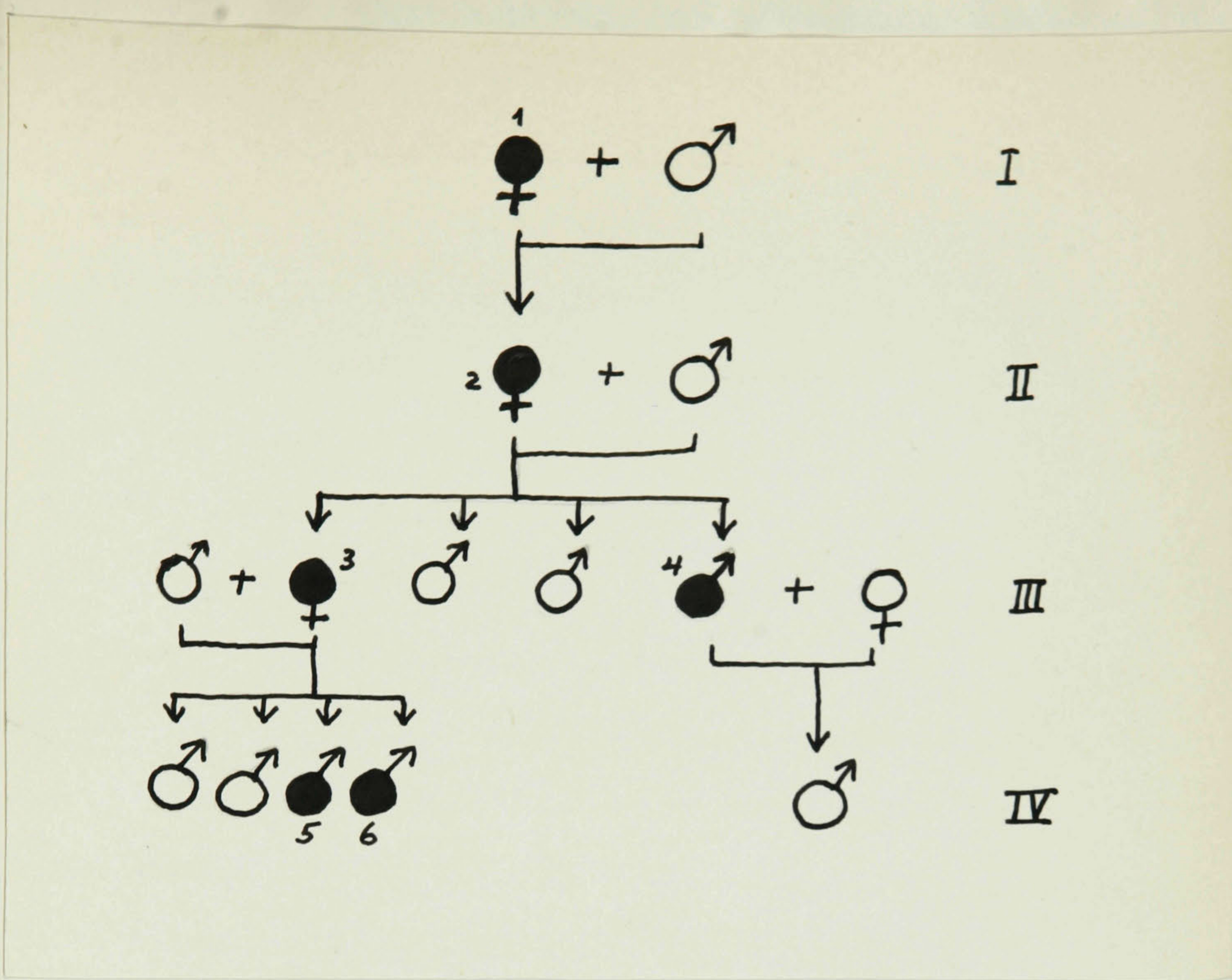

Fig. 25. Chart of the family tree having six cases of funnel chest in four generations. After Sainsbury, (122). The individuals having this condition are in solid black and indicated by Arabic numerals. The generations are indicated by Roman numerals.

Figure 26.

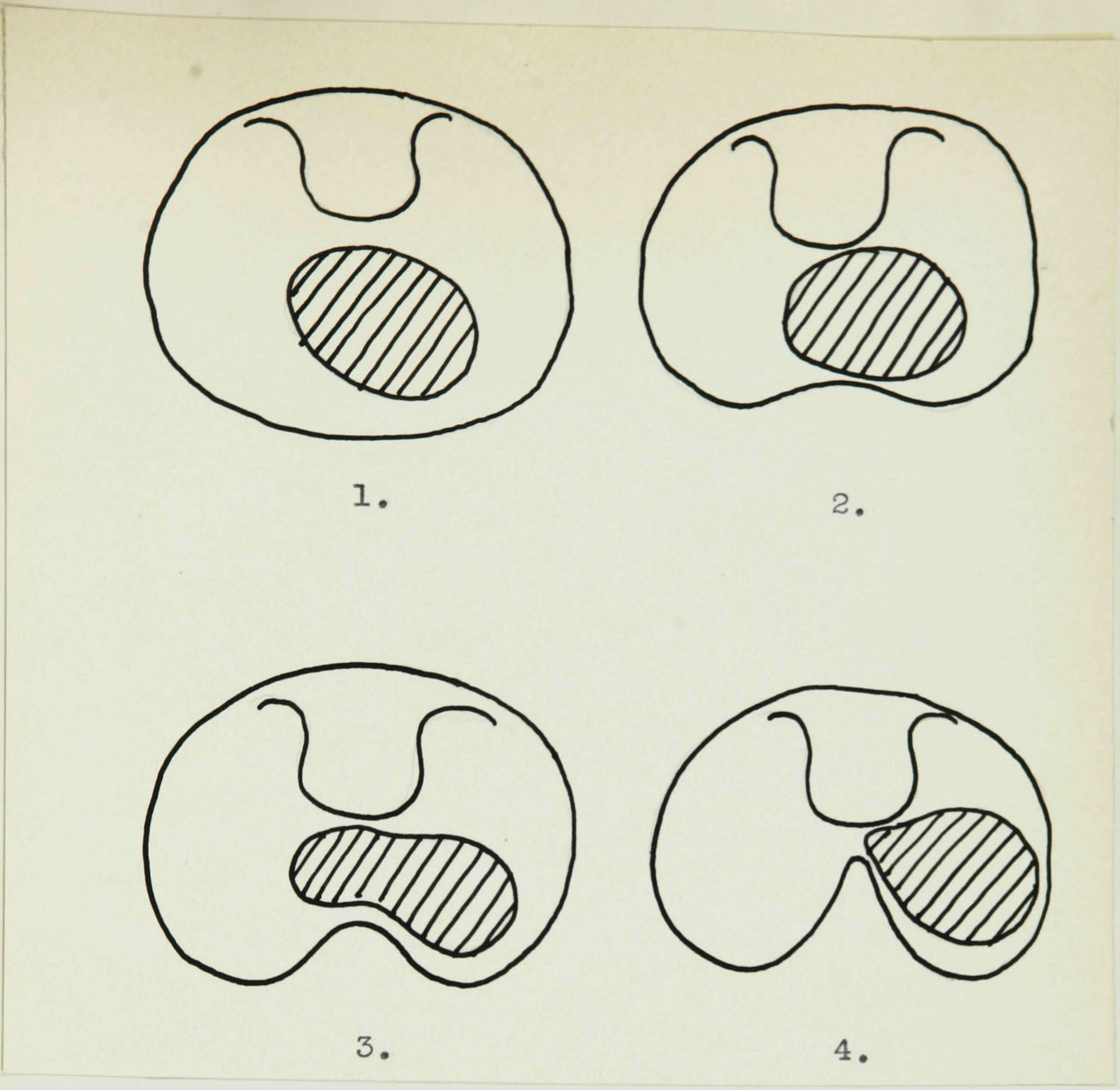

Fig. 26. Diagrammatic transverse section through the chest at the level of the lower sternum, with the heart shown in situ, (ruled lines). 1., normal; 2., 3., and 4., the saucer, cup, and funnel forms of pectus excavatum and their effect on the heart. After Evans, (50).

etc., of the infant could be fitted.

Certain cases occurring in later life are acquired, but these are very rare; Arneill cites a case in a railroad worker accustomed to push heavy cars with an bar pressed against his lower sternum, while Codman (29), cites a similar case in a circus performer balancing from an early age upon a pole against the involved area.

Respiratory infections in infancy were blamed for the onset of funnel chest by most early writers; whether this precedes or follows the defect in appearance is sometimes difficult to ascertain. The asthenic habitus, if it predisposes to the defect, may also be responsible for the frequency of respiratory infection in these children. Lester (84), has recently re-introduced the causal effect of infection in an attempt to account for the contracture of the diaphragm said to be present in these cases. Rickets was also blamed by the early authors, Richards (118), reporting two cases in 1903; Brown (19), however, states that funnel chest has never been associated with a proven case of rickets.

Regardless of the initiating factor, the problem of the anatomy of the defect and the mechanism of its production is still not solved. This has become important recently in the evaluation of the operative procedures now being proposed for the correction and arrest of the deformity.

The apex of the depression is opposite the lower end of the sternum and xiphi-sternal junction, with the body of the sternum, adjacent costal cartilages, and upper epigastrium sloping inwards to form a circular concavity of varying degree; the manubrium sterni remains in a normal position. The underlying pericardium and heart are usually deviated to the left, but may be held in the midline or be pushed to the right (19). Evans (50), notes three degrees of depression, the saucer, cup and funnel, with increasing displacement of the heart; Figure 26. In the case developing during childhood, there is usually an associated faulty posture, with round shoulders, a flat type of chest and an accentuated dorsal spinal curve.

Specific symptoms rarely result despite the cardiac distortion (49); Beck (9), has shown that displacement of the heart taking place gradually causes little disturbance of the circulation unless there is torsion or angulation of the great vessels, when the heart becomes hypersensitive. Adorno (1), states that E.C.G. changes are not found unless the depression is associated with kypho-scoliosis; Teplick and Drake (134), and Paul and Richter (113), point out the necessity of differentiating the apparent enlargement of the heart in this condition, due to rotation, and true enlargement due to intrinsic cardio-vascular disease. They noted only minor E.C.G. changes, usually right axis deviation. Manning (89), cites a case in a 26 year old boxing champion with a 5.7 cm. depression, who had marked displacement of the heart but only minor E.C.G. changes and no disability. The presenting symptoms of fatigue, dyspnoea, and palpitation in some cases are difficult to evaluate. Sutton (131), and Master (92), ascribe such symptoms to neurasthenia associated with the poor physical condition and posture; Wood (147), in discussing the "effort syndrome", notes the preponderance of poor postural types in this condition, and suggests that the chest pain which is complained of may be on a somatic basis, arising from mechanical dysfunction of the diaphragm and lower chest wall. Hutcheson (66), believes that the displacement of the heart may limit cardiac reserve and so tend towards invalidism and neurasthenia, while Chapman (26), describes a syndrome of pulmono-cardiac failure associated with funnel chest, kypho-scoliosis, and other severe chest deformities, characterized by progressive dyspnoea, palpitation and cough. He believes such cases have a mechanical defect in the use of their chests which renders them liable to respiratory infections.

Mention has already been made of the views of Brown (19), regarding the existence of a thickened sub-sternal ligament and shortened central tendon of the diaphragm in cases of funnel chest. He notes the indrawing of the lower sternum seen in normal children on forced inspiration in the presence of many respiratory infections, and concludes that the diaphragm is the only structure so located that it may draw the chest wall inwards; his description of the anatomy of the defect is based on observations made at operation. Hutchinson (67), in 1897, believed the central tendon of the diaphragm was fixed to the lower sternum by fibrous bands. Unfortunately, there is no description available of the state of affairs found at autopsy on a human with this condition. Only one dissection has been reported on a funnel chest, that of Brodkin (17), on a four week old dog having a depression resembling that in the human. He found the anterior leaf of the central tendon of the diaphragm to be absent, with overdeveloped lateral musculature fused in the anterior midline and attached to the xiphi-sternal junction. He attributes this to failure of development of that portion of the diaphragm formed from the septum transversum. In one case subjected to operation for the correction of funnel chest at the Children's Memorial Hospital in 1949, at which the author was present, a substernal ligament could not be found. The xiphoid process was found to be directed straight backwards, but separation of the anterior fibres of the diaphragm did not result in any release of the lower sternum.

It is not certain that the diaphragm is the only, or indeed the main cause of indrawing of the lower sternum in forced inspiration. In a case of respiratory infection, the indrawing is minimal unless associated with obstruction of the airway; this suggests that the depression which is then very marked, especially in infants, is not so much an indrawing as an inpushing by the atmospheric pressure in the presence of an abnormally low intra-thoracic pressure. On normal inspiration, descent of the diaphragm is in part resisted by the tone of the abdominal wall, so that there is also an upward force exerted on the lower ribs; by virtue of the costo-vertebral articulations, this is accompanied by a concomitant torsion or flaring of these ribs, resulting in expansion of the bony thoracic cage (141). In the presence of a very low intra-thoracic pressure, there must be considerable resistance to this movement; the most likely area to succumb to this resistance would be the lower sternum and adjoining costal cartilages. Miller (98), by taking thoracic tracings in humans under increasing anaesthesia, has shown that when intercostal paralysis occurs, there is paradoxical movement of the whole anterior chest wall; when obstruction of the airway is added, actual indrawing is markedly increased. Since the diaphragm had been acting alone both before and after the addition of respiratory obstruction, the appearance of the indrawing would seem to depend on some factor other than direct action of the diaphragm. Fisher (52), says that in a child under two and a half years, respiratory obstruction results in a transverse groove across the lower chest, but that after this age, when the bony ribs are more complete, funnelling of the chest is produced as in the adult. Kuhns (76), states that complete paralysis of the diaphragm results in indrawing of the lower sternum with each inspiration probably due to the unopposed pull of the recti; a fixed defect does not persist since this condition is incompatible with life. The depression of the lower chest associated with congenitally short rectus muscles has been mentioned in the case described by Clarke (28). Ochsner (105), quotes a similar case of Habs, in which a typical funnel chest was relieved by section of the rectus. The opposite condition, a flaring of the lower ribs, is seen in cases of deficient abdominal muscles. Truesdale (139), describes the case of a seventeen year old with a severe funnel chest in which the apex posteriorly was only 3.5 cm. from the vertebral column;

the xiphoid pointed forwards so that the anterior attachment of the diaphragm was in front of the apex, and could not have been the cause of the fully developed lesion. He describes another case in a man of sixty, with the sternum only a finger's-breadth from the vertebrae, while Sweet (132), describes the findings in a girl of fourteen in which the apex of the funnel was 1 cm. behind the anterior surface of the thoracic spine; he states that it seemed as though the sternum was being pushed backward by the unusually long and curving costal cartilages. Indrawing was still present on inspiration in this latter case.

Ochsner (105), quotes Flesch, in 1873, as saying that funnel chest was due to a disorder of the costal cartilages themselves. Phillips (116), describes a case of funnel chest in which the costal cartilages were bunched together and overlapped the anterior sternum as high as the third rib. Hanson (62), in discussing the development of the sternum, states that there is a tendency of the costal cartilages to grow towards the median line and to fuse with one another; the length of the sternum is independent of the number of ribs reaching it, which may vary from six to eight on each side. In 50 percent of cases, the seventh ribs articulate with each other anterior to the sternum and xiphoid process. Dwight (45), reports a case in which the fifth, sixth and seventh cartilages all met in front of the sternum.

It seems probable that the development of funnel chest may be different in different cases. In the group with a hereditary background, the decision as to whether it is due to a congenital malformation of the diaphragm or to a disturbed growth pattern of the costal cartilages will have to await accurate post-mortem examination. In the group which apparently follow respiratory tract disease and chronic obstruction to inspiration, there would seem to be a good case for the effect of low intra-thoracic pressure on the weak lower sternum; whether potentiation and progression of the depression is the result of a changed direction in the growth of the ribs, or of contractures of the central portion of the diaphragm, is not settled. It is certain that in the older child or adult, the deformity is a rigid one by virtue of the conformation of the sternum and ribs, so that an extensive plastic procedure is required for its correction. The part played by faulty posture and muscle imbalance (51), particularly the lowered position of the diaphragm and the changed pull of the recti, is difficult to evaluate.

Carr (23), states that funnel chest in itself is not an indication for operation, which should only be undertaken if there is a high degree of probability of relationship between the symptoms and the deformity. Brown, L. T. (20), Taylor (133), Kuhns (76), and Master (91), agree that surgery is rarly required, and claim that the deformity and symptoms can be largely overcome by exercises designed to correct posture, particularly in those cases associated with neurasthenia. Lester (84), and Brown, A. L. (19), recommend a radical plastic procedure in the developed case having functional restriction of respiration or circulation, and for cosmetic reasons. They also recommend a relatively simple procedure, consisting of division of the xiphi-sternal junction and separation of the anterior attachment of the diaphragm, to be used in infants to prevent the progression of an early tendency to funnelling. This latter proposition would seem to unsubstantiated on anatomical grounds, and in view of the frequency of indrawing of the chest in infancy compared to the infrequency of progressive funnel chest, would seem to threaten many children with an unnecessary surgical risk. Sweet (132), stresses the importance of the psychological disturbances resulting from funnel chest as a reason for early operation, but a program of exercise and rehabilitation may be as effective as the operative treatment in such cases.

6. Other Anomalies of the Chest Wall

Brodkin (17), considers pigeon breast, or congenital chondro-sternal prominence, to be closely related to the opposite deformity, funnel chest. He found the incidence of the former condition to be 0.6 percent in 41,863 school children examined. The prominence of the lower sternum and adjacent costal cartilages begins shortly after birth, increases with age, and rarely interferes with nomal activity. He describes the autopsy findings in a thirteen month old girl with pigeon chest, in which the anterior sternal fibres of the diaphragm were markedly underdeveloped, while the lateral costal origin was strongly muscular. This strong lateral pull causes narrowing of the chest, with a concomitant increase in the antero-posterior diameter; the anterior leaf of the trefoil tendon is supposed to be unusually long, in contra-distinction to the short tendon of funnel chest. He believes both deformities are due to congenital deficiencies of that part of the diaphragm formed from the septum transversum. which appear after birth with the changing proportions of the chest incident to diaphragmatic respiration.

In one case in this series, No. 13, there was a mild degree of pigeon breast deformity. On dissection, the chest and abdominal walls were not otherwise unusual. The xiphoid processes were unusually short, so that the xiphoid origin of the diaphragm ran almost straight backward on a level with the central tendon and floor of the pericardium, whereas the most medial fibres of the costal origin arose five eighths of an inch below this from the seventh costal cartilage, running upwards and back to the tendon. The endo-thoracic fascia on the upper surface of the xiphoid origin musculature and reflected to the back of the sternum was thickened and suggested a low-lying sterno-pericardial ligament. The lateral musculature and that of the xiphoid origin did not in itself appear to be abnomal. This would seem to be the state of affairs to be expected in a case of funnel chest rather than pigeon breast.

Perhaps the most common and least serious of the anomalies of the chest are the minor variations from normal of the ribs. Stuart (129), found anomalies of the thoracic cage in 1.9 percent of 19,050 pre-enlistment X-rays in males 18-38 years of age, including cervical ribs, rudimentary first ribs, fusions between adjacent ribs, and bifurcated ribs. Funnel and pigeon chests are not noted. Crookshank (32), has described a case having a depression of the right chest due to absence of the anterior extremities of the second, third and fourth ribs. Thomsen (136), reports congenital flattening of the one side of the chest associated with agenesis of one lung and ipsilateral absence of the diaphragm, while Lauber (79), reports collapse of the chest in congenital idiopathic osteoporosis.

Diaphragmatic herniae in general need not concern us here, since the majority occur through the eosophageal hiatus, a congenitally patent pleuro-peritoneal canal, or are due to failure of development of the whole of one side of the diaphragm, in any case in an area posterior to that with which we are concerned (34). Harrington (63), has recently reported 24 cases of subcostosternal hernia seen in a ten year period. This consists of the protrusion of abdominal contents, within a peritoneal sac, upwards through the foramen of Morgagni in fron of the cleft between the xiphoid and costal origins of the diaphragm and deep to the medial end of the seventh costal cartilage, usually on the right side. He states that occasionally, due to a deficiency of the xiphoid origin of the diaphragm, the two triangular foramena really constitute a single subcostosternal space. When a hollow viscus is involved, these herniae must be repaired, due to the likelyhood of obstruction in the future; the possibility arises that the severence of the anterior attachment of the diaphragm advocated for infants with insipient funnel chest will result in herniae of this type occurring, and requiring subsequent re-attachment of the divided structures.

Brief mention has been made of those clefts infolving the chest wall, and resembling those of the abdominal wall known as omphalocele. Although those involving the chest are usually associated with ectopia cordis, and incompatible with life, Maier (86), has recently reported a case in which the sternum was completely cleft, with protrusion of the pericardium but without exposure of the heart, in which surgery was effective. In this case, the manubrium, body and xiphoid processes of the sternum were represented by paired bands of cartilage, close together below, but separated for 1.5 cm. above. The ribs and clavicle were normally attached to these bands. There was no hernia of the abdominal wall, the upper epigastrium presenting a scarified appearance. He refers to Greig (57), who reviewed 39 cases of cleft sternum in 1926, and found 20 of these not to be associated with ectopia cordis. He also reported 15 cases of ectopia cordis in which the sternum was not cleft, 13 below or abdominal, and 2 above or cervical. Congenital absence of the sternum also occurs, differing in that longitudinal bars are not present, and the ribs are not joined anteriorly.

Chapter V

Summary and Conclusions

An attempt has been made to trace the history of the abdominal wall, lower chest wall and diaphragm, in their evolution in the animal kingdom, and in their development in the human individual, in order to related the structure and function of these regions to the various congenital anomalies to which they are subject.

The evolution of a true body-cavity between the viscera and body wall apparently fulfills the need for a nutritive and later respiratory circulatory system, and permits enlargement of the individual organism. The earliest muscular body-wall exists primarily to resist the environmental water pressure, and persists as the thoracic cage, internal intercostals and internal oblique muscles in man. The development of a pulmonary respiration parallels the increasing complexity of the abdominal wall, with the second layer of muscles, corresponding to the external oblique layer in man, arising originally to provide increased locomotion, and being adapted to decrease intra-thoracic pressure as the external mechanism of respiration. The diaphragm is considered as arising from the third layer of the body wall, the transverse layer, both being primarily compressive in function. Adaptation of the diaphragm as the internal and chief mechanism of respiration is apparently a late and purely secondary manifestation of the evolutionary process.

Mijsberg's views on the evolution of the sheaths of the rectus abdominis muscle have been presented, as one idea on the means by which the arcuate lines are formed.

The accepted views of the embryology of the body-wall, chest wall, sternum, and diaphragm are presented, as an introduction to the anatomy found in the child and adult.

The anatomy of these regions is presented as found in the dissection of twenty specimens from two adults, sixteen children aged 12 hours to thirteen years, one fetus of about seven months, and a newborn infant with a large omphalocele. The growth of the abdominal wall as a whole is proportionate to that of the chest wall and pelvis, so that the relationships of one muscle to another is constant from birth to adulthood. No significant increase in the relative amount of aponeurotic to muscular portions of the flat muscles could be detected in this series, and the relationship of the musculo-aponeurotic junctions to the lateral border of the rectus muscle was surprisingly constant. This latter feature was also found to be true in the case of the infant with a large omphalocele, prompting the author to favour the opinion that some cause other than a defective growth of the abdominal muscles themselves was responsible for this malformation. No constant growth change or pattern could be made out for the linea alba in the series; the author noted considerable variation in the width of this structure, and would hesitate to call a separation of the recti in mid-epigastrium of less than three quarters of an inch an abnormality unless accompanied by a similar separation of the muscles at their insertion on the chest wall.

The changes occurring in the region of the umbilical scar following birth are described, and corroborate the views of other writers, that there is normally a liability towards the development of umbilical hernia within the first six months. The consolidation which takes place in this area during the first year is adequate to explain the tendency of these herniae to undergo spontaneous cure, whereas if the hernia should persist until the umbilical region has undergone consolidation around the hernial defect, the potentiality for further cure will no longer be present in the now mature scar, and operative therapy will be required.

The problem of the etiology and treatment of pectus excavatum has been discussed. The author is of the view that more than one factor is concerned in the production of the final funnel-shaped deformity of the lower chest wall. The view currently in favor, namely that there is a congenitally shortened central tendon of the diaphragm and a contracted "sub-sternal ligament", the cutting of which in infants may prevent the subsequent development of the fully formed deformity, does not seem to be applicable in all cases. The effect of atmospheric pressure and respiratory infections or anomalies in the initial so-called indrawing seems to be under-rated, while it seems to be undeniable that in the advanced deformity, either primary or secondary changes in the costal cartilages themselves are responsible for holding the sternum backwards. That the deformity may be initiated by poor posture and the consequent imbalance of the musculature of the body-wall, seems not improbable; the changed action of a normally constituted diaphragm and the action of the rectus abdominis muscles in such cases deserves further investigation. The solution of the problem, as is the case with many congenital anomalies, will probably have to await the opportunity to study the anatomy of these defects at autopsy.

Appendix A

Description of Cases

The following is a brief listing of the pertinent data concerning the cases from which specimens were obtained for this report.

Case 1. Fetus. Clinical data unknown. Body length; crown-rump, 6-3/8 inch, crown-heel, 11-1/2 inches. Estimated age, 7-8 lunar months. Sex, female. No congenital abnormalities found. See Fig. 9.

Case 2. Baby C., female, died within 1 hr. of birth. Maternal history not available. CMH-A50-1. Congenital defects include a large omphalocele, multiple deformities of the four extremities, malformation of the liver, and malrotation of the gut. Preserved in formalin soon after death. See Fig. 24.

Case 3. Baby S., male, age 12 hours. Died Aug. 31st/49. CMH-A-49-72. Wt. 3 lb. 12 oz. Length, C-R, 34 cm., C-H, 53 cm. Presumed cause of death, prematurity and subdural hematoma. Specimen consisted of the rt. rectus and linea alba detached from the chest wall and pubis. Patent urachus. Stump of the umbilical cord attached.

Case 4. S. L., female, age 1 week. Died Aug. 7th/49. CMH-49-2580. Wt. 6 lb. 1 oz. Length, C-R, 33 cm., C-H, 47 cm. Presumed cause of death, pneumonia, and tracheo-oesophageal fistula. Specimen consisted of rt. half of the abdominal wall detached from the chest. Umbilicus attached.

Case 5. M. B., male, age 13 days. Died Sept. 18th/49. CMH-A-49-75. Wt. 6 lb. 4 oz. Length, C-R, 35 cm., C-H, 53 cm. Cause of death: diarrhea and vomiting, septicemia. No external abnormalities. Specimen: Abdomen and lower chest wall. See Fig. 10.

Case 6. P. D., male, age 25 days. CMH-A-49-86. Wt. 8 lbs. Length, C-R, 34 cm., C-H, 51 cm. Death due to a central nervous system defect or disease with pharyngeal paralysis. No external abnormalities.

Specimen: Abdomen and lower chest wall, with umbilical cord still attached. See Fig. 11.

Case 7. C. L., female, age 1 month. CMH-A-49-73. Wt. 7 lbs. 3 oz. Length, C-R, 37 cm., C-H, 54 cm. Death from meningitis. Specimen: Abdominal and lower chest walls. No external abnormalities. See Fig. 12.

Case 8. Baby T., male, age 6 wks. CMH-A-49-85. Wt. 13 lbs. 12 oz. Length, C-R, 36 cm., C-H, 56 cm. Death due to meningococcal mengitis. No external abnormalities beyond a slight bulging in the umbilical region. Numerous petechial haemorrhages of the peritoneum. Specimen: Abdominal and lower chest walls. See Fig. 13.

Case 9. J. G., male, age 8 wks. CMH-A-49-71. Wt. 5 lbs. 6 oz. Length, C-R, 32 cm., C-H, 48 cm. Death due to bilateral pneumonia. No external abnormalities. Specimen: Rt. abdominal wall and lower chest wall. See Fig. 14.

Case 10. K. B., female, age 8 wks. CMH-A-49-70. Wt. 7 lbs. 1 oz. Length, C-R, 35 cm., C-H, 53 cm. Death due to aspiration in association with cardiac disease. No external abnormalities. Specimen: Rt. abdominal wall detached from the chest.

Case 11. R. A., male, age 6 mos. CMH-A-49-76. Wt. 6 lbs. 9 oz. Length, C-R, 38 cm., C-H, 59 cm. Death due to marasmus and pneumonia associated with pancreatic fibrosis. Specimen: Rt. abdominal wall removed from chest.

Case 12. Hurst, male, age 1 year plus. Wt. 13 lbs. Length, C-R, 45 cm., C-H, 67 cm. Dead on arrival, cerebral haemorrhage? CMH-A-49-84. Specimen: Abdominal and lower chest walls. See Fig. 15.

Case 13. D. F., female, age 19 mos. Wt. 12 lbs. 14 oz. Length, C-R, 42 cm., C-H, 67 cm. CMH-A-49-92. Mild pigeon breast deformity.

Mongolian idiosy. Cause of death unknown. Specimen: Abdominal and lower chest walls. See Fig. 16.

Case 14. C. C., male, age 25 mos. CMH-A-49-87. Death following operation for hydro-cephalus at M.N.I. No external abnormalities. Specimen: Abdominal and lower chest walls. See Fig. 17.

Case 15. Female, age 4 1/2 years. CMH. Death due to nephrosis and superior vena caval syndrome. Specimen: Lower chest wall and upper abdominal wall; lower rectus muscles incomplete.

Case 16. S. W., female, age 7 years. CMH-A-50-18. Length, C-R, 62 cm., C-H, 117 cm. Malnutrition, no external abnormalities. Death due to chronic leukemia. Specimen: Abdominal and lower chest walls. See Fig. 18.

Case 17. Female cadaver, age 13 years. Generalized edema, malnutrition, massive pulmonary Tbc. Cadaver embalmed in the usual manner and subsequently the arterial system was injected with red latex. Chest and abdominal walls removed for study. No congenital abnormalities encountered.

Case 18. Adult male cadaver. Estimated age exceeds 40 years. Death probably due to malnutrition and Tbc. Routine embalming procedure. No external abnormalities.

Case 19. Adult male cadaver. Estimated age exceeds 40 years. Death probably due to extensive bilateral pulmonary Tbc. No external abnormalities. Routine embalming procedure.

Case 20. Female child cadaver. Estimated age 12-13 years. Death probably due to gross pulmonary Tbc. Usual embalming procedure. Specimen: Chest and upper half of the abdominal wall; trunk trans-sected and lower half of the body disposed of before it could be examined by the author. Used in the demonstration of the continuity of the transversus abdominis and diaphragmatic muscles. See Fig. 11.

Appendix B

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