THE SHEATH OF THE RECTUS ABDOMINIS

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A STRUCTURE of such complexity as the rectus sheath could not fail to attract the attention of anatomists, and its comparative form, its morphological interpretation, and its possible functional significance have been the subjects of numerous studies. The construction of the sheath in the mammals, in which group alone it may be said properly as a sheath to exist, was soon discovered to vary, and to do so not only from order to order but even among related species. The sheath exists in three main forms: (1) the superficial wall of the sheath is formed by the obliquus externus and the deep wall by the obliquus internus and transversus (*Ornithorhynchus*, most marsupials, Talpidae, *Pteropus*); (2) the superficial wall is formed by the obliquus externus and the obliquus internus and the deep wall by the transversus (rabbit, dog, Insectivora (except Talpidae), gibbon, chimpanzee, gorilla); and (3) the obliquus internus splits into two lamellae, one of which with the obliquus externus forms the superficial wall and one with the transversus the deep wall (cat, pig, horse, ox, sheep,

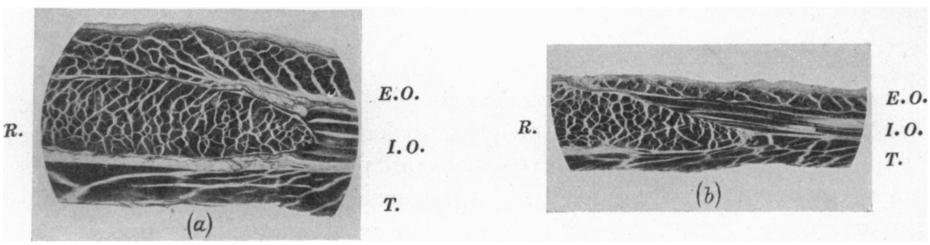

Fig. 1. Transverse sections of the anterior abdominal wall of the mouse; *a*, at the middle part, and *b*, at the lower part.

mouse, man). Further, however, in some species the construction of the sheath is different at its upper, middle, and lower parts, the construction of the middle part being considered to be typical and that of the upper and lower parts to be variants of it. The variations at the upper part are due to the presence of the costal skeleton in the abdominal wall, the primary morphological position of the skeleton being in the middle muscle layer. The variations at the lower part of the sheath have been less satisfactorily explained. They always consist of a shifting forwards into the superficial wall of a part, or the whole, of the deep wall of the sheath, the change taking place in the lower third or lower quarter of the abdominal wall and with an abrupt suddenness so that there is a sharp free border for a part, or the whole, of the deep wall. In the mouse (Fig. 1), for example, the lower part of the internal oblique muscle, which at the typical level splits to enclose the rectus, suddenly changes its insertion wholly into the superficial wall of the sheath; the transversus alone then forms the deep wall of the sheath as far as its lower border, beyond which the rectus rests on the fascia transversalis. In the dissection of a gibbon it was demonstrated that the transversus, in the lower quarter of its length, suddenly splits into two layers, one of which passes into the superficial wall of the sheath and one continues in the deep wall which it forms as far as the pubis. In the ox and the sheep, as in the human subject, the deep wall of the sheath ceases abruptly in the lower quarter of the abdomen, the lower part of the internal oblique being undivided and with the transversus passing into the superficial wall of the sheath; in the chimpanzee, on the contrary, the transversus maintains its position in the deep wall of the sheath in its whole extent. In a baboon it was demonstrated that the internal oblique passed wholly anterior to the rectus; the deep wall of the sheath was formed by transversus, but midway between the umbilicus and pubis it abruptly passed into the superficial wall, a typical arcuate line (linea semicircularis) being formed.

The differences in the construction of the sheath are therefore only differences in the relationship of the rectus to the differentiated parts of the deeper of the two primary muscle layers of the lateral trunk; and if each of the secondary layers (obliquus internus and transversus) of the primary deep layer be divided into two further layers, it is possible, by postulating the absence of one of the final layers, to describe the differences in the formation of the sheath on a purely morphological basis (Fig. 2).

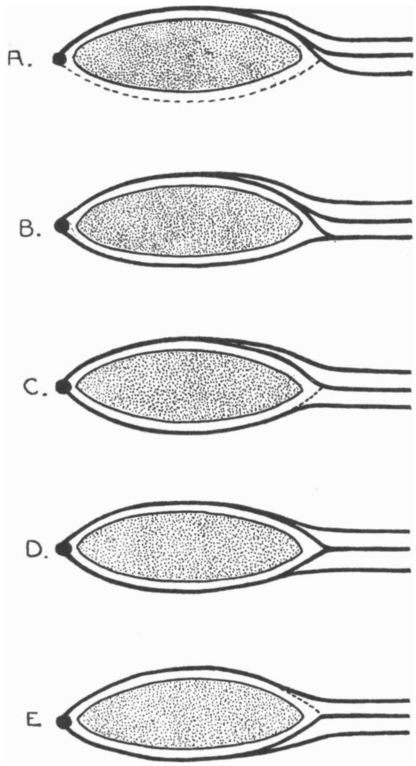

Fig. 2. The varieties of the rectus sheath.

It is obvious that such a basis of explanation is entirely artificial, and it must therefore be recognized that here also, as in other regions of the body, the particular relations of muscles are determined not by their homology but by their action. The form of the sheath of the rectus is then the expression of the action of the lateral strata.

The general morphological facts seem to be clear. The differentiation of the lateral abdominal muscle into strata has been determined, at least in part, by the rhythmical movements of pulmonary respiration. Phylogenetically there are two primary strata, the internal oblique stratum which is differentiated first and the external oblique stratum which is differentiated later; both strata are (in Urodela) in primary union with the ventral rectus. The secondary and definitive muscles arise from the lamination of the primary strata, there being so added the transversus and subvertebralis (from the internal oblique stratum), the obliquus externus superficialis (from the external oblique stratum), and the rectus superficialis from the ventral rectus. In their further history there is undoubtedly an unequal development of the secondary strata and even some retrogression of some of them (in Anura of the primary internal oblique); so that there are, as a rule, in reptiles, birds, and mammals three lateral muscles. The orthodox view is that the mammalian muscles are the obliquus externus superficialis (the deep externus having undergone retrogression in the abdominal wall though it persists in the thoracic wall), the obliquus internus, and the transversus; and the mammalian rectus is the rectus profundus, the pyramidalis possibly being a part of the rectus superficialis. This arrangement of laminae would explain satisfactorily the anterior position and the independence of insertion of the aponeurosis of the external oblique in the linea alba in the sub-umbilical region in the human subject (in Insectivora the aponeurosis has an independent insertion in its whole length), and allow it to be assumed that, strictly speaking, the external oblique aponeurosis is not a true part of the rectus sheath but a superficial covering of it. The fibres of the external oblique aponeurosis, it may be stated, do not fuse or form any connexion with the tendinous intersections of the rectus but pass freely over them as a complete layer, and at these places the external and internal oblique aponeurotic systems are easily separated. The first intersection in the rectus occurs at the level of the upper margin of the internal oblique.

It is now generally held that in mammals the musculature of the ventral abdominal wall arises not in a prolongation of the myotomic mesoderm but directly in mesenchyme, which may or may not be derived from the myotomes; and that in its development, therefore, this musculature resembles the musculature of the head, the tongue, and the limbs. The developmental history of the ventro-lateral muscle in the human subject shows the rectus to be the ventral part of the internal oblique stratum. In the 20 mm. embryo (Fig. 3) the three lateral strata and the rectus anlage are defined. The superficial and deep strata are continued ventrally, independently of the rectus mass, towards the umbilical margin. The rectus mass is as yet not differentiated, but the central area of it is obviously pre-muscle tissue while the peripheral area is the muscle sheath. The amount of the muscle sheath is considerable and, as is to be seen in the 60 mm. embryo (Fig. 4), there are formed from it the dense fibrous bands at the margins of the rectus[1] and the looser ventral and dorsal walls of the sheath proper. The earlier purely bursal condition of the sheath,

[1] These marginal bands are fully described by Eisler; in the adult they are attached to the medial and lateral margins of the rectus and the angles of the sheath, and, with the rectus, subdivide the cavity of the sheath into anterior and posterior compartments.

however, has been altered in the later embryo by the attachment to it of the aponeurosis of the internal oblique, and through the sheath the internal oblique muscle now reaches its insertion in the linea alba. The ventral and dorsal

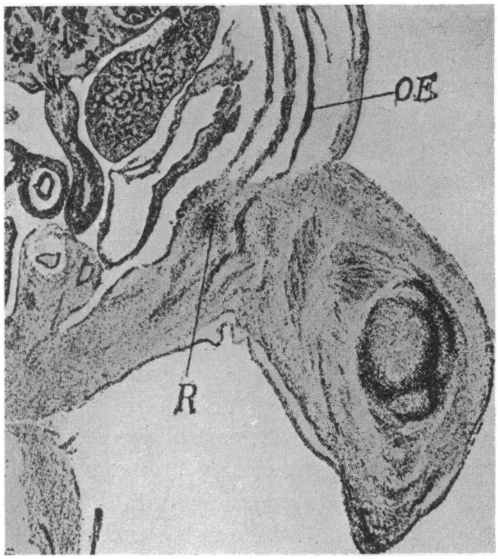

Fig. 3. Transverse section of the abdominal wall of a 20 mm. human embryo.[1]

walls of the sheath thus become aponeurotic, and as such are expressions of the function and manner of action of the internal oblique; and the external oblique and transversus aponeuroses maintain their primary superficial and

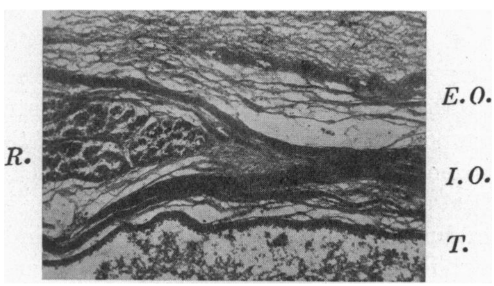

Fig. 4. Transverse section of the abdominal wall of a 60 mm. human embryo.

deep relations to the sheath and are separate from it (Fig. 4). In those forms in which in the adult the internal oblique aponeurosis passes either wholly into one wall or in unequal amounts into the dorsal and ventral walls of the sheath, it must be assumed that the plane of the action of the muscle is not in

[1] Portion of figure from the "Development of the ventral abdominal walls in man", F. P. Mall (1898), *J. Morph.* vol. XIV, p. 347.

the coronal plane through the rectus mass but in a plane partly or wholly on one or other side of it. In the latter condition, for example in the baboon where the internal oblique "aponeurosis" passes wholly in front of the rectus, I have been able to demonstrate the posterior wall of the true rectus sheath between the rectus muscle and the transversus aponeurosis; it is a distinct non-aponeurotic fascial layer and when traced laterally becomes continuous with the internal oblique aponeurosis. In the human subject also the proper posterior wall of the sheath is represented below the arcuate line (linea semicircularis) by a thin delicate fascial sheet which is distinct from the fascia transversalis. The comparative differences in the form of the typical parts of the rectus sheath (Fig. 2 *c*, *d*, and *e*) can be explained then in this way, namely, by the relation of the plane of action of the internal oblique to the rectus. The sheath proper itself is primarily a true rectus sheath and is derived from the rectus mass, but it gains its final significance only when it is considered in mechanical terms of the muscle resultants of the lateral muscles; the sheaths of the two sides then become equivalent, as has been pointed out by Solger (1886 *et seq.*), to the central tendon of the diaphragm.

The atypical condition of the lower part of the rectus sheath occurs in the lowest of the three regions of the anterior abdominal wall, that is, in the human subject, in the region below the interspinous line. It is well known that in its developmental history this region, which in the early foetus is relatively much smaller than in the newborn, differs from the upper regions of the abdominal wall in its much later muscularization; and most of the explanations of the atypical sheath are based on this fact. A final statement of the developmental history of the musculature of this region and of the causes of its late appearance has, I believe, not yet been given. It is a striking fact that even in Teleostei the posterior part of the rectus system develops differently from the anterior part, in that its segmentation occurs after it has lost all connexion with the myotomes (Harrison, 1894); that the segmentation does occur indicates that in teleosts there are mechanical causes which favour segmentation. It is probably true that there is some causal relation of the lateness of the muscularization to the temporary extra-abdominal position of the intestines, to the developmental relations of the urachus, to the course of the intra-abdominal parts of the umbilical arteries, to the development of the processus vaginalis, and to the flexed-adducted position of the lower limbs and their contact with this region of the abdominal wall. That these factors are the causes of the atypical form of the rectus sheath, however, as is advanced in the explanations of Henle, Gegenbaur, Douglas, and Eisler,[1] cannot be maintained, for in

[1] The explanations of the atypical sheath, all of which have been shown to be not correct in fact, are as follows: Henle—to allow the passage of the inferior epigastric artery within the rectus sheath; the artery perforates the sheath far below the arcuate line. Gegenbaur—due to the contact of the embryonic bladder with the abdominal wall and its recession later in development; the bladder never reaches the arcuate line. Douglas—due to the course of the umbilical arteries. Eisler—due to the development of the processus vaginalis; the possibility of the processus is due to the nature of the wall.

many forms, the chimpanzee for example, the lower part of the sheath is not atypical from the parts above, that is, in the chimpanzee the transversus muscle is not displaced forwards and there is therefore no arcuate line.

I am as yet unable to explain the retention of the typical form of the lower sheath in the chimpanzee, but the atypical form in the human subject is due, I believe, to a difference in the function of the lowest part of the abdominal wall; and this view is supported, I consider, by the structural arrangements which I have summarized below:

(1) The arcuate line lies in the early foetus immediately distal to the umbilicus. It migrates distally as the infra-abdominal muscles develop and, generally speaking (i.e., in not less than 70 per cent of adult subjects, Chouke, 1935), it lies on the interspinous line. The fold may fail to descend to its normal position but then, as when it is in the normal position, its medial part is formed by the fibres of the transversus and its lateral part by the fibres of the internal oblique which arise from the anterior end of the crest of the ilium; the fold represents, therefore, the lower edge of the parts of the muscles which have a fixed bony origin from the iliac crest.

(2) Distal to the arcuate line the deep wall of the rectus sheath is formed by a thin fascial layer which is easily separated from the fascia transversalis. As has frequently been described (Mackay, 1889) there is a very constant arrangement of fibres in it, and these fibres when they are well developed form the secondary arcuate line (Henle's band) between the true fold and the pubis, and below it the ligament of Hesselbach which extends downwards to the medial part of the inguinal ligament (Braune, 1884). These bands, I have satisfied myself, are always distinct from the conjoined tendon when it is present, though the ligament of Hesselbach may fuse with it; they belong also to the parts of the internal oblique and transversus which arise from the iliac crest, and they represent, as I understand them, the incomplete translation forwards of the aponeuroses into the anterior wall of the sheath and they illustrate transitional stages of the formation of the conjoined tendon.

(3) The lowest intersection of the rectus muscle lies at the level of the interspinous line, that is, at the level of the arcuate line. I found this also to occur in the baboon and a rhesus monkey. The supra-umbilical segments of the rectus as judged by their nerve supply are derived from, or at least are equivalent to, the 7th, 8th, and 9th thoracic myotomes, and the infra-umbilical segments correspond with the 10th, 11th, and 12th myotomes. The segmentation of the rectus, however accurately it may finally correspond to the original segmentation of the 7th to the 12th thoracic myotomes, is generally accepted to be a secondary occurrence, for in the early stages of development (11 mm. embryo, Lewis, 1910) the rectus mass is a continuous sheet in which there are no myosepta. The causes of the segmentation (see Strasser, 1918), whatever they may finally prove to be, operate then as far as the interspinous line and are inoperative below it, so that at least the 11th and 12th myotomes are not separated. The lowest part of the rectus appears therefore to be subjected to

mechanical requirements which are different from those of the upper part, whether these requirements be confined to itself or imposed on it by the lateral muscles.

(4) The lower border of the fleshy belly of the external oblique lies along the interspinous line, the "Muskelecke" of Gaupp (the angular projection between the anterior and lower borders of the fleshy belly) being in my examinations remarkably constantly opposite the anterior superior spine. Thus below the interspinous line the external oblique is entirely aponeurotic; it cannot by itself alter the curvature of this part of the abdominal wall.

The coincidence of these structural changes at the upper level of the hypogastrium strongly suggests a difference in function of the musculature of the upper and lower parts of the anterior abdominal wall; and this difference may be (*a*) in the active and postural contraction of the muscles to produce movement of the trunk, or (*b*) in their passive contraction and relaxation in reciprocal activity with the diaphragm and thoracic wall in respiration, or (*c*) in producing and maintaining a proper intra-abdominal pressure by their tonic activity and so acting as a weight-bearing mechanism for the viscera, or (*d*) in raising the intra-abdominal pressure by active contraction as is required in expulsive acts (and as occurs when the trunk is fixed to act as a basis for the doing of heavy muscular work by the limbs). The analyses of the muscles in these regards are as follows:

1 (*a*). The rectus and in man the external oblique, through their attachments to the thorax above and the pelvis below, are concerned in the maintenance of the posture and in the movements of the trunk, the rectus being more active in the antero-posterior movements and the oblique in the lateral movements. The hypogastric region, since it is between the iliac bones and in this sense part of the pelvis and moving with it, does not take part in these movements; nor is it in man greatly influenced by the movements of the lower limbs. All the flexion lines of the trunk therefore lie above it and the flexion lines of the lower limbs below it. The external oblique over this area is thus free to become aponeurotic in character and, so far as movements of the trunk are concerned, skeletal in function (the inguinal ligament, the epipubic bone). This "skeletal" part of the aponeurosis normally lies on a flattened rather than on a curved plane, is anterior to the rectus, and reaches the linea alba independently, or almost so, of the rectus sheath (Fig. 5). It is in this "skeletal" area that the rectus is unsegmented and unattached to its sheath; and it is here also that it so frequently acquires an attachment to the linea alba. (*b*) The rectus and the external oblique also act as part of the mechanism for the weight carrying of the viscera, transferring the weight to the thorax through their upper attachments. The high extension of both muscles on the thoracic wall which is characteristic of so many forms is to be ascribed to their two functions. In the human subject they extend farther forwards in the female than in the male, as would be expected on this interpretation, which seems to me a better explanation than that "the muscles have regressed less in the female than the

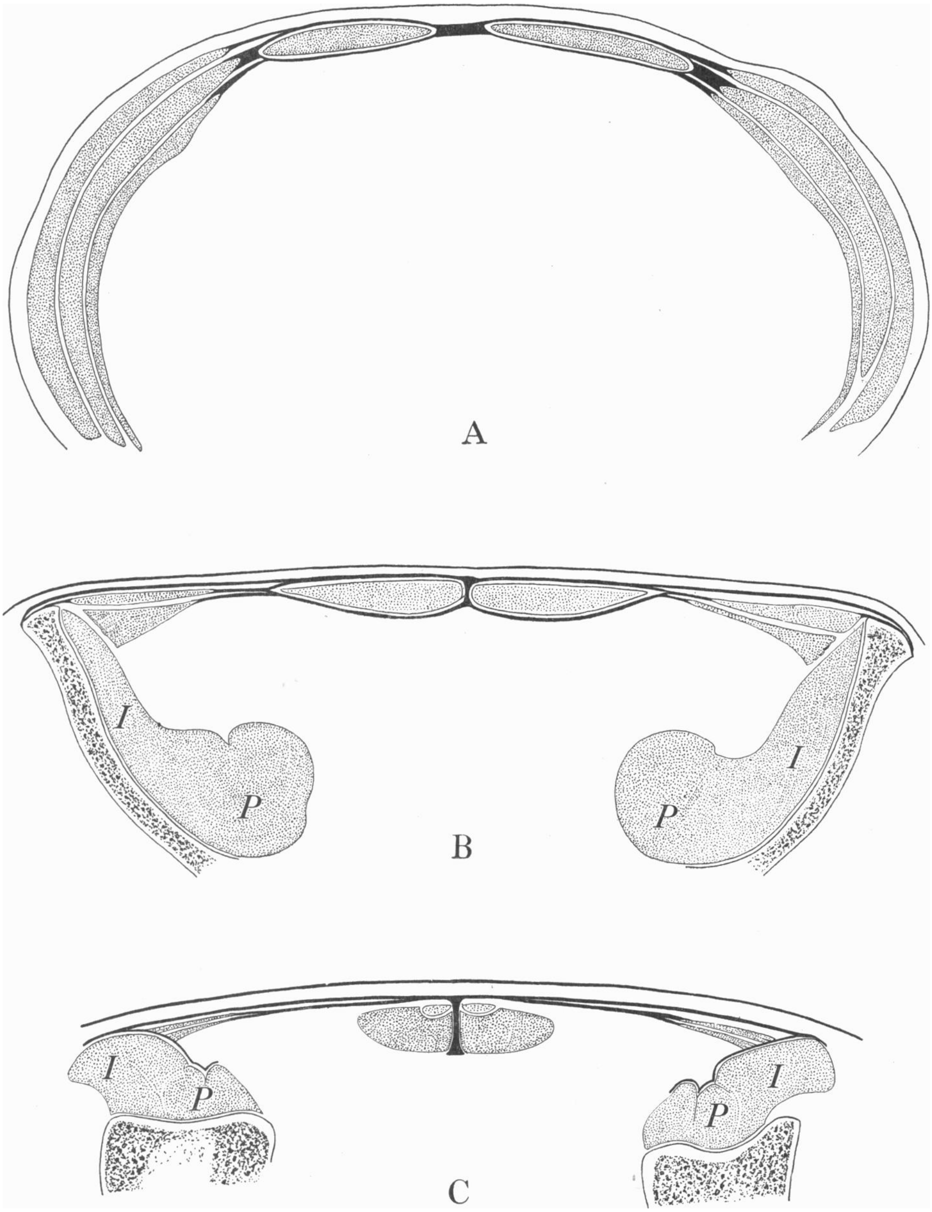

Fig. 5. Transverse sections of an adult male trunk: A, 1 in. above the umbilicus; B, 1 in. below the umbilicus; and C, 1 in. above the symphysis pubis.

male" (Loth, 1931). It is also a striking fact that in older men, when the thoracic curve of the vertebral column is increased and the thorax is ante-flexed, the yielding of the abdominal wall is in what I have termed the "skeletal" area and there are formed there the lateral swellings in the inguinal triangles and the median swelling above the symphysis pubis (the *fleur de lys* of French surgeons). (*c*) The two muscles must also take part in the passive respiratory movements of the abdominal wall. I have been unable to discover in the living subject a difference in kind in the respiratory movements of the upper and hypogastric parts of the wall, apart from the side to side increase and decrease which occurs above but not below; the hypogastric area moves forwards and backwards with the upper areas, though to a much less extent. The backward movement must be produced by the rectus, which when it contracts and diminishes the front to back measurement of the abdomen in the middle line might be expected to cause a counter forward movement in the inguinal triangle. In my experience this does not occur; not does it occur in the active contraction of the rectus with the other abdominal muscles in powerful expulsive acts or the fixation of the trunk for heavy work.

2 (*a*) The upper part of the internal oblique, arising from the vertebral column and the iliac crest and lying in the same plane as the rectus (Fig. 5), acts equally well whether it reaches the linea alba in front of or behind the rectus in all movements of the abdominal wall which are purely respiratory, that is, when all the muscles of the abdominal wall act together in relaxation and contraction and the curvature of a horizontal section is increased and decreased both antero-posteriorly and from side to side. When the upper part of the internal oblique acts with the rectus and external oblique, however, especially with those of the opposite side, to flex the costal margin towards the pelvis, a position in front of the rectus is mechanically better, but when it acts with the transversus as an expulsive constrictor of the abdomen it is better placed deep to the rectus. The active function must be the chief function in the many forms, for example, the baboon and the chimpanzee, in which it passes wholly in front of the rectus. (*b*) The upper part of the transversus obviously acts as a circular compressor of the thoracic outlet and the abdominal cavity; its fibres can take no primary part in the postural or active movements of the trunk. Its morphological position deep to the rectus is its best mechanical position and its origin from the deep surface of the thoracic wall ensures that it will maintain it; in comparative anatomy its position deep to the rectus is constant.

3. The lower parts of the internal oblique and transversus, attached as they are wholly to the pelvis and the "skeletal" area of the abdominal wall, cannot be concerned in the postural position or the movements of the trunk. Their activity must be localized within the area in which they lie. It is unnecessary, I think, to postulate a highly specialized action for them, as, for example, that they are sphincter mechanisms for the deep abdominal ring. They are part of the expulsive musculature, they contract with it, and they prevent the forward

movement of the "skeletal" area of the hypogastrium which would otherwise occur when the upper parts of the abdominal muscles contract. In this sense they are antagonists to them, and especially to the lower part of the rectus, rather than active agents in raising the intra-abdominal pressure; and in this interpretation the eruption of the testis below their lower border is more easily understood, and, in their relatively slight strength or defective development, the genesis of inguinal hernia is better appreciated. It appears to me that they may act in the same way as reciprocal muscles to the iliacus and psoas which, lying close behind them (Fig. 5), will alter the pressure in the hypogastric abdomen when they contract. If this difference in the action of the upper and lower parts of the internal oblique and transversus muscles is accepted, it becomes possible to explain the interval which sometimes is found between them, the possibility of a difference in their ventral extension, and the sharp definition of the arcuate line. The upper parts of the muscles are active energetic contracting parts, while the lower parts, much less active and containing much less contractile substance, only resist the downward pressure of the diaphragm and of the upper parts of the abdominal wall. The arcuate line is the lower edge of the upper parts.

The anterior position of the aponeuroses of the lower parts of the internal oblique and transversus is the most favourable which is possible for this "resisting" action, for their fibres then act on the most curved surface which is available; they also then pass over the rigid pillar which the contracted rectus forms for them. The anterior position is thus due to more than simply the shifting forwards and more anterior position of their origin, for the muscle fibres which are attached to anterior aponeuroses will in virtue of their greater curvature contract earlier and remain contracted longer than fibres which are attached to posterior aponeuroses, and, as it were, they will develop at their expense. The sheath of the rectus even in its variations thus remains the expression of the action of the lateral muscles.

SUMMARY

1. Developmentally the sheath is a true rectus sheath derived from the rectus mass, but as the lateral muscles obtain attachment to it, it assumes an aponeurotic character.

2. The sheath gains its final significance only when it is considered in mechanical terms of the muscle resultants of the lateral muscles.

3. The typical portion of the rectus sheath exists in three main forms, each form being an expression of the action of the lateral abdominal muscles.

4. The atypical form of the lower part of the rectus sheath is due to a difference in the function of the lower parts of the abdominal muscles.

5. The arcuate line (linea semicircularis) is the lower edge of the upper actively contracting parts of the abdominal muscles.

6. The sheath of the rectus, even in its variations, remains the expression of the action of the lateral muscles.

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