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Surgical anatomy of the aponeurotic expansions of the anterior abdominal wall

Omar M Askar MD MCh

Professor of General Surgery, Faculty of Medicine, Kasr-El Aini Hospital, Cairo University, Cairo, Egypt

Summary

Dissection of the anterior abdominal wall in 40 fresh cadavers, with confirmation of the anatomical findings at operation in 25 patients, has enabled the patterns of distribution of the aponeurotic expansions of the abdominal muscles to be traced and the relation of structure to function to be determined. It is pointed out that the linea alba should no longer be regarded as the line of insertion of the abdominal muscles but as the area of decussation of the tendinous aponeurotic fibres of the muscular strata passing from one side to the other, for which the name 'midline aponeurotic area' is proposed. Two separate functional areas are described, a 'parachute respiratory mechanism' in the upper abdomen and a belly support in the lower abdomen. Attention is drawn to the functional derangement that may follow some of the standard abdominal incisions and to possible mechanisms of herniation through the midline aponeurotic area.

Introduction

The existence in the aponeuroses of the muscles of the anterior abdominal wall of a pattern closely similar to that seen in the deep fascia of the leg[1, 2] (Fig. 1) drew the author's attention to its possible functional role. As no mention of such a pattern has appeared hitherto in the literature a study of the anatomy of the anterior abdominal wall was carried out, aiming at a clearer understanding of its function. Particular attention was directed to the aponeurotic area forming the major portion of the anterior abdominal wall. The results of this work have been embodied in a series of articles[3] of which this is the first to be published.

In the present article only the anatomical data of surgical importance are given, with special reference to the structural–functional relationship of the abdominal wall aponeuroses.

Materials and methods

The material for this work consisted of 40 cadaveric specimens of the abdominal wall. They were mounted on wooden frames, dissected, and examined in as fresh a state as possible, since prolonged preservation was found to blur the aponeurotic texture. The detailed structure of the aponeuroses was studied by tracing the aponeurotic fibres through a scaled grid. Drawings were made on a similarly scaled chart.

The anatomical findings were verified in vivo in 25 patients aged 30–65 years under-

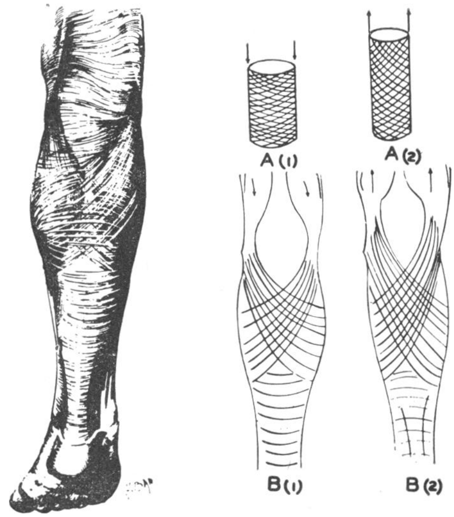

FIG. 1 *Structural-functional relations of deep fascia of the leg.*

going abdominal operations. This study was carried out within the limits permitted by the operative exposure, the incision being upper right paramedian in 12 cases, midline epigastric in 6, lower right paramedian in 3, lower left paramedian in 1, and midline subumbilical in 3. The different areas of the aponeuroses were studied and small pieces (0.5 × 0.5 cm) were examined under the dissecting microscope.

Findings

The aponeuroses could be seen under the dissecting microscope (magnification × 10) to be formed of fine tendinous fibres invested in loose areolar tissue (Fig. 2). The course and behaviour of these fibres in the various strata of the abdominal wall are described below.

External oblique In addition to their downward, forward, and medial inclination, the aponeurotic fibres of the external oblique muscle were found to describe a gentle upward curve which was most marked in the region of the umbilicus (Fig. 3). There were differences in the aponeurotic pattern above and below the umbilicus.

Above the umbilicus the majority of the external oblique aponeurotic fibres crossed the midline to appear on the surface of this layer on the other side. There they formed the superficial layer of a double-stratum pattern, the fibres of which passed downwards and laterally at right angles to those of the deeper stratum formed by the ipsilateral external oblique aponeurosis (Figs 2–4). In 16 specimens (40%) the two strata were fairly separate. In the remaining 24 specimens (60%) some degree of interlacement was noted; this was so marked in 8 of them (20%) that the fibres of the two strata were intricately interwoven and inseparable.

The fibres of the superficial stratum proceeded across the musculoaponeurotic line and ended by dipping between the muscle bundles of the contralateral external oblique, where they fused with the intermuscular connective tissue. The lowermost group of these fibres reached down to a level slightly below that of the anterior superior iliac spine. In 4 specimens (10%) they were seen to form a distinct curved margin (Fig. 5). This margin is often noticed in iliac and McBurney's incisions. Some of the aponeurotic fibres, however, after

FIG. 2 *Anterior rectus sheath (above umbilicus) as seen under the dissecting microscope (fresh specimen).*

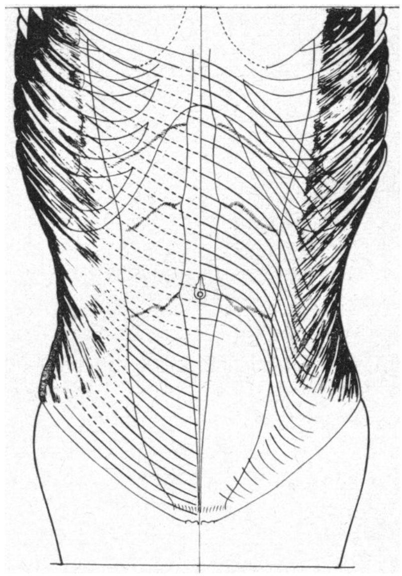

FIG. 3 *Course and behaviour of fibres in right external oblique aponeurosis (---- = deep stratum).*

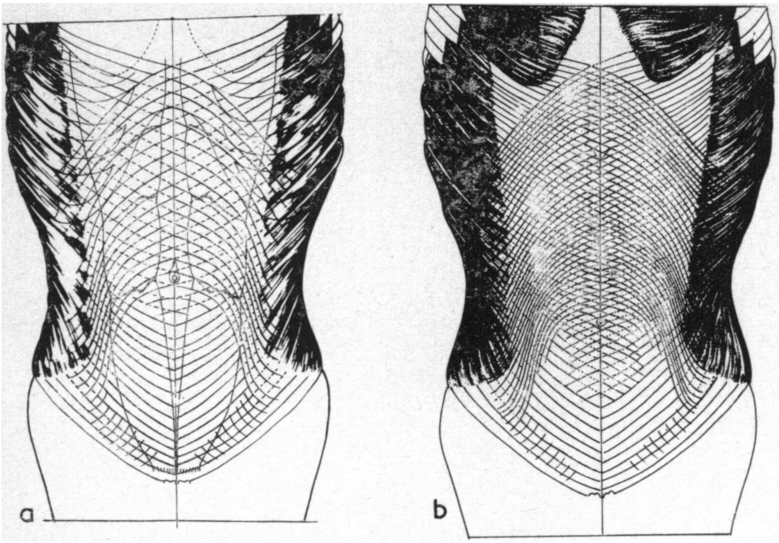

FIG. 4 *External oblique aponeurosis with (a) single and (b) triple pattern of decussation at midline.*

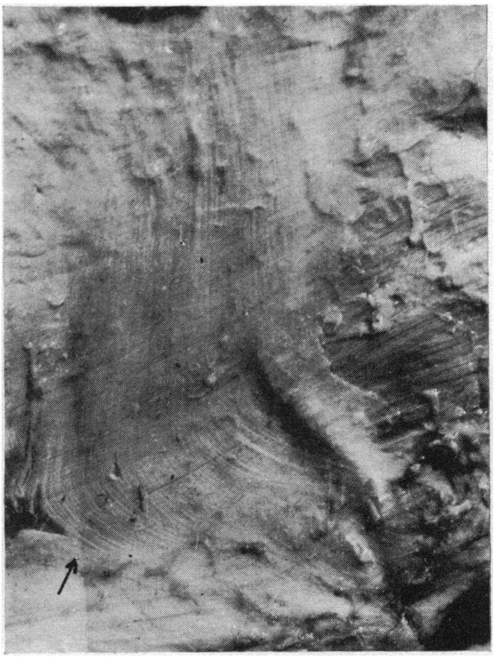

FIG. 5 *Curved margin formed by lowermost group of crossed external oblique aponeurotic fibres (left iliac region, postmortem specimen).*

crossing the midline passed deep to the other external oblique to join the anterior lamina of the contralateral internal oblique aponeurosis (Fig. 6).

The aponeurotic fibres of one side in their journey across the midline decussated with their fellows of the opposite side. In 16 specimens (40%) in which the two strata were separable this decussation took place only once, in the midline ('single decussation') (Figs 4 and 7*a*). In the other 24 specimens (60%) two additional lines of decussation were seen, one on each side of the midline ('triple decussation') (Figs 5 and 7*b*). This triple decussation was seen only above and never below the umbilicus. In single decussation

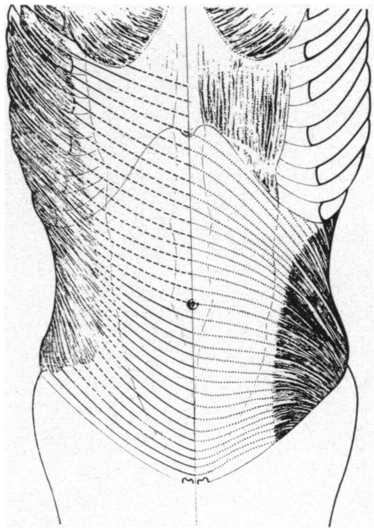

FIG. 6 *Digastric pattern between external oblique (right) and contralateral internal oblique (left).*

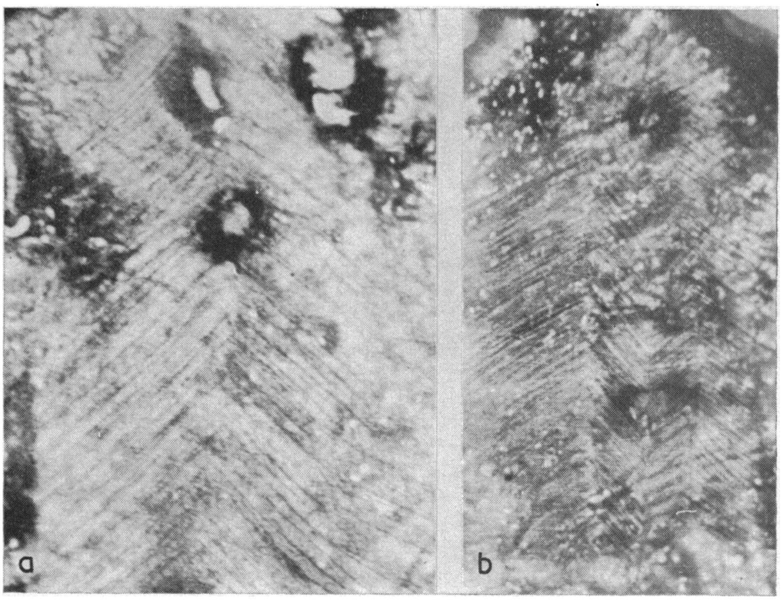

FIG. 7 *(a) Single and (b) triple pattern of decussation of external oblique aponeurosis as seen in midline epigastric incision.*

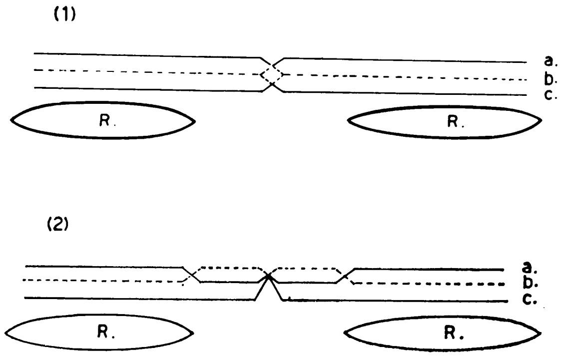

FIG. 8 *Patterns of decussation in front of rectus muscles (R): (1) single decussation; (2) triple decussation. (a) Superficial stratum of external oblique aponeurosis; (b) deep stratum of external oblique aponeurosis; (c) anterior lamina of internal oblique aponeurosis.*

the fibres of the deep stratum of one side emerged to gain a superficial plane on the opposite side (Fig. 8(1)). In triple decussation these fibres appeared on the surface at the additional line and then dipped across the midline to redecussate and become superficial at the other additional line (Fig. 8(2)).

Below the umbilicus the double-stratum pattern was not seen except for a small zone around the umbilicus. The aponeurotic fibres of the external oblique invariably passed downwards and medially in a single stratum (Figs. 4, 5, and 9). They all crossed the midline in a single decussation to join the contralateral internal oblique aponeurosis forming a clearly visible digastric pattern.

Internal oblique The muscular portion of this fan-shaped muscle consisted of fairly thick bundles (5–8 mm). The upper fibres were directed upwards and medially and the middle almost horizontally, while the lower arched downwards and medially. The aponeurotic fibres on both the anterior and

FIG. 9 *Lower half of abdominal wall (post-mortem specimen) showing single-stratum pattern of external oblique aponeurosis below umbilicus (compare with Figs 4a and b).*

posterior laminae followed the same direction as the muscle bundles (Figs 7 and 10).

The anterior lamina fused with the external oblique aponeurosis along a vertical line which, in its upper part, descended parallel to the outer border of the rectus, then curved medially below the level of the umbilicus to end near the midline at the pubis. The fusion of the anterior lamina of the internal oblique with the aponeurosis of the external oblique was visible by virtue of the escape of aponeurotic fibres from one aponeurosis into the other. However, aponeurotic fibres of the internal oblique could still be identified in the anterior rectus sheath as a third posterior stratum. The fibres of each stratum passed at right-angles to those of the next, constituting a triple criss-cross (plywood) pattern (Fig. 2). Below the umbilicus most of the internal oblique aponeurotic fibres merged into the anterior lamina, which became identifiable as a separate layer near the pubis.

The posterior lamina was seen in the upper part of the posterior rectus sheath as a thin, glistening sheet through which the upper fleshy bundles of the transversus abdominis could be seen. Midway between the xiphoid and the umbilicus the aponeurotic fibres in this layer were indistinct but could still be seen curving gently upwards and medially (Fig. 10), then gradually losing their thickness to fade out near the pubis. However, some of the aponeurotic fibres from the posterior lamina were seen to pierce the transversus aponeurosis along a line of decussation parallel to the outer border of the rectus (Fig. 11). The internal oblique in this way gains a more posterior plane to the transversus aponeurosis in the posterior rectus sheath below the umbilicus.

Transversus abdominis In all specimens studied the fleshy bundles of this muscle were not really transverse. In 38 specimens (95%) the upper bundles passed upwards and medially. The middle ones were almost horizontal, while lower down they curved downwards and medially, the lowermost being almost parallel to the inguinal ligament (Fig. 10). In two specimens (5%) the muscle bundles of the transversus were all directed downwards and medially and were parallel to each other.

Above the umbilicus the whole transversus aponeurosis passed into the posterior rectus sheath behind the posterior lamina of the internal oblique. The aponeurotic fibres, after emerging from the muscle bundles, proceeded for a short distance in the direction of the muscle and then split into two sets of fibrils, 'down-turned' and 'up-turned' (Figs 12–14).

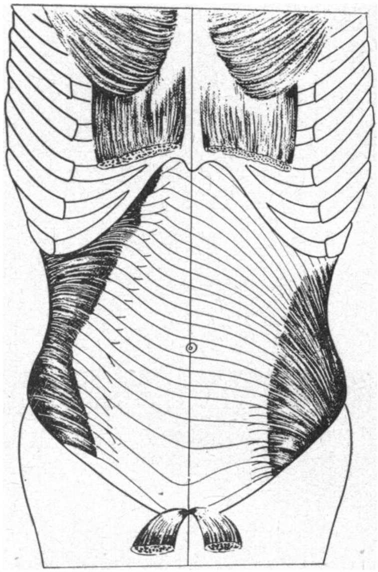

FIG. 10 *Aponeurotic pattern of posterior lamina of internal oblique (left) and digastric pattern between it and transversus (right) on posterior rectus sheath.*

FIG. 11 *Posterior aspect of right posterior rectus sheath below umbilicus showing internal oblique aponeurotic fibres piercing transversus aponeurosis to gain a more posterior plane (postmortem specimen).*

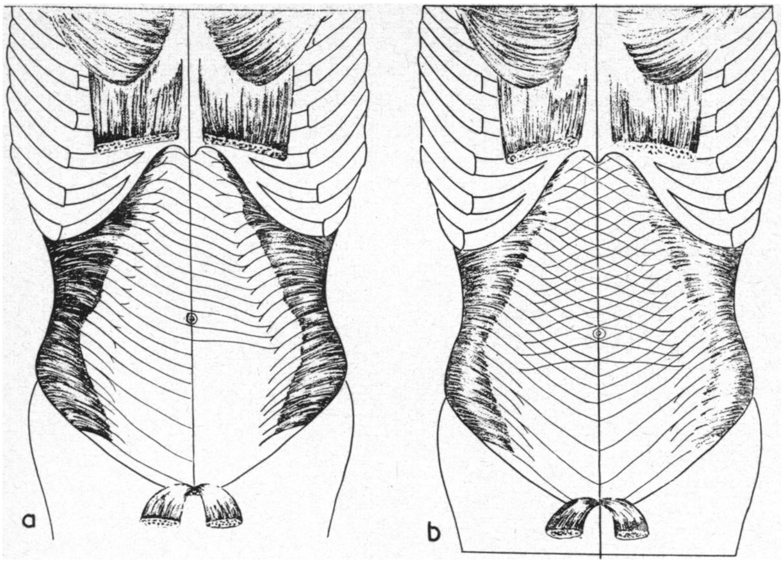

FIG. 12 *(a) Digastric pattern of the two transversi showing 'down-turned' fibrils (right) and 'up-turned' fibrils (left). (b) Pattern completed.*

FIG. 13 *Transversus aponeurosis above umbilicus showing double-stratum pattern (postmortem specimen).*

Each of the two sets passed in a separate plane, constituting a double-stratum pattern for the transversus aponeurosis. In 28 specimens (70%) the down-turned fibrils formed the anterior stratum and the two strata, together with the posterior lamina of the internal oblique (up-turned) formed a triple criss-cross pattern on the posterior rectus sheath (Fig. 15). In the remaining 12 specimens (30%) the up-turned fibres formed the anterior stratum and blended with the posterior lamina of the internal oblique, having the same direction, and formed only a double criss-cross pattern. In the former group (70%) a triple decussation was seen on the posterior aspect of the linea alba (Fig. 16(2)). In the latter group (30%) a single line of decussation was visible (Fig. 16(1)).

The decussating patterns on both the anterior and the posterior aspects of the midline were joined together by aponeurotic slips which connected fibres passing in the same direction in both decussations (Fig. 17). The formation of a midline aponeurotic area (linea alba) was thus completed.

In 16 specimens (40%) aponeurotic fibres originating from the sternal portion of the

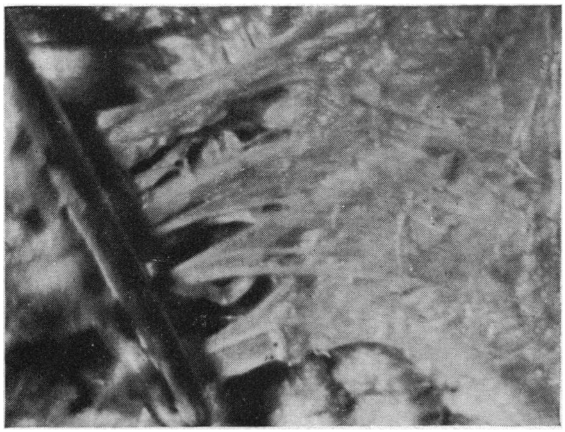

FIG. 14 *Splitting of transversus aponeurotic fibres into 'down-turned' anterior and 'up-turned' posterior sets of fibrils.*

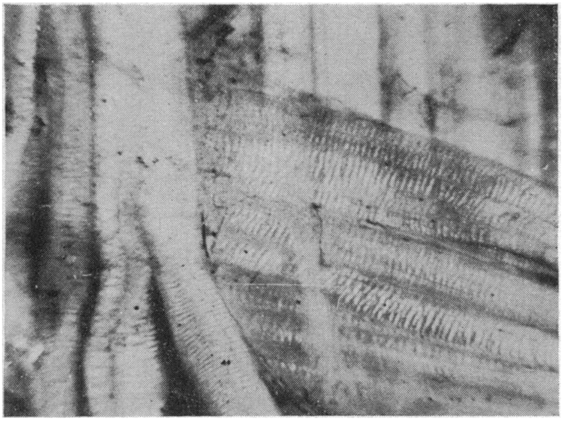

FIG. 15 *Triple criss-cross pattern on posterior rectus sheath above umbilicus (fresh operative specimen).*

diaphragm were seen descending vertically from under the costal margin to about midway between the xiphoid process and the umbilicus; there they curved medially towards the midline and tapered, to end by interlacing with the aponeurotic fibres on the posterior rectus sheath at the linea alba.

Below the umbilicus a real division of the transversus aponeurosis into anterior and posterior laminae was a constant finding. The anterior lamina could be seen forming a third posterior stratum in the anterior rectus sheath. The posterior lamina together with that of the internal oblique formed the posterior rectus sheath. A real arcuate line could not be identified in the material examined. A condensation of aponeurotic fibres was seen in 3 operative cases to delineate an arcuate line. Though both laminae tended to fade out near the pubis, yet the aponeurotic texture in the posterior rectus sheath could be seen.

Relation of skin to aponeurosis In all patients with a midline epigastric incision a noticeable feature was the presence of fibrous bands between the skin and the abdominal aponeurosis at the midline which needed to be cut with the knife, whereas lateral to the midline the skin could be peeled off easily by gentle dissection. This adhesion was found to result from minute aponeurotic fibrils, X-shaped, emerging from the linea alba to gain insertion into the skin (Fig. 18). Below the umbilicus such fibrous bands were not seen.

Discussion

The linea alba, as could be gathered from this study, should no longer be regarded as the line of insertion of the abdominal muscles. More accurately it is an area at the midline across which the fine tendinous aponeurotic fibres of the three muscular strata pass freely from one side to the other (Figs 4, 6, 10, and 12). A

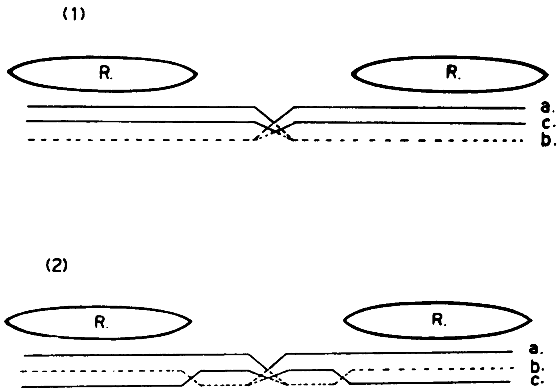

FIG. 16 *Patterns of decussation behind rectus muscles (R): (1) Single decussation (30%); (2) triple decussation (70%). (a) Internal oblique (posterior lamina); (b) 'down-turned' stratum of transversus aponeurosis; (c) 'up-turned' stratum.*

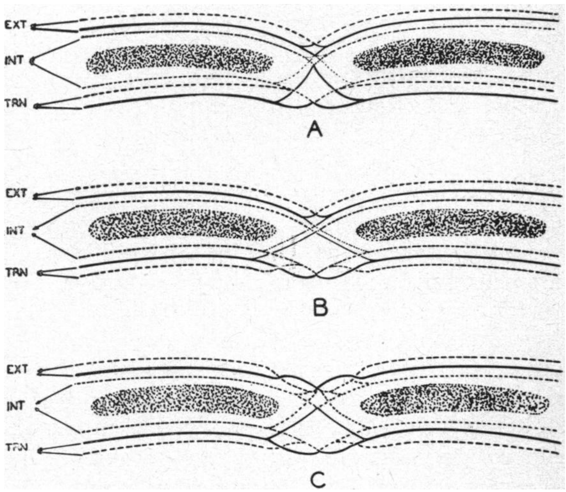

FIG. 17 *Patterns of decussation at midline aponeurotic area (linea alba): (A) single anterior and single posterior lines of decussation (30%); (B) single anterior and triple posterior lines of decussation (10%); (C) triple anterior and triple posterior lines of decussation (60%).*

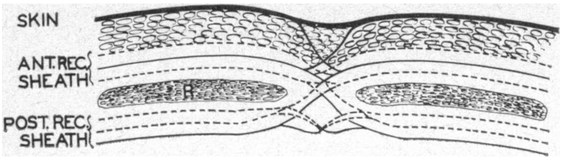

FIG. 18 *Fibrous X-shaped bands connecting skin to midline decussation above umbilicus.*

more precise description would be the 'midline aponeurotic area' (Fig. 19).

The triple pattern of decussation provides additional strength to the midline aponeurotic area. The more frequent presence of this triple pattern on its posterior aspect (70%) points to the fact that nature provides additional strength to the first line of defence against herniation. Herniation has been found to occur more frequently when only single decussation is present[3].

The digastric pattern between the muscles of the two sides exemplifies the harmonized action of all the muscles in the anterior abdominal wall; the action of an individual muscle or the muscles of one side cannot be worked out separately.

The way in which the aponeurotic fibres of one side end on the other side, as seen in the external oblique aponeurosis, seems of significance in preventing the separation of the muscle bundles which could result from muscular contraction on the opposite side (Figs 4 and 5). Extensive splitting of muscle or aponeurosis is apt to interfere with this action. This fact needs special consideration in the repair of hernial defects following lumbar and iliac incisions.

The fact that the anterior abdominal wall aponeuroses are formed of fine tendons invested in loose areolar tissue indicates their free mobility over each other, which allows an appreciable degree of mobility in the resultant fabric, the aponeuroses. The oblique direction in which the aponeurotic fibres are placed in this fabric offers freedom for changes in both the longitudinal and transverse diameters (Fig. 20). This allows for changes in the shape of the aponeurosis in adaptation to movements of the trunk. As an example of this, the midline aponeurotic area will always describe a straight line whether the trunk is extended or fully flexed; flexion of the trunk will produce folds in the skin and subcutaneous tissues only, not in the aponeuroses. One can imagine how much of this function would be lost as a result of a rigid scar following a midline incision.

The triple criss-cross pattern seen in both the anterior and posterior rectus sheaths above the umbilicus accounts for the ample durability of the aponeuroses. Such strength is extremely important in quadrupeds, where all the weight of the abdominal viscera falls on these aponeuroses, with the umbilicus placed nearer to the pubis[4].

The difference in the aponeurotic pattern above and below the umbilicus points to the

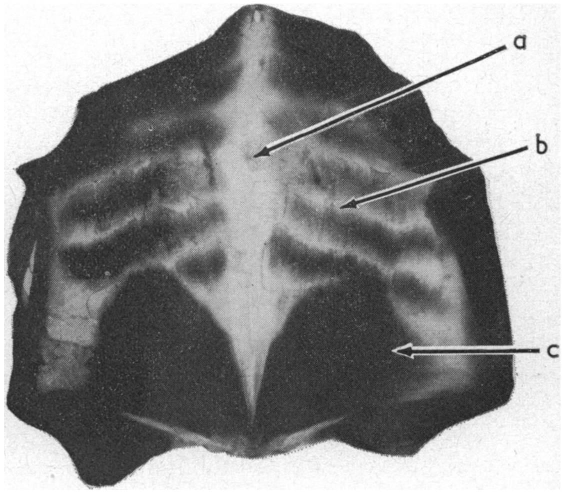

FIG. 19 *Silhouette picture of anterior abdominal wall (postmortem specimen) demonstrating: (a) midline aponeurotic area; (b) respiratory area (parachute mechanism); (c) lower belly support area.*

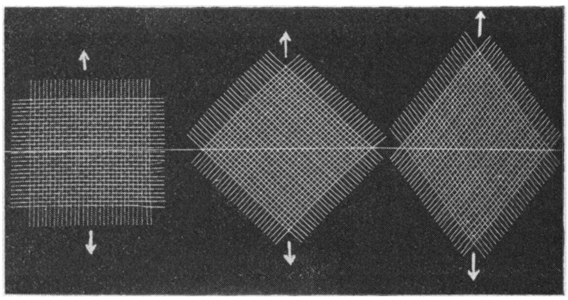

FIG. 20 *Allowance for changes in both longitudinal and transverse diameters where the fibres in a fabric are obliquely placed.*

difference in function of the two regions. Above the umbilicus the pattern and shape of the aponeuroses fulfil the required expansile distensibility needed for respiration—simulating, in a way, an open parachute. The diaphragm is another example of this 'parachute mechanism'. Whenever the balanced traction at the edges of this parachute is disturbed as a result of injury to the fibres (pararectal incision) or paralysis of the pulling muscles (subcostal incisions) a paradoxical movement of the abdominal wall with respiration results. The aponeurotic slips descending from the diaphragm synchronize the movements of the two parachute mechanisms. At the same time these slips could be responsible for the production of epigastric hernial defects[3]. Below the umbilicus most of the muscular bundles as well as their aponeurotic fibres, being directed downwards and medially, closely simulate an elastic belly support.

The first suggestion of a similarity in function between the abdominal wall and the diaphragm was given by Solger in 1886[5]. He pointed out that the rectus sheaths of both sides were equivalent to the central tendon of the diaphragm. Wolmsly[6] in 1937 had the impression that there were two functionally separate zones in the abdominal wall, stating that 'the lower tendinous intersections of the rectus demarcate two functionally different parts in the anterior abdominal wall. Above that level the muscles are actively contracting but below it they offer passive support for the rectus and hence their anterior position to the rectus is more significant'. The present study demonstrates anatomically the two functionally separate zones, an upper respiratory (parachute mechanism) and a lower (belly support). An explanation is thus provided for the suggestions of earlier workers.

The curve described by the aponeurotic fibres from all the strata, most marked in the region of umbilicus, points to an allowance for physiological grades of abdominal distension—that is, as much as would bring this curvature into a straight line. Abdominal distension exceeding these physiologically permissible limits would thus tend to concentrate its stress on this area. This fact is discussed in another article of this series[3].

The presence of a connection between the skin and the midline aponeurotic area above and not below the umbilicus may explain why a pendulous belly occurs below and not above the umbilicus. The X-shaped pattern of these aponeurotic bands may account for the loculations observed in midline hernial sacs above the umbilicus. Such loculations are seldom seen in other types of hernia.

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