Original article

Regional variations in the microscopic organisation of the human rectus sheath

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Abstract

The pattern of formation of the rectus sheath from the aponeuroses of external oblique, internal oblique, and transversus abdominis muscles shows regional variations. These variations may influence the microscopic organisation of the rectus sheath. Specimens were collected during autopsies from thirty one subjects (16 male, 15 female) aged 18-70 years old. The rectus sheath was exposed through gentle dissection of the superficial fascia of the anterior abdominal wall. Five millimeter thick sections were harvested and processed for light microscopy. Both walls of the rectus sheath were made up of three distinct zones: superficial, intermediate, and deep. The superficial and deep zones were fibroelastic while the intermediate zones comprised compact bundles of collagen fibres. In the anterior wall of the rectus sheath, these bundles above and below the arcuate line, respectively, were obliquely and transversely disposed. The bundles of the posterior wall of the rectus sheath were, however, transversely aligned. In conclusion, the microscopic organisation of the rectus sheath is determined by its pattern of formation. This sheath is mainly formed by the aponeuroses of the internal oblique and transversus abdominis.

Keywords: human rectus sheath, anterior abdominal wall, microscopy.

1 Introduction

The formation of the walls of the human rectus sheath from the aponeuroses of three anterolateral abdominal muscles usually varies according to the level of the anterior abdominal wall. Above the costal margin, only the anterior wall of the rectus sheath (AWRS), made up of the aponeurosis of external oblique muscle (EO), is present (WILLIAM, BANNISTER, BERRY et al., 1995). Below the costal margin, the internal oblique muscle (IO) splits into two laminae: a superficial lamina which blends with the aponeurosis of EO to form the AWRS and a deep lamina that fuses with the aponeurosis of transverses abdominis muscle (TA) to form the posterior wall of the rectus sheath (PWRS). This is the formation up to the arcuate line of Douglas which marks the inferior extent of the PWRS (SINNATAMBY, 2000). Below the arcuate line, all the aponeuroses pass anterior to RA leaving the RA to lie directly on fascia transversalis (WILLIAM, BANNISTER, BERRY et al., 1995).

The variations in the pattern of formation of RS may influence the microscopic organisation of the connective tissue fibres therein. It is also possible that the fibre orientation and composition in the AWRS and PWRS differ as the former is firmly attached to the rectus abdominis muscle while the latter is not (WILLIAM, BANNISTER, BERRY et al., 1995). This suggestion employs the fact that the pull by the anterolateral abdominal wall muscles is oblique while that of the rectus abdominis is vertical (McARDLE, 1997). Despite this, data on the microscopic organization of the human rectus sheath remain scarce. This study therefore aimed at describing the histomorphology of the human rectus sheath with regard to its pattern of formation.

2 Material and methods

The approval to carry out the study was granted by the KNH-Ethics and Review Committee. Specimens were collected during autopsies from thirty one subjects (16 male, 15 female) aged 18-70 years old. The autopsies were conducted within 24 hours after death of the subjects at the Nairobi's Chiromo and City Mortuaries. A written consent for the use of postmortem material was given by the relatives of the deceased. The rectus sheath was exposed through a midline incision followed by gentle dissection of the superficial fascia of the anterior abdominal wall. Transverse segments of 5 mm thickness were then taken from five levels (as described in Figure 1). For each level, the segments were taken from the lateral (a), middle (b) and medial (c) parts of the rectus sheath.

The segments harvested were fixed in 10% formaldehyde by immersion followed by dehydration through increasing concentrations of alcohol (starting from 70% to 100%). Clearing and infiltration using paraffin wax was followed by embedding. Seven micrometer thick serial sections were cut using a Lezlar® microtome (SM2400, Germany). These sections were floated, picked on slides, and left for drying in an oven overnight after which they were stained using Weigert's Elastic stain with van Gieson counterstaining to elaborate the elastic fibers. Other sections were stained using Masson's Trichrome to demonstrate the collagen fibers (DRURY and WALLINGTON, 1967). For the microscopic observations, a Leica® light microscope (BME model, Germany) was used. Photographs illustrating the fiber orientation and composition of the rectus sheath were taken using a Fuji® digital camera (Finepix A900, 9 megapixels) and a Sony® analogue camera.

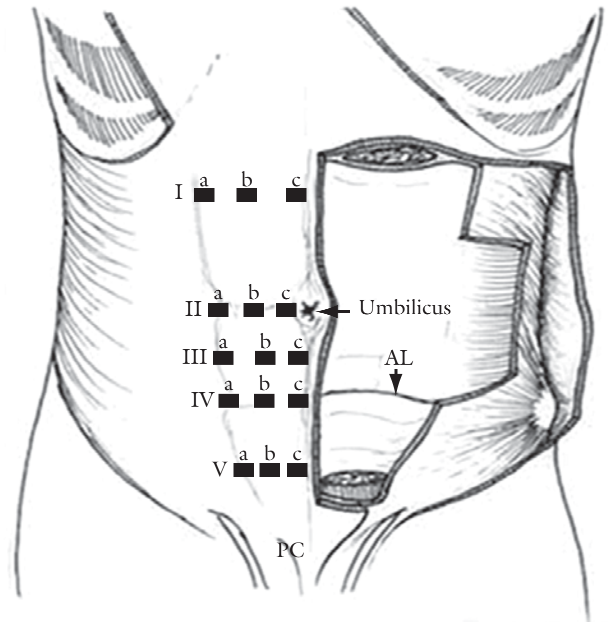

Figure 1. Anterior view of the anterior abdominal wall showing tissue sampling sites. I) midway between umbilicus and costal margin; II) At the umbilical region; III) Midway between the umbilicus and arcuate line (AL); IV) At the arcuate line; and V) Midway between AL and pubic crest (PC).

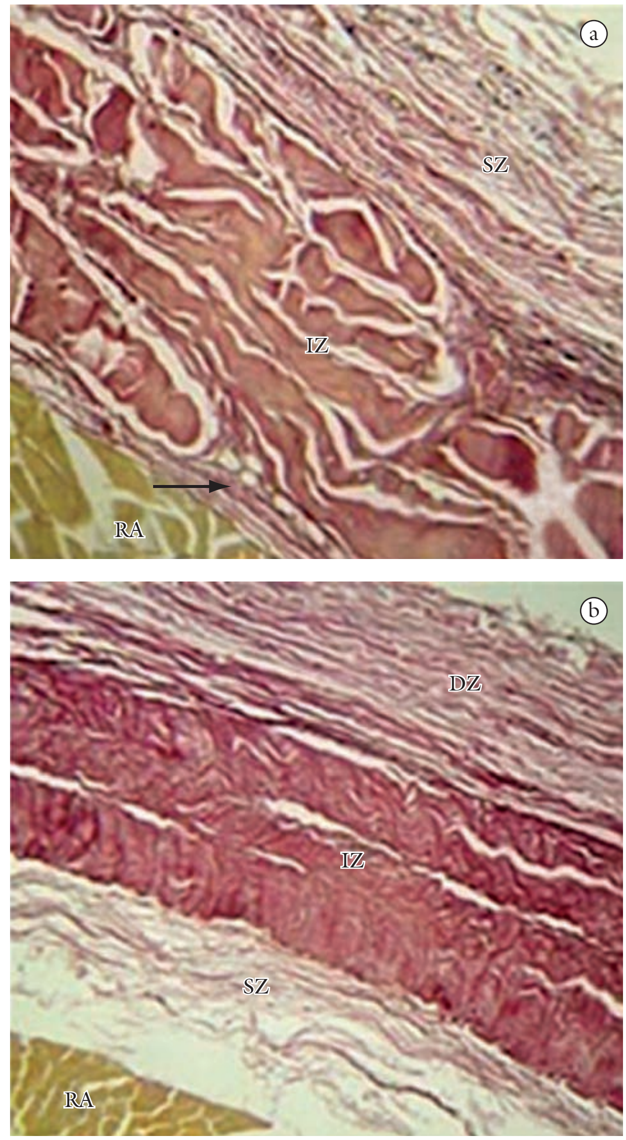

Figure 2. General microscopic organisation of the a) AWRS; and b) PWRS. Arrow points at the deep zone of the AWRS. RA, rectus abdominis muscle; DZ, deep zone; IZ, intermediate zone; SZ, superficial zone.

3 Results

3.1 General organization

Both the AWRS and PWRS contained collagen and elastic fibres which were organized into three distinct zones: superficial, intermediate, and deep in relation to the skin (Figure 2a, b). The superficial and deep zones in both the AWRS and PWRS contained loosely arranged collagen and elastic fibres. The intermediate zones, on the other hand, were made of compact bundles of collagen fibres (Figure 2a, b). Mediolateral (from linea semilunaris towards linea alba) and craniocaudal (from the costal margin towards the pubic crest) differences were observed in the fibre composition and orientation. No notable gender differences were seen.

3.2 Mediolateral variations

3.2.1 Anterior wall of the rectus sheath

Above the arcuate line and at the lateral border of the rectus abdominis muscle was a clear cut separation between the aponeuroses of EO and the superficial lamina of IO (Figure 3a). These aponeuroses contained collagen and elastic fibres. Most of the collagen fibres were organized into compact bundles of variable sizes with an oblique orientation. There were more elastic fibres in the aponeurosis of EO than IO. The elastic fibres were mainly located superficial to the collagen fibre bundles of EO and together with some loosely arranged collagen fibres that formed the superficial zone of the AWRS (Figure 3b). These elastic fibres decreased towards the linea alba (Figure 3c, d). At the point of fusion of the aponeurosis of EO and IO, the collagen fibres at the interface of these aponeuroses intermingled leaving no plane of separation (Figure 3d). The thickness of collagen fibre bundles of EO decreased distally to the fusion leaving the superficial lamina of IO to form the intermediate zone of the AWRS (Figure 3e). Other levels of the rectus sheath studied displayed similar mediolateral differences.

3.3 Posterior wall of the rectus sheath

The aponeuroses of TA and deep lamina of IO were made of collagen and elastic fibres. Like in the AWRS, most of the collagen fibres were organized into bundles. At the lateral border of RA, the bundles of the deep lamina of IO intermingled with those of TA (Figure 4a). Distal to the fusion of these aponeuroses, the collagen fibre bundles of both IO and TA were transversely aligned (Figure 4b). The elastic fibres were concentrated deep to the collagen fibre bundles of the transversus abdominis. Together with some loosely arranged collagen fibres, they formed the deep zone

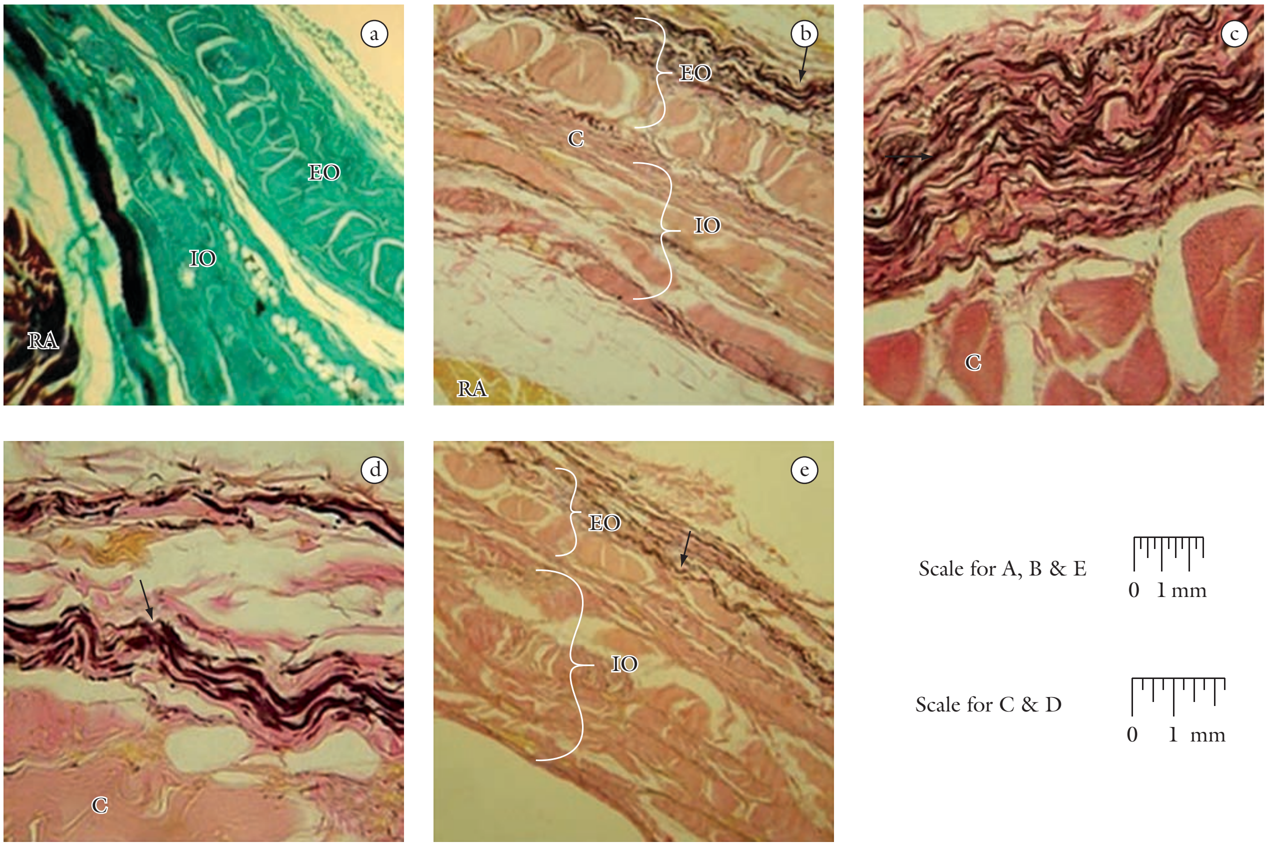

Figure 3. a-e) Transverse sections of AWRS showing mediolateral microscopic differences. a) AWRS midway between the umbilicus and the arcuate line at the linea semilunaris (Masson's Trichrome stain). IO, superficial lamina of internal oblique; EO, external oblique; RA, rectus abdominis muscle; b) AWRS midway between the umbilicus and the arcuate line at the lateral border of the rectus abdominis muscle (Weigert Elastic stain with Van Gieson counterstaining). The arrow points at the band of elastic fibres forming the superficial zone. C, collagen fibres at the interface of EO and IO; c) AWRS midway between the umbilicus and the arcuate line at the lateral border of RA (Weigert Elastic stain with Van Gieson counterstaining). Note the abundance of elastic fibres in the superficial zone (arrow); d) AWRS midway between the umbilicus and the arcuate line at the middle of the rectus abdominis muscle (Weigert Elastic stain with Van Gieson counterstaining). Note the decrease in the elastic fibres (arrow); and e) AWRS midway between the umbilicus and the arcuate line at the point of fusion of EO with IO (Weigert Elastic stain with Van Gieson counterstaining). Note that distal to the fusion of EO with IO, collagenous bundles of IO diminish.

of the PWRS. These fibres progressively decreased towards the linea alba (Figure 4c, d).

3.4 Craniocaudal variations

3.4.1 Anterior wall of the rectus sheath

The superficial zone comprised elastic and collagen fibres that were irregularly spaced (Figure 3a). In the supra-umbilical regions, these elastic fibres were obliquely disposed while those of the infra-umbilical regions were transversely oriented (Figure 5a, b). The intermediate zone was made of collagen fibres that were organized into bundles. Above the arcuate line, this zone was made of oblique collagen fibre bundles that were arranged in rows (Figure 5c, d). The angulation of these bundles increased towards the costal margin so that some of these bundles appeared longitudinal (Figure 5c). At the arcuate line, these bundles ran transversely (Figure 5e). In addition, these bundles exhibited branching and also contained collagen fibres that were wavy (Figure 5f). This organisation was seen in the regions below the arcuate line but the only difference was that the collagen fibre bundles in this zone were thicker. The deep zone in all regions contained irregularly spaced collagen and elastic fibres (Figure 5e).

3.5 Posterior wall of the rectus sheath

The superficial and deep zones were made of irregularly arranged collagen and elastic fibres (Figure 6a). The deep zone was more extensive than the superficial zone and contained more elastic fibres (Figure 6a, b).The intermediate zone contained collagen fibres that were organised into bundles that were transversely oriented (Figure 6c). The thickness of this zone decreased towards the arcuate line (Figure 6d, e). Throughout the PWRS, the collagen bundles were transversely arranged irrespectively of the position of the arcuate line. In addition, these bundles displayed branching and contained collagen fibres that were wavy (Figure 6c).

3.6 Discussion

The human rectus sheath, as observed in the current study and by other researchers, contains both collagen and

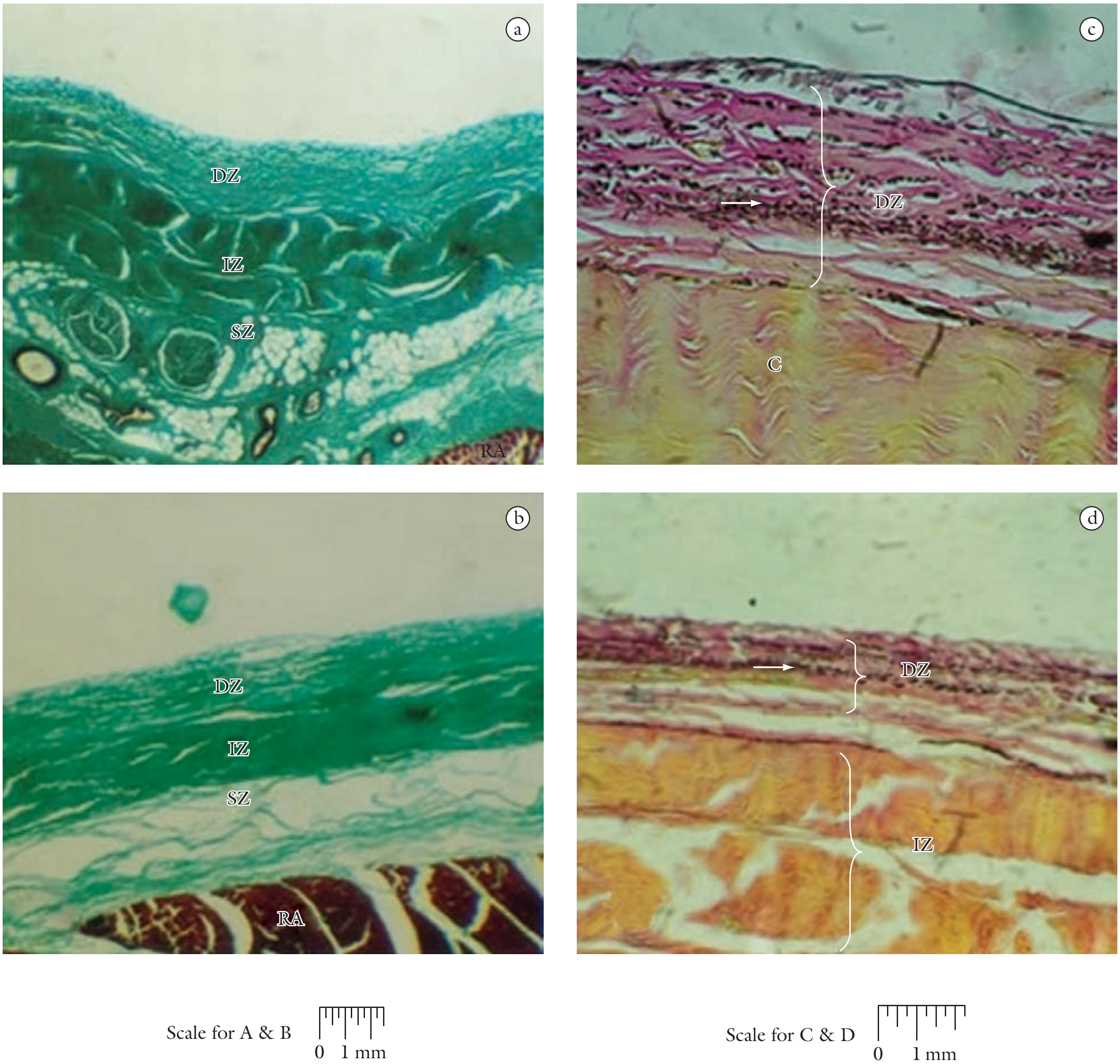

Figure 4. a-d) Transverse sections of PWRS showing mediolateral microscopic differences. a) PWRS midway between the umbilicus and the arcuate line at the lateral border of the rectus abdominis muscle (Masson's Trichrome stain). RA, rectus abdominis; DZ, deep zone; SZ, superficial zone; b) PWRS midway between the umbilicus and the arcuate line at the middle of the rectus abdominis muscle (Masson's Trichrome stain). Note that the collagen fibre bundles are transversely oriented; c) PWRS midway between the umbilicus and the arcuate line at the lateral border of the rectus abdominis muscle (Weigert Elastic stain with Van Gieson counterstaining). Note that the deep zone (DZ) has a preponderance of elastic fibres; and d) PWRS midway between the umbilicus and the arcuate line at the middle of the rectus abdominis muscle (Weigert Elastic stain with Van Gieson counterstaining). Note that the deep zone (DZ) has less elastic fibres compared to that in Figure 4c.

elastic fibres (AXER, DIEDRICH and PRESCHER, 2001; SZCZESNY, CERKARSKA, TRETYN et al., 2006). The view generally held is that collagen fibres provide tensile strength (DIAMANT, KELLER, BAER et al., 1972; PARRY, BARNES and CRAIG, 1978) while elastic fibres allow stretch and recoil of tissues to their original shape and size (KIELTY, SHERATT and SHUTTLEWORTH, 2002). Accordingly, as suggested by McArdle (1997), the fibroelastic composition of the rectus sheath may be a design to enable it to withstand high levels of biomechanical stresses emanating from the pull of the muscles and also to tolerate sudden changes in the intra-abdominal pressure.

Furthermore, the rectus sheath is organized into three distinct zones. Although this is hitherto unreported, other structures in the anterior abdominal wall such as the linea alba exhibit zonation (AXER, DIEDRICH and PRESCHER, 2001). Disparities in fibre composition and orientation in the various zones, however, suggests that these zones are modified for specific functions. Loosely arranged connective tissue fibres function to anchor tissues to one another

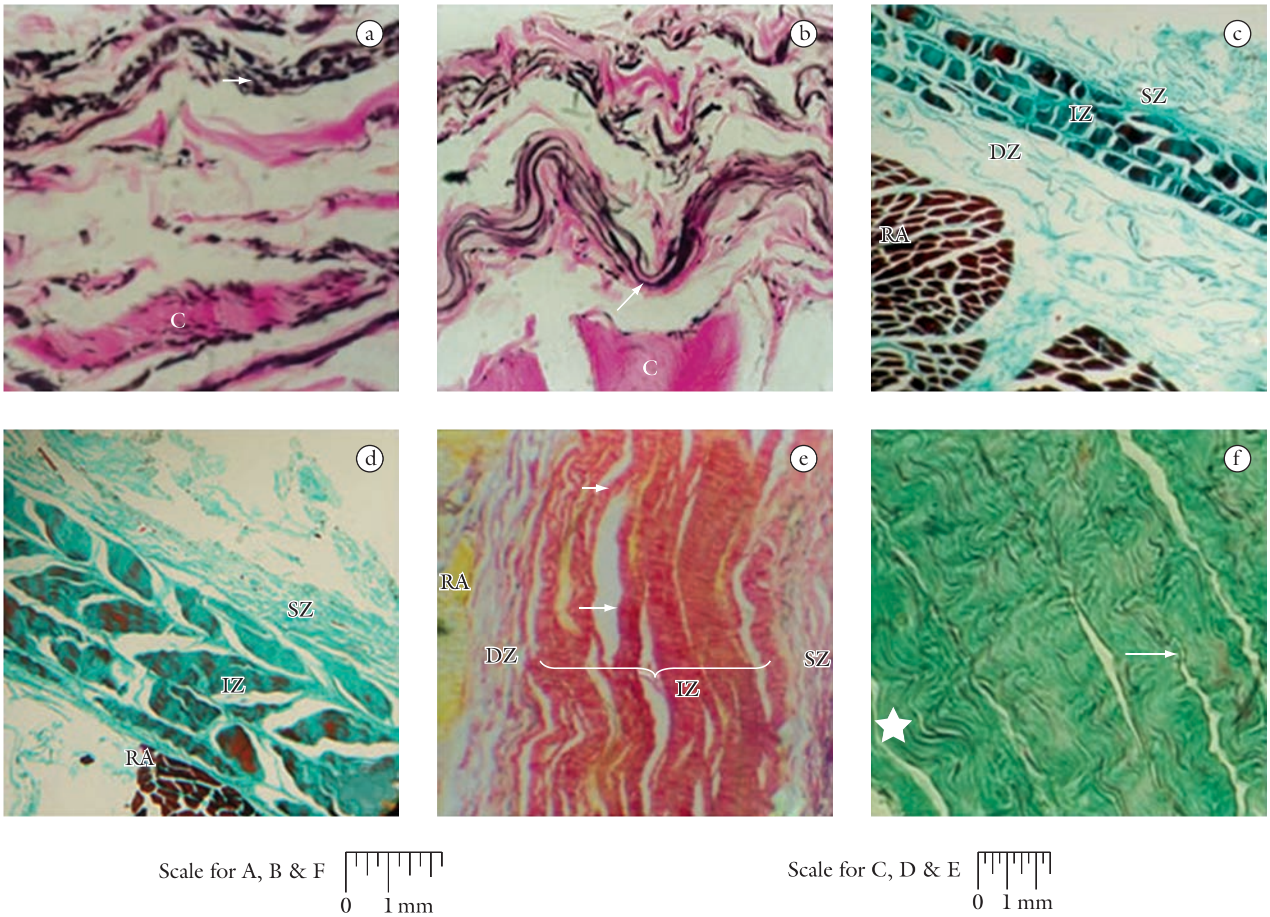

Figure 5. a-f) Transverse sections of AWRS showing craniocaudal microscopic differences. a) AWRS midway between the umbilicus and the costal margin (Weigert elastic stain with Van Gieson counterstain). Note that the elastic fibres are predominantly oblique (arrow); b) AWRS midway between the umbilicus and the arcuate line (Weigert elastic stain with Van Gieson counterstain). Note that some elastic fibres are transversely disposed (arrow); c) AWRS midway between the costal margin and the umbilicus (Masson's Trichrome stain). Note that the collagen bundles in the intermediate zone are longitudinally disposed and are arranged in rows. SZ, superficial zone; IZ, intermediate zone; DZ, deep zone; d) AWRS at the umbilicus (Masson's Trichrome stain). Note that the collagen bundles are all oblique; e) AWRS at the arcuate line (Weigert Elastic stain with Van Gieson counterstaining). Note that the collagen bundles are transverse; and f) AWRS at the arcuate line (Masson's Trichrome stain). Note that the collagen bundles exhibit branching (arrow) and contain collagen fibres that are wavy (star).

(PURSLOW, WESS and HUKINS, 1998). It is therefore possible that the superficial and deep zones of the AWRS function to anchor the rectus sheath to the superficial fascia of the anterior abdominal wall and to the rectus abdominis muscle, respectively.

The random arrangement of collagen and elastic fibres in the deep zone of the AWRS in the present study suggests a functional adaptation. In support of this is the report by Viidik (1978) that the orientation of connective tissues fibres is greatly influenced by the mechanical activities of tissues around. By virtue of its position, this zone is subjected to multidirectional forces emanating from the pull of the rectus abdominis muscle as well as those from the three anterolateral muscles (McARDLE, 1997). Accordingly, the multidirectional orientation of collagen and elastic fibres may be designed to accommodate these forces.

Elastic fibres in the superficial zone of AWRS and deep zone of PWRS were more concentrated on the lateral parts of the rectus sheath. This asymmetry in the concentration of elastic fibres suggests that the stretching forces acting on the anterior abdominal wall are not uniformly distributed. These forces appear to decrease towards the linea alba.

Apart from medio-lateral variations in the concentration of elastic fibres in the superficial zone of the AWRS, there was a cranio-caudal increase in these fibres. As elucidated by McArdle (1997), the assumption that the upright nature in human beings leads to the generation of more intra-abdominal pressure in the lower abdomen as a result of the weight of abdominal viscera. Consequently, the presence of more elastic fibres in the lower parts of the rectus sheath could be an adaptation for conferring this region with stretchability to accommodate these forces.

Compact bundles of collagen fibres were seen in the intermediate zones of the AWRS and PWRS. This organisation was also reported by Axer, Diedrich and Prescher (2001) and appears to be a feature of the tissues subjected to biomechanical stresses such as tendons and ligaments (PARRY, BARNES and CRAIG, 1978; BIRK and

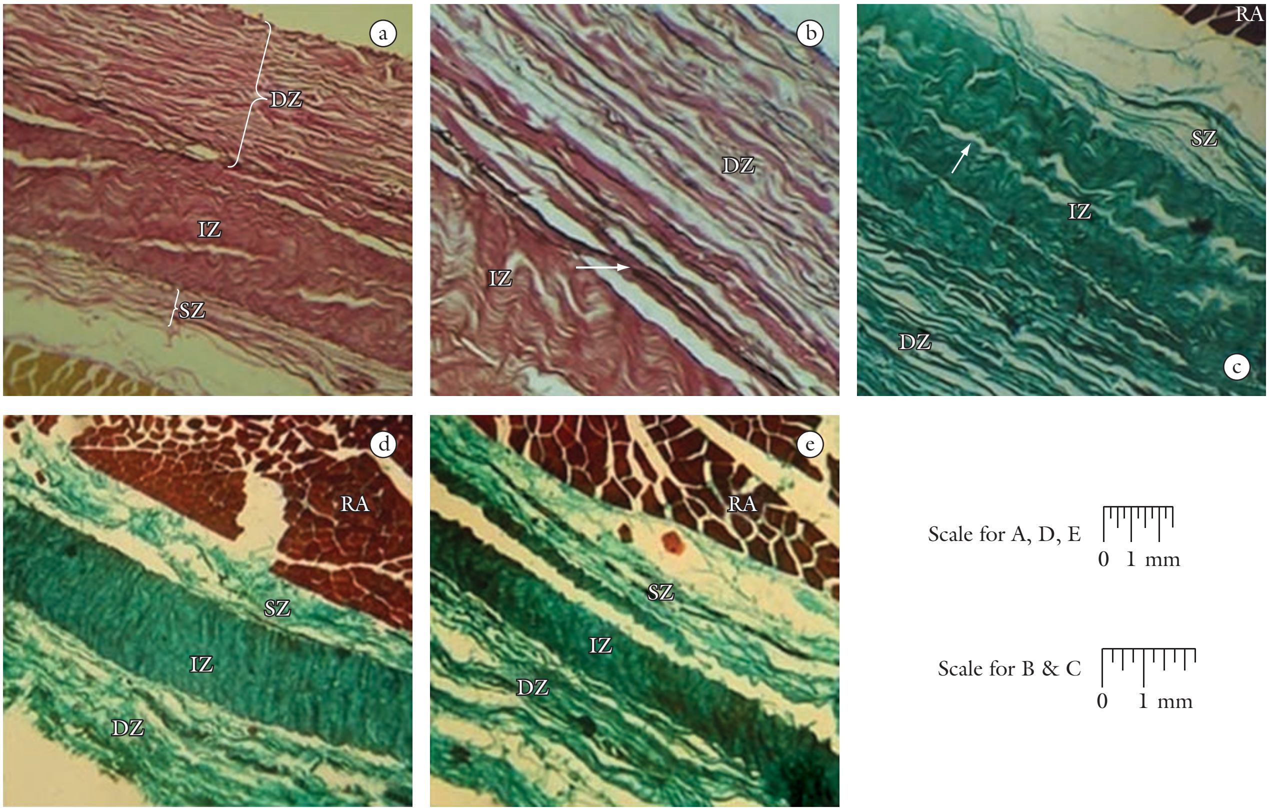

Figure 6. a-e) Transverse sections of PWRS showing craniocaudal microscopic differences. a) PWRS midway between the umbilicus and the costal margin (Weigert's elastic stain with Van Gieson counterstain). Note that the deep zone (DZ) is more extensive than the superficial zone (SZ); b) PWRS midway between the umbilicus and the costal margin (Weigert's elastic stain with Van Gieson counterstain). The arrow points at the elastic fibres; c) PWRS midway between the umbilicus and the costal margin (Masson's Trichrome stain). Note the branching of the collagen bundles and the undulating nature of the collagen fibres; d) PWRS midway between the umbilicus and the arcuate line (Weigert's elastic stain with Van Gieson counterstain); and e) PWRS at the arcuate line (Weigert's elastic stain with Van Gieson counterstain). Note that the intermediate zone is thinner than that in Figure 6a, c.

TRELSTAD, 1986). It is possible that the intermediate zones of AWRS and PWRS are designed to provide tensile strength to the rectus sheath. Pertinent to this is the report by Parry, Barnes and Craig (1978) that the presence of collagen fibres in compact bundles increases the cross-linkages in these fibres leading to an increase in the tensile strength.

The collagen fibre bundles in the AWRS ran in the same direction as the fascicles of internal oblique muscle (WILLIAM, BANNISTER, BERRY et al., 1995). The lower fascicles of this muscle are transversely disposed while the upper ones slant upwards and medially to be inserted into the costal margin. In the PWRS, the collagen fibre bundles were transversely aligned in tandem with the orientation of the transversus abdominis muscle (WILLIAM, BANNISTER, BERRY et al., 1995).

The collagen fibre bundles in the PWRS also ran in the same direction as the upper fascicles of the transversus abdominis. Consequently, the muscle that exerts more effect on the posterior wall of the rectus sheath is the transversus abdominis. It is probable that the entire rectus sheath above the arcuate line takes part in all movements of the transversus abdominis such as in respiration (HODGES, GANDEVIA and RICHARDSON, 1997; URQUART, HODGES and STORY, 2005). In this way, the contraction of TA pulls the deep lamina of IO because they are fused. This traction force then draws the superficial lamina of IO together with the rectus abdominis muscle. This phenomenon is observed during normal respiration and supports the classification of the upper abdominal wall into a respiratory portion (RATH and ZHANG, 1997).

4 Conclusion

The microscopic organisation of the rectus sheath is largely influenced by its pattern of formation. The chief muscles that form the rectus sheath are the internal oblique and transversus abdominis. These muscles complement each other in forming the anterior and posterior walls of the rectus sheath. The fibre composition and orientation above the arcuate line are suited for generating intra-abdominal pressure while those below this line are for resisting the intra-abdominal pressure generated.

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