

The development of the anterior abdominal wall in the rat in the light of a new anatomical description

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INTRODUCTION

A new anatomical description of the anterior abdominal wall has been given recently (Rizk, 1976, 1980). It describes each abdominal aponeurosis as bilaminar and each wall of the rectus sheath as trilaminar. The fibres of all aponeurotic layers, in all mammals studied, cross the middle line to form digastric muscles with the corresponding aponeurotic layers of the opposite side. This description raises the question of the developmental origin of such a structure.

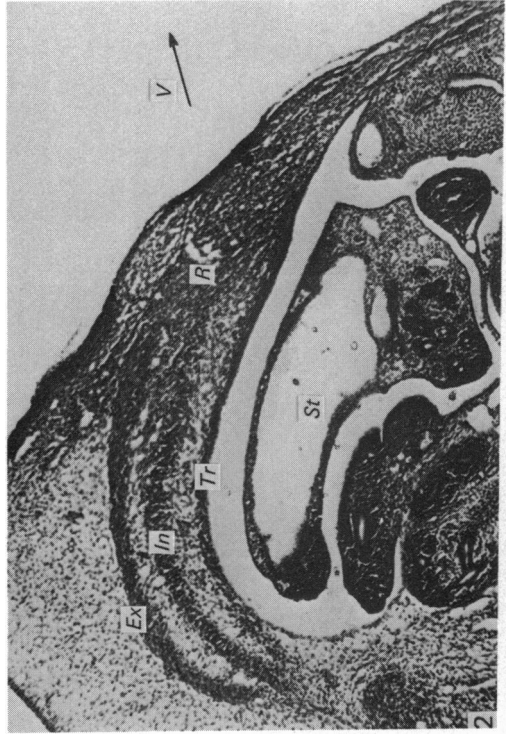
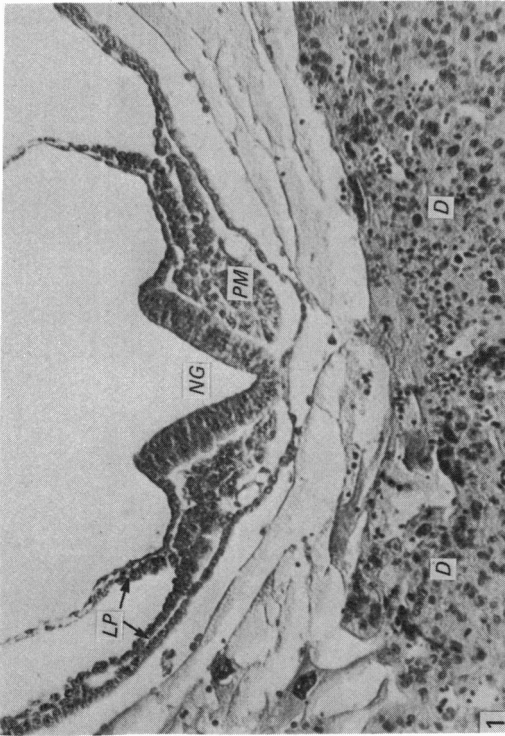
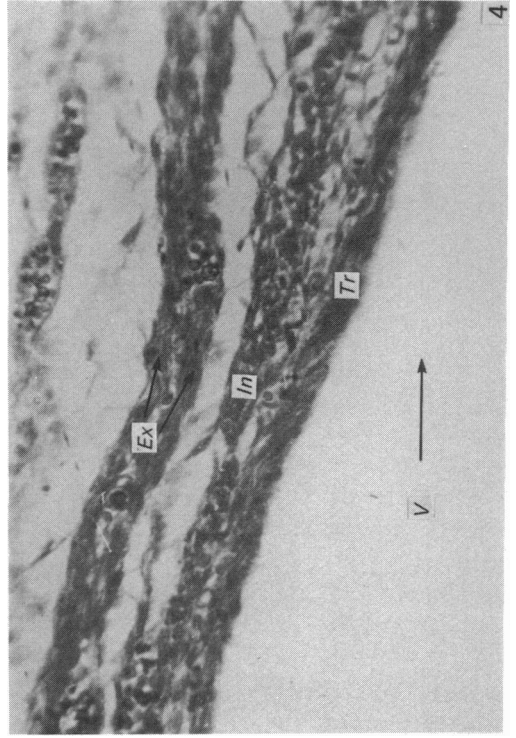
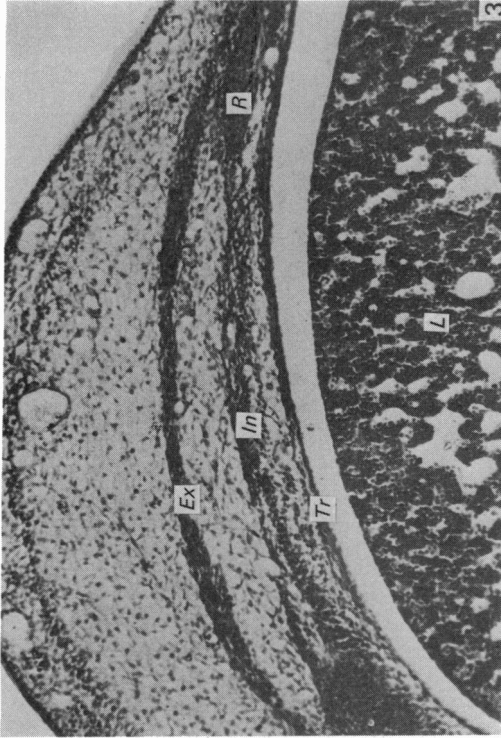
A point of controversy to be settled is the mesodermal origin of the abdominal muscles. Some authors describe the thoracic myotomes as extending ventrally to form the ventrolateral muscles of the thorax and the abdomen (Bardeen & Lewis, 1901; Patten, 1964; Arey, 1965; Hamilton, Boyd & Mossman 1972). However, more recently Snell (1975) stated that the abdominal muscles differentiate locally from the mesenchyme of the somatopleure. The further course of development of the abdominal mesoderm is a point of agreement between some investigators (Hamilton *et al.* 1972; Snell, 1975), but the literature seems to be deficient in embryological reports that could be related to the new anatomical description. The present work describes the development of the ventrolateral abdominal muscles of the albino rat in the light of this description.

MATERIALS AND METHODS

Sixty albino rat embryos, from twenty two different mothers, were studied starting from the 10th *postcoitum* (*pc*) day to the 30th day after birth. Embryos were taken every 12 hours from the 13th day to the 18th day inclusive, and every 24 hours from the 10th day to the 22nd day *pc* inclusive. The older specimens were taken immediately after birth and 10, 20 and 30 days postnatum. The first day of pregnancy was designated to commence the first morning *pc* using the vaginal smear method. Pregnant rats were anaesthetized by inhaling ether and then killed by increasing the inhaled dose. The embryos were fixed in Bouin's solution and embedded in paraffin. The hypodermic tissue of the ventral abdominal walls of the postnatal specimens was perfused with 10 % formalin for one hour prior to excision. The specimens were serially sectioned transversely and longitudinally at 7 μm , and stained with haematoxylin and eosin and Mallory's trichrome stains.

RESULTS

On the 10th day *pc*, the dense paraxial mesoderm could be differentiated from the loose mesenchyme of the lateral plate (Fig. 1). During the 13th day *pc*, the thoracic myotomes were seen to invade the loose tissues of the lateral body wall. By the 14th



day *pc*, the invading bud had divided into a small ventral portion, oval in cross section, and a dorsal segment that was split into three ill-defined layers.

By the 15th day *pc*, the migrating myotomal mesoderm, which was relatively more advanced caudal to the umbilicus, reached the middle line in the inguinal region. The splitting of the dorsal segment of the migrating mesoderm into three layers became more apparent. They could be arranged according to their relative thickness as: internal oblique (middle layer), external oblique (outer layer) then transversus abdominis (inner layer). The ventral portion of the migrating mesoderm remained unlamellated as a thick mass oval in cross section, the 'rectus abdominis' (Fig. 2). Histogenesis started at this age when some elongation of the cells was seen, but a definite direction of fibres for each layer was still difficult to identify.

Further subdivision of each of the three muscular strata into two thinner laminae appeared at the beginning of the 15th day *pc*, first in the transversus abdominis and the internal oblique muscle (Fig. 3), then, slightly later (by the end of the 15th day *pc*) in the external oblique muscle (Fig. 4). Re-fusion of the two laminae of each of the three muscles occurred in the same sequence between the ages of the 15th and the 17th day *pc* (Fig. 4).

On the 16th day *pc*, a similar tangential splitting of the cranial third of the rectus abdominis occurred, to form two laminae, superficial and deep (Fig. 5). The superficial wall of the rectus sheath became well defined, and crossed the middle line to continue into its fellow of the opposite side (Fig. 6). During this day (16th *pc*) the further histogenesis of the cells was apparent in their elongation and orientation so that a definite direction could be identified for the cells of each layer. The cells of the outer and inner layers were parallel to each other, but those of the middle layer were perpendicular to those of both the others (plywood arrangement).

On the 17th day *pc*, the medial extension of the ventral wall of the rectus sheath progressed. Thus, apart from the umbilicus, which remained as a small foramen, continuity between the two sheaths of the two sides became complete throughout the linea alba. At the 18th day *pc* a ventral and thin aponeurotic part could be differentiated from a thicker, dorsal and fleshy one. However, the aponeuroses were not yet collagenized. Definite collagenous bundles, as shown by Mallory's trichrome stain, were not seen before the 19th day *pc*. By the 20th day *pc*, a condensation of fine collagenous fibres was visible around the three muscle layers, especially ventral to the external oblique, and formed the deep fascia (Fig. 7). Tendinous intersections were seen only in postnatal specimens; they were attached to the ventral, but not to the dorsal, rectus sheath (Fig. 7).

At 10 days postnatum, the tendinous intersections were thickened, and colla-

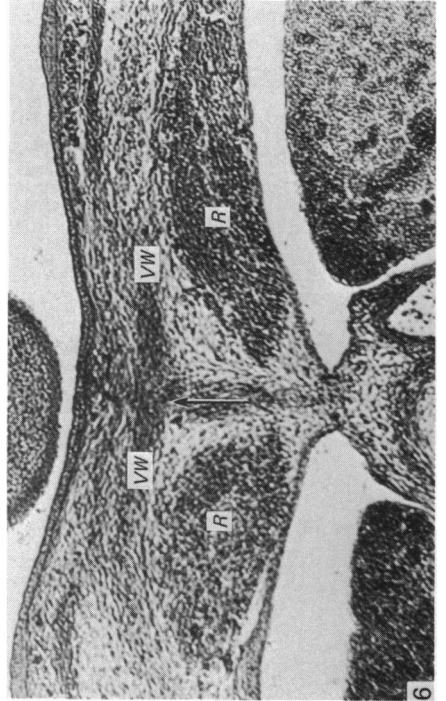
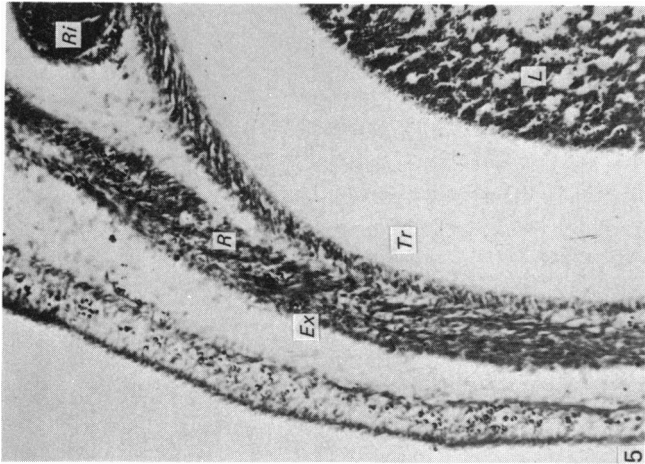
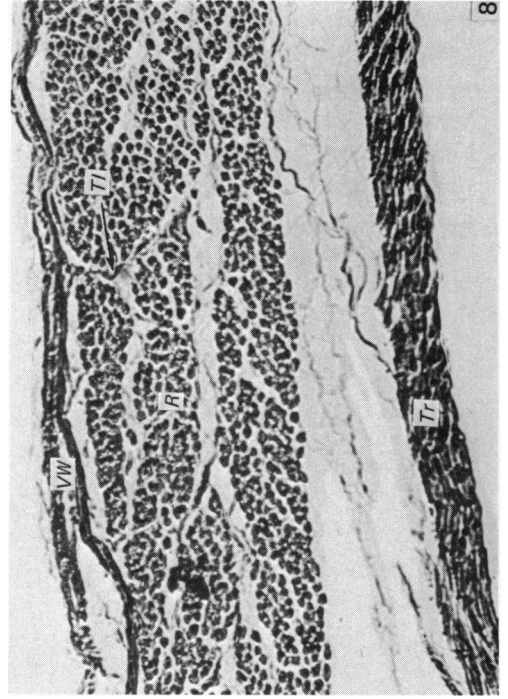
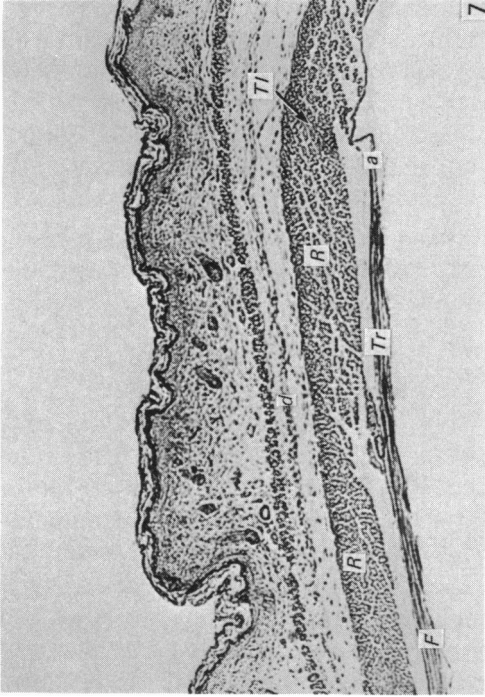
Figs. 1-8 are photomicrographs of paraffin sections of albino rat embryos and postnatal specimens. See p. 242 for abbreviations.

Fig. 1. Transverse section of the gestation sac on the 10th day *postcoitum*. The dense paraxial mesoderm (*PM*) is differentiated from the lateral plate mesenchyme (*LP*). The neural groove (*NG*) is still open. *D*, decidual tissue. *H* and *E*. $\times 150$.

Fig. 2. A transverse section (left half) on the 15th day *pc* showing the ventral segment of muscles ('Rectus abdominis') and dorsal segment which is split into the three abdominal muscles (*Ex*, *In* and *Tr*) and showing their relative thicknesses. *H* and *E*. $\times 50$.

Fig. 3. A transverse section at the end of the 15th day *pc* showing further splitting of each of the transversus abdominis and internal oblique muscles. *H* and *E*. $\times 50$.

Fig. 4. A transverse section at the end of the 15th day *pc* showing splitting of the external oblique muscle and re-fusion of the split transversus and internal oblique muscles. *H* and *E*. $\times 150$.



genous fibres were present as endomysium and epimysium around the muscular fibres and bundles (Fig. 8). From this age on, the development was just a gradual increase in size and in degree of differentiation of the various structures.

DISCUSSION

The present observations illustrate that the ventral abdominal muscles arise from the paraxial mesoderm, with no evidence of a contribution from the lateral plate mesoderm. The fused thoracic myotomes migrate and invade the lateral body wall, starting at the 13th day *pc*. The mesodermal bud first reaches the middle line at the inguinal region (on the 15th day *pc*) and then successively at higher levels. This could be explained by the relatively smaller size of the caudal parts of the abdominal wall. Soon after, the mesodermal bud crosses the middle line and continues with its fellow of the opposite side. At the 17th day *pc*, the area of continuity between the mesoderm of the two sides extends over almost the whole extent of the linea alba, except for the region of the umbilicus which remains as a patent foramen. A similar umbilical foramen was always noticed in adult human specimens (unpublished work). Differentiation of the mesoderm into fleshy bellies and intermediate aponeuroses starts later, at the 18th day *pc*. Thus, the digastric abdominal muscles (Rizk, 1980) do not result from fusion of the two lateral sets of abdominal muscles, but develop as differentiation within one digastric mesodermal primordium already established.

Splitting of the main dorsal segment of the migrating mesoderm into three layers starts early on the 14th day *pc*. The relative thickness of the three layers shows marked similarity to the corresponding muscles of adult man, which could be arranged in descending order of their thickness as internal oblique, external oblique and transversus abdominis (Rizk, 1974). Further splitting of each of the three muscles into two laminae was noticed as occurring temporarily and for a short period, which was followed by fusion of the two laminae in the period between the 15th and 17th day *pc*. This is comparable to the fact that, in man and in many other mammals, each abdominal aponeurosis is bilaminar (Rizk, 1976, 1980). The temporary tangential splitting of the rectus abdominis is also comparable to the splitting of the rectus abdominis of the kangaroo, in which the muscle is formed of two layers, superficial and deep. It is suggested that the superficial rectus regresses along the scale of evolution into the pyramidalis muscle, which is big in apes but rudimentary and occasionally absent in man (Rizk, 1974).

These observations might support the suggestion that mammals are evolved from one original stem in which each of the four ventral abdominal muscles was bilaminar, and that this characteristic persists in the adult aponeuroses of man and other mammals but with minor variations.

Fig. 5. A longitudinal section at the 16th day *pc* showing the last rib, and the rectus abdominis muscle split into two laminae. H. and E. $\times 90$.

Fig. 6. A transverse section at the 16th day *pc* showing the ventral wall of the rectus sheath (*VW*) crossing the middle line (arrow) and continuous with its fellow of the opposite side. H. and E. $\times 300$.

Fig. 7. A transverse section of a neonatal rat showing the tendinous intersection (*TI*). Note the fleshy (*F*) and aponeurotic (*a*) parts of the transversus abdominis muscle. *d*, deep fascia. Mallory's trichrome stain. $\times 50$.

Fig. 8. A transverse section on the 10th day postnatum showing endomysium and epimysium around the fibres and bundles of the rectus abdominis muscle. Note that the ventral wall of the rectus sheath is adherent to the rectus muscle and its tendinous intersections, while the posterior wall ('transversus') is separated from them. Mallory's trichrome stain. $\times 150$.

A trilaminar plywood arrangement was noticed in each wall of the human rectus sheath (Rizk, 1980). The present observations on the rat embryo showed that, during histogenesis, the elongated cells and, later, muscle fibres orient themselves in a similar plywood arrangement. Thus the particular direction and orientation of the abdominal muscle fibres are most probably genetically rather than mechanically determined.

Deposition of collagen in the aponeuroses and in the deep fascia was seen to occur on the 19th and 20th day *pc*, respectively. The fact that the tendinous intersections were not seen except postnatally probably suggests that they are not representative of the original segmentation of the myotomes, but rather represent some sort of intermediate tendons of a multigastric, longitudinal column of muscle. The fact that they were, as in man and other mammals, attached to the fibres of the ventral but not the dorsal rectus sheath supports the phylogenetic similarity between man and various mammals.

SUMMARY

The development of the ventral abdominal muscles of the albino rat was studied histologically in 60 embryos and 10 postnatal specimens. The lower thoracic myotomes were seen to migrate ventrally in the lateral body wall, cross the middle line and continue with their contralateral fellows of the opposite side, thus forming a digastric mesodermal primordium. Differentiation of this primordium into fleshy bellies and intermediate aponeuroses occurred later in the prenatal period. Similar to the bilaminar arrangement of each of the human abdominal aponeuroses, recently described, each of the ventral abdominal muscles of the rat embryo was temporarily bilaminar; and similar to the trilaminar (plywood) arrangement of each wall of the human rectus sheath, the three lateral abdominal muscles of the rat embryo were so arranged. The tendinous intersections of the rectus muscle were seen only postnatally. They might be considered less as the remnants of a segmental origin, but rather as the intermediate tendons of a multigastric longitudinal muscle column.

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ABBREVIATIONS FOR FIGURES

Ex, external oblique; *In*, internal oblique; *L*, liver; *NG*, neural groove; *R*, rectus abdominis; *Ri*, rib; *St*, stomach; *Tr*, transversus abdominis; *V*, ventral aspect; *VW*, ventral wall of rectus sheath.