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A NEW PERSPECTIVE REGARDING THE RECTUS ABDOMINIS MUSCLE-DEVELOPMENT AND ONTOGENESIS

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ABSTRACT. The present paper aims to do an objective research over the ontogenesis process of the anterolateral abdominal wall and, using the results obtained, to verify the validity of the theories formulated until now; it also aims to elaborate a theory regarding the process, if the analysis elements allow it. To fulfil the objectives of this study, we have used dissections, video images through transillumination, photographic pictures and histological studies. We have carried out a microscopic study that aims to minutely observe the processes that happen in dynamic time from early ages on. We have also run a macroscopic study through the inspection of the anterolateral abdominal wall.

Keywords: somitic, mesenchyme, plasmodium, polynucleated, sarcolemma

INTRODUCTION

Because of a great number of theories concerning the genesis of the walls of the trunk, the present work aims to verify which theory is valid and possibly, by using the results, to develop a theory concerning the development of the rectus abdominal muscle. With regard to the muscles of the anterolateral abdominal wall, especially the rectus abdominal muscle, there is a series of opinions that are worth considering and according to which this musculature would be entirely of somitic origin. Other authors stress the role of the longitudinal vessels on this level as an organizing factor in the development of the rectus abdominal muscle. The somites are among the first parts segmentally organized, which form the skeletal, muscular and dermal structures. By using the personal observations, the work aims to prove the existence of some gradients of development on the level of the rectus abdominal muscle.

MATERIALS AND METHODS

This study was carried out on a number of 15 subjects: 9 adult embryos and fetus and 6 human adult corpses. The macroscopic study involved the inspection of the anterolateral abdominal wall, supplemented by the dissection, the parietal and umbilical morphometry and the study by transillumination. The microscopic study consisted of the sampling of parts of the embryos, fetus and adults studied macroscopically. The authors carried out the colouring using Hemalum Eosin Sofran, the Van Gusson method and the silver impregnation. We also used the method using the lemon juice and gold chloride according to Roschin. The Nikon binocular microscope with objectives of x2 to x40 contributed to the execution of microphotographies according to the microscopic preparations.

RESULTS AND DISCUSSIONS

The study showed that the non-differentiated mesenchyme dominates the anterolateral zone of the abdominal wall at 45 days of age. The researchers have also observed, in the parietal superumbilical area, a muscular mass belonging to the broad muscles of the abdomen where one can see mononucleated myoblasts. The density of the myoblasts is larger on the level of the origin and of the insertion of the broad muscles. The whole parietal subcutaneous space is occupied by primary mesenchymatic tissue, while the process of myoblastic differentiation is in an early stage.

We can observe the occurrence of muscle fibers with polynucleated aspect (plasmodium) and of the myoblasts still present in great number, in the muscular superumbilical mass at the 7-week old embryo.

At this age of 6.5 weeks, in the underumbilical region, the process of myoblastic differentiation is at its beginnings, which is proven by the small number of myoblasts, as compared to the superumbilical region, where the myoblasts are far more numerous. In exchange, in the underumbilical region, almost the whole space is occupied by primary mesenchymal tissue – case 2. Still at this age, the mesenchymatic conjunctive mass is still well represented, including all the muscular cells (the mononucleated plasmodii and myoblasts which will be different in striated muscular line), while on the underumbilical level, the mesenchymatic structure prevails with non-organized mesenchyme in myoblasts (Diedrich et al. 2002).

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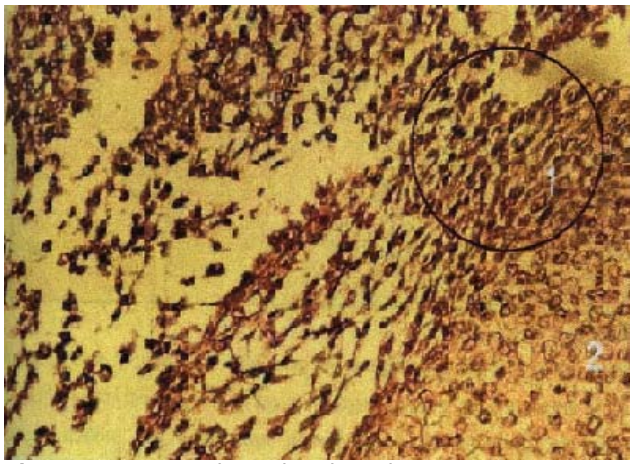

Fig. 1 14 mm embryo (week 6,5), case 1, transverse superumbilical section, objective 40x, coloring V.G. Detail in which one can clearly see the myoblasts of the muscular mass (1). The myoblasts are located in a mass of mesenchyme tissue (2) which will become the conjunctive tissue of the muscle. The mesenchymal tissue is also to be found at the level of the insertion structure of the muscular mass on the rib, in contact with the coastal perichondrium. This is clearly differentiated from the coastal chondroblastic structure. At the age of 6.5 weeks, at the subcutaneous, underumbilical level, one cannot speak of a muscular mass (the rectus abdominis muscle is not structured) – case 2.

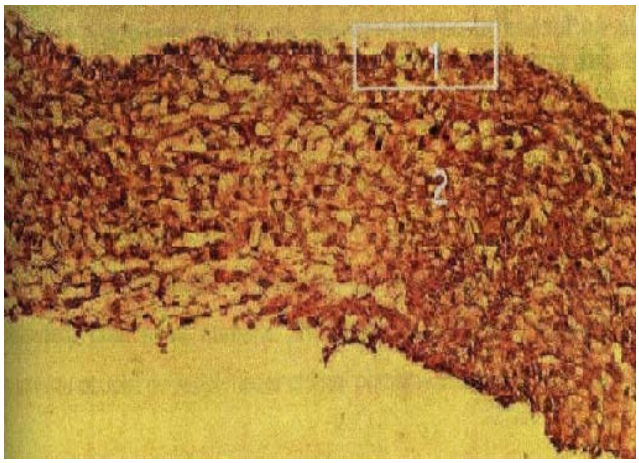

Fig. 2 14 mm embryo (week 6,5), case 2, in underumbilical cross section, objective 10x, H.E colouring. The image shows the antero-lateral abdominal wall in cross section where we can see mesenchyme tissue (1) with very rare myoblasts (2) under the tegument. This structure shows that the myoblastic differentiation process is at its initial point, which is proven by the fact that the primary mesenchymal tissue occupies the whole subcutaneous parietal space, showing a time difference regarding the mesenchymal differentiation towards myoblastic structures between the superumbilical antero-lateral abdominal parietal region and the underumbilical one. If at the same age in the superumbilical region the myoblasts are more numerous and occupy the largest part of the space represented by the future muscle, in the underumbilical region, the myoblasts are much less numerous.

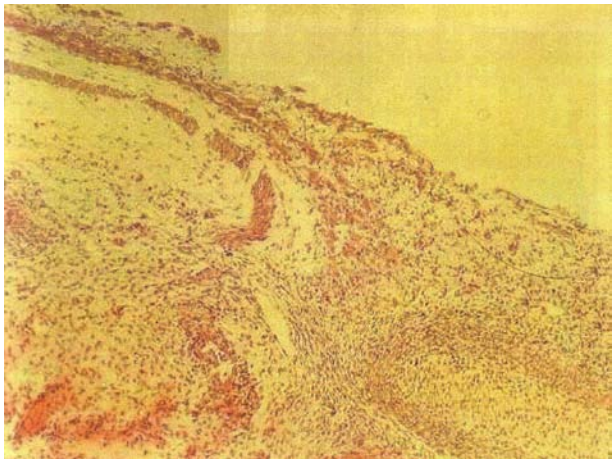

Fig. 3 22 mm embryo (week 7,5), case 20, objective 10x, H.E. colouring, in underumbilical cross section on the level of the anterolateral abdominal wall. The section highlights two distinct plans. On a side the umbilical area, on the other side the muscular plan of the abdominal broad muscles in the course of laminated organization. We can notice at least two muscular layers, a superficial one (beneath the hypoderm), which includes the future oblique muscles and a second deep muscular plan represented by the future transverse abdominus

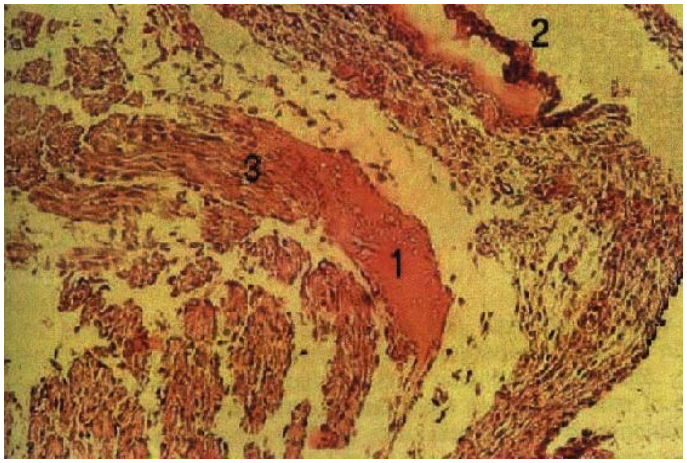

Fig. 4 42 mm embryo (week 7,5), case 18, objective 20x, H.E. colouring, in superumbilical cross section on the level of the anterolateral abdominal wall. 1-rib, 2-tegument, 3- muscular mass. At this level, a young muscular mass is forming; its muscular fibers are sectioned obliquely and transversely. The muscular fibers are still myoblasts and begin to organize fascicularly. The fascicles are differently sized and non-uniformly disposed. The mesenchymal tissue is very well represented among the fascicles. The muscular mass has insertion points on a rib at this level; this rib is in the ossification process. The replacement of chondroblasts by the osteoblasts is markedly noticed. In the peripheral region, the strata of the tegument are well differentiated

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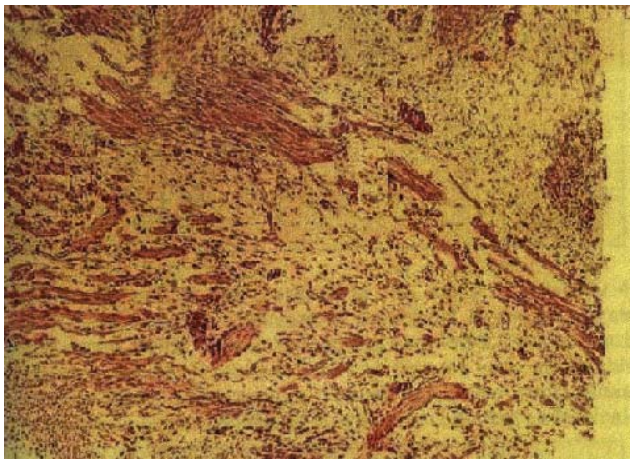

Fig. 5 22 mm embryo (week 7,5), case 19, objective 10x, H.E. colouring, in umbilical cross section on the abdominal level of the anterolateral wall. Some of the muscular fibers are sectioned longitudinally; some are sectioned transversely obliquely (from the anterior muscular mass). The muscular fibers differentiate. Some fibers already have peripheral nuclei; most of them have a myoblastic (mononucleated) aspect. Moreover, the fascicular structure is being organized, but has a non-homogenous aspect

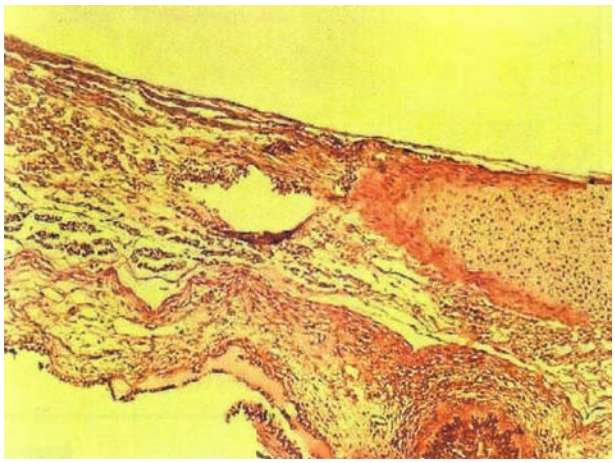

Fig. 6 39 mm embryo (week 8), case 22, objective 10x, colouring VG., in superumbilical cross section, through the thorax-abdominal wall. The omphalo-enteric duct is visible in the figure; in the lateral side, some of the parietal muscular fascicles are longitudinally sectioned, while others are transversely obliquely sectioned

Among the muscular fibers, there is mesenchyme which will become the future endomysium. In the underumbilical region, there are two muscular layers; one of them is superficial, under the hypoderm, which includes the future oblique muscles alongside the rectus abdominis muscle and a second deep muscular plan represented by the future transverse abdominal muscle. Medially from the broad muscles of the abdomen there are some muscular fibers organized within the structure of the future rectus abdominis muscle (Oligny 2001).

Thus, at the age of 7.5 weeks, the abdominal broad muscles are already clearly represented and disposed on two layers:

- an external layer, which corresponds to the future oblique muscles;
- an internal layer which corresponds to the future transverse abdominus.

These muscular layers are clearly delimited and composed of muscular fibers that tend to organize in a fascicular way. At the same age, as opposed to the abdominal broad muscles, the rectus abdominal muscle is composed of myoblasts and some plasmodia layers.

An important aspect to notice is the development of the rectus abdominal muscle which is better represented by its lateral portion (which is differentiated more early), close to the broad muscles, than in its medial portion (7.5 weeks of age).

Thus, even from the age of 7.5 weeks, we can notice the occurrence of a differentiation gradient within the structure of the rectus abdominal muscle, within all the three plans.

- vertically, the rectus abdominal muscle is more developed at superumbilical level than at underumbilical level;
- frontally, it is more developed at the lateral side than at the medial side;
- sagittally, it is more developed at ventral (superficial) level than at dorsal (deep) level.

The existence of this triple development gradient is visible even beginning with the start of the fetal period, at the age of 8.5 weeks and even at the age of 9 weeks.

At the age of 8 weeks, the embryo has two special characteristics: the fibers of the parietal muscles have an aspect of plasmodii, while the muscle has a prevalent fascicular structure. On the superumbilical level two plans of the broad muscles of the abdomen are highlighted, the majority of fibers having a plasmodium aspect. Between the plasmodii one observes rare mononucleated myoblasts. One can also see the aponevrosis insertion, marked by distinct morphological elements: the conjunctive structure of the aponevrosis and fasciculated fibers.

At the level of the broad muscles of the abdomen, their differentiation is visible; it is also visible that they are disposed on two layers. Between the superficial stratus (which will give birth to the two oblique muscles) and the deep stratus (which will turn into the transverse abdominal muscle) there is a parietal lateral vascular-nervous interstice.

Thus, at the age of 8 weeks, the abdominal wall has a different aspect, given by the presence in the superumbilical portion of many plasmodii organized in a fascicular way and rare myoblasts, while on the underumbilical level, there are numerous myoblasts and little plasmodii which cannot be considered groupings of fascicules (Rizk 1990).

The study highlights some elements that are worth noticing, such as: the homogeneity of the medial conjunctive structure, the considerable distance

between the two rectus abdominal muscles and the inter-rectal dehiscence, equivalent to the width of a muscle.

At the age of 9 weeks, the development of the rectus abdominal muscle takes place between the two thin, filmy tissues of its sheath. The ventral or superficial thin tissue is situated deep beneath a well represented hypodermal layer. Deep beneath this ventral thin tissue of the rectus abdominis sheath we can notice well represented muscular fibers. In the dorsal portion of the muscle, the mesenchymal mass has a little amount of myoblasts. The mesenchymal mass is in direct contact with the deep thin tissue of the rectus abdominis sheath.

The age of 9 weeks represents an important moment within the development of the rectus abdominis because both the thin tissues of its sheath are visible – the superficial one and the deep one.

At the age of 10 weeks, we can observe the fascicular organization of muscle fibers of the rectus abdominal muscle; the muscles are also surrounded by isolated muscle fibers. In the underumbilical area the myoblasts are seldom highlighted, while the density in muscle fibers is smaller than on superumbilical level. The dense conjunctive tissue in this area loses density transversely, but gains in anteroposterior direction. In the medial portion we can notice the very large density of collagen fibers of the inter-rectal interstice. These fibers unify between the two rectus abdominal muscles.

With a higher age, of 11 weeks, the number of muscle fibers grouped in fascicles increases, we can not notice yet the sarcolemma in striated fibers yet, while in the interfibrillar mesenchyme there are myoblasts beside striated fibers. The sheath and the fascia of the muscle are not well represented yet.

In the following stage of age, 12 weeks, the number of myoblasts in conjunctive tissue is relatively reduced, the muscle fibers being generally organized in fascicles. On superumbilical level, the muscular fascicles have, in their proximity, a reduced number of myoblasts, being highlighted in differentiated morphological aspect.

At the age of 16 weeks, the width of the rectus abdominis in the superumbilical part is of averagely 5.5 mm, while the width of the white line is of 3 mm. At this age, the ratio of widths in the super and underumbilical regions of the white line and the rectus abdominis are approximately equal to 2. The distance between the symphisis and the umbilicus is averagely of 26 mm, while that between the umbilicus and the xiphoid process is of 59 mm. At the age of 17 weeks, the above mentioned ratio remains approximately constant. The width of the superumbilical muscle is of 6 mm (in average), the width of the underumbilical muscle is of 3 mm and the thickness of the white line is of 2 mm (in average) in the superumbilical part and of 1 mm in the underumbilical part, while the distances between the umbilicus and the pubic symphisis and between the umbilicus and the xiphoid process are of 68 mm all dimensions.

Within this period (weeks 16-17) there is a tendency of the umbilicus to move from the caudal part to the cranial part. The ratio of the distances between the umbilicus and the xiphoid process, respectively between the umbilicus and the symphisis decreases as the umbilicus moves to the cranial part.

Beginning with weeks 18-19 to 30-32 an amount of subcutaneous adipose tissue appears in the lateral zone of the abdomen.

At the age of 30 weeks, the development is almost completed, as the following ages do not bring significant changes of the fetal morphometry. At the age of 9 weeks, the ratio of distances between the xiphoid process and the umbilicus, respectively between the umbilicus and the symphisis is around 1.5-1.7 mm, the vertex coccis development brings along an accelerated growth of the superumbilical region of the muscle as compared to the underumbilical portion, being a process manifested by the migration of the umbilicus in a cranial-caudal direction (Selleck et al. 1992).

The progressive and continual reduction of the space between the two rectus abdominal muscles is due both to the migration of the secondary mesenchyme from the lateral side and to the growth of the rectal muscular mass because of some latero-medial gradients which act at the level of the primary paraumbilical mesenchyme (Murray et al. 2002).

The macroscopic study of the fetuses by dissection and transillumination pointed out the changes in ontogenesis of the rectus abdominals and of the space between them. The interrectal dehiscence, with rhombic shape for early ages of fetuses, becomes increasingly prolonged; its width decreases after the age of 20 weeks. The method of dissection points out the apparition of preperitoneal fat around the preperitoneal vessels of the anterolateral abdominal wall.

CONCLUSIONS

The sheath of the rectus abdominis muscle is organized along with the apparition of the latter's muscular structures. The posterior lamina of the sheath gets differentiated faster than the anterior one. The posterior lamina is thicker than the anterior one, in the periumbilical region inclusively.

Within the intrauterine life, the superumbilical mesenchyme starts organizing into myoblasts very early, faster than in the underumbilical region. This process is visible for the 14 mm embryo (week 6.5) where the myoblastic differentiation process is in progress, in the superumbilical region of the abdominal wall, while in the underumbilical region the same process is only beginning. Among the myoblasts, there are mesenchymal cells that evaluate towards the conjunctive tissue of the muscle, endo-, peri- and epimysium respectively. At the origin and insertion of the broad muscles, there is a greater density of myoblasts – case 1 – than in the rest of the muscular mass.

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The low density of myoblasts within the fiber is due to the fact that the differentiation of muscular elements is at its starting point and progresses with a lower speed than in the case of the differentiation of osseous elements (which also takes place within the mesenchyme) case 2.

The mesenchyme dominates this region and there are no relevant clues upon its direction of future differentiation, while at the same age but in the superumbilical region – a region which comes from the plica encephali that is more developed that the caudal one which will give birth to the underumbilical region - we can notice the tendency of the mesenchyme to differentiate into cartilaginous and muscular structures (the conjunctive structures occur later on).

The craniocaudal plication and the primary migration of the mesenchyme give rise to the rectus abdominal muscle.

The differences in development between the cranial and caudal ends represent the explanation for the differences in development in the superumbilical portion compared to the underumbilical one.

The rectus abdominal muscle does not appear as a consequence of a dorsolateroventral migration, according to the traditional assertion, but following a craniocaudal migration.

The dorsolateroventral plication determines the somitic migration of the mesenchyme which, in its turn, appears after the craniocaudal migration.

The super and underumbilical portions will get to the same level of development in an interval of 10-14 days.

Besides the existence of the shift between the development of the superumbilical area as compared to the underumbilical one, there is still a shift between the development of the broad and long muscles of the abdomen. This is why, starting with the age of 7-8 weeks, the long muscles of the abdomen are formed exclusively by myoblasts surrounded by non-differentiated mesenchyme tissue, while the broad muscles of the abdomen contain fibers which have the tendency to be structured.

The craniocaudal migration represents a first stage of the occurrence of this muscle. The migration is carried out in double direction, by avoiding two obstacles: the future navel and the stern. The two rectus abdominal muscles appear well individualized following the migration, being separated by a “V”-shaped space. This dehiscence contains mesenchyme conjunctive tissue, rich in collagen fibers, at which elastic fibers are later on added. It represents the white line in structural and functional formation, at the same time with the help of the "abdominal press", whose existence is conditioned by the development of the abdominal internal organs and afterwards by the motility of the trunk.

The second stage in the evolution of this muscle is represented by the dorsolateroventral migration. This one determines the formation of some new fibers in the somitic mesenchyme, being added to those existing as of the preceding stage and having as a result the final formation of the rectus abdominal muscle.

The rectus abdominal muscle develops less quickly than the broad ones. Thus, the time difference is shown (10-14 days).

It is a shift in the differentiation of the superumbilical portion and the underumbilical one.

There is a series of inductive factors which influence the development of the muscles of the superumbilical area. These factors are represented both by the longitudinal vessels of the abdominal wall (higher and lower epigastric vessels) and by the osseous elements of insertion and origin of these muscles which are in a state of condrification for the period of differentiation of the muscular structures.

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