Three-Dimensional Reconstruction of the Anorectal Continence Organ in a 14-Week-Old Fetus

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Background/Purpose: The fetal development and anatomy of the muscular structures of the anorectal continence system are unclear. To the pediatric surgeon, these structures are of clinical relevance in reconstructive surgery. The aim of this study was to investigate the fetal development of the anorectal continence organ.

Methods: A male fetus (14 weeks postconceptionem) of 114-mm crown-rump length was sectioned serially at 18-μm intervals. The sections were stained, and relevant contours of the sections were transferred onto paper using a Zeiss Axioskop drawing apparatus. The drawings then were scanned and digitized.

Results: Three-dimensional images were created (and animated in a video). These have permitted the demonstration of isolated anatomic structures, the disassembling and reassembling of compound structures, as well as the visualization of structures from different angles.

Conclusions: Further studies are now undertaken of older fetal stages through to birth, as well as during postnatal stages. Comparative studies in animals and animations of isolated muscles also are required to show functional capacities. Such studies may lead eventually to an improvement of contemporary surgical techniques.
lateral segment of the levator muscle is called the iliococcygeus by anatomists. It originates from the area of the arcus tendineus all the way around to the spina ischiadica of the pelvis, and thus almost completes the funnel (Fig 3).

The back part of the funnel is closed by the coccygeus, a rather voluminous muscle clearly separated from the other levator segments. The caudal part forms a U-shaped sling (the puborectalis sling), which is open anteriorly (Fig 4).

The inferior tip of the funnel marks the transition of the rectum into the anus. There, the rectum leaves the funnel through the urogenital hiatus. The anus is surrounded by a circular system. The external sphincter is a 3-part circular system. Its deep, subcutaneous, and superficial segments are clearly discernible (Fig 5).

Most orally is the deep segment, followed aborally by the superficial and, most aborally, by the subcutaneous segment. In the anterior area of the anus, all 3 segments are joined. In addition, anteriorly, longitudinal muscle fibers subdivide the muscle radially (not seen on the 3-D reconstruction because only surface structures are represented). Furthermore, laterally and posteriorly, all 3 muscle segments can be identified clearly. The external sphincter appears not to make contact with any bony structures.

Both the funnel and the external sphincter are interconnected by additional intermediate muscle fibers. Originating from behind the pubic bone, these fibers run isolated from the funnel, separated from it by mesenchymal tissue. Behind the anus, the fibers join the external circular system. The cranial section of the intermediate fibers splits, with the inner and cranial fraction of the fibers running toward the coccyx. The caudal fraction of the fibers crosses behind the anal canal. This sling has been called the puborectalis sling. It cannot be distinguished from the uppermost (ie, the deep) part of the external sphincter.

When the ventral aspect of the funnel is electronically faded out, an additional narrow muscle band becomes visible. This originates at the inner aspect of the levator in close contact with the rectum. It inserts at the coccyx. It may be assigned to the rectococcygeus muscle (Fig 1).

DISCUSSION

The first promyeloblasts of the levator have been found in the sixth week of gestation, and those of the external sphincter in the seventh week of gestation.2 Both main constituents of the anorectal continence organ, the levator funnel, and the external sphincter, have been shown as early as in the eighth week of gestation.3 Our electronic reconstructions confirm these findings. Anatomic differences between sexes, however, could not yet be identified in our 14-week-old fetus. Nor was the
anococcygeal ligament seen, which has been observed during surgery later in development.

The early development of the tripartite composition of the funnel also was known previously. There is inconsistency in denoting the different muscle parts among anatomists and surgeons. The terms are misleading. Although called pubococcygeus and ileococcygeus muscles—suggesting origin and insertion, even function—in fact, only a small proportion of most caudally and posteriorly situated muscle fibers actually insert at the coccyx.

de Vries and Friedland identified 2 layers of the pubococcygeus muscle, a craniolateral and a mediocaudal layer. Our findings confirm that the ventral funnel is 2 layered and that the cranial majority of the muscle mass does not make contact with the coccyx. Ventral to the anus, the caudal section further divides into 2 parts; only the cranial part contacts the coccyx and thus deserves the name pubococcygeus.

Our findings show that the puborectalis muscle is the major anterior component of the funnel, anchoring it to the symphysis. On its course posteriorly, it splits, together with the puborectalis. Posteriorly, it cannot be distinguished from the external sphincter. Other researchers also have seen one uniform structure. The uniformity is so pronounced that the puborectalis muscle has even been considered an integral part of the external sphincter. Even in the adult, this has been confirmed in magnetic resonance imaging.

Most anatomists consider the external sphincter a 2-loop system; surgeons are uncertain. Levi has, in 18 human embryos, only seen 2 portions of the external sphincter. The fetus investigated in our study showed 3 distinct circular structures.

Kluth et al studied normal and abnormal fetal mice, and found, in normal embryos, that the region of the future anal opening can be identified soon after the very early establishment of the cloacal membrane. They concluded that the “fistula” in anorectal malformations resembles a normal anus at an ectopic position.

In anorectal anomalies of children, Paidas and Peña were unable to distinguish separate external sphincter components; they all appeared fused. In his usual surgical approach from the posterior, Peña would encounter a longitudinal “muscle complex,” which he considers to represent the junction of the levator muscle with the external sphincter. Electrical stimulation of the upper part (ie, the levator) would be answered by pulling the anus anteriorly. This is mostly the function of cranial majority of the pubococcygeus muscle mass, which does not make contact with the coccyx. Stimulation of the lower part (ie, the “muscle complex”) results in a cranial movement and simultaneous closure of the anus. This appears to be the function of the caudal pubococcygeus muscle section. The current study is unable to contribute to the open question of the presence of an internal sphincter.

In the organ of the fetus, we have found a clear tripartite funnel system and a tripartite circular system of
muscles. The funnel is composed of the levator ani, iliococcygeus, and coccygeus muscles. The pubococcygeus and puborectalis muscles play an intermediary role. The ring system consists of the various parts of the sphincter ani externus muscle.

It appears from this study that the puborectalis is the key continence muscle, as on contraction its sling pulls forward where it is anchored to the pubic bone and simultaneously narrows circularly because it is also an integral part of the external sphincter. Possibly, its components are unable to contract individually and will react with mass contraction upon a physiologic stimulus. The predominance of the puborectalis as an adaptation of both the levator ani and the pubococcygeus in this magnitude is only found in primates walking upright.2

The technique presented is now being applied to older fetal stages through to birth, as well as during postnatal stages. Comparative studies in animals and animations of isolated muscles are also planned to show comparative functional capacities. The animation technology allows us to animate every single muscle and to show its function in isolation and in combination with other muscles. Such studies may lead eventually to an improvement of surgical techniques.

REFERENCES