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# Clinical Anatomy of the Pelvic Floor

With 42 Figures and 1 Table

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Our work is dedicated to our friends Andres and Harald who lived and worked with us and who died too early.

# Contents

# Abbreviations

| | |
|---|---|
| ac | Anal canal |
| b | Bladder |
| bp | Bulbus penis |
| cu | Cervix uteri |
| dtm | Deep transverse perineal muscle |
| eas | External anal sphincter |
| if | Ischioanal fossa |
| ilc | Iliococcygeal muscle |
| isc | Ischiococcygeal muscle |
| is | Internal sphincter |
| lam | Levator ani muscle |
| lm | Longitudinal muscular layer |
| md | Müllerian duct |
| nvp | Nerve vessel plate |
| oi | Obturator internus muscle |
| p | Prostate |
| pbo | Pubic bone |
| pc | Pubococcygeal muscle |
| pr | Puborectalis muscle |
| r | Rectum |
| rup | Recto-uterine pouch |
| rvp | Recto-vesical pouch |
| u | Urethra |
| v | Vagina |
| vup | Vesico-uterine pouch |

# 1 Introduction

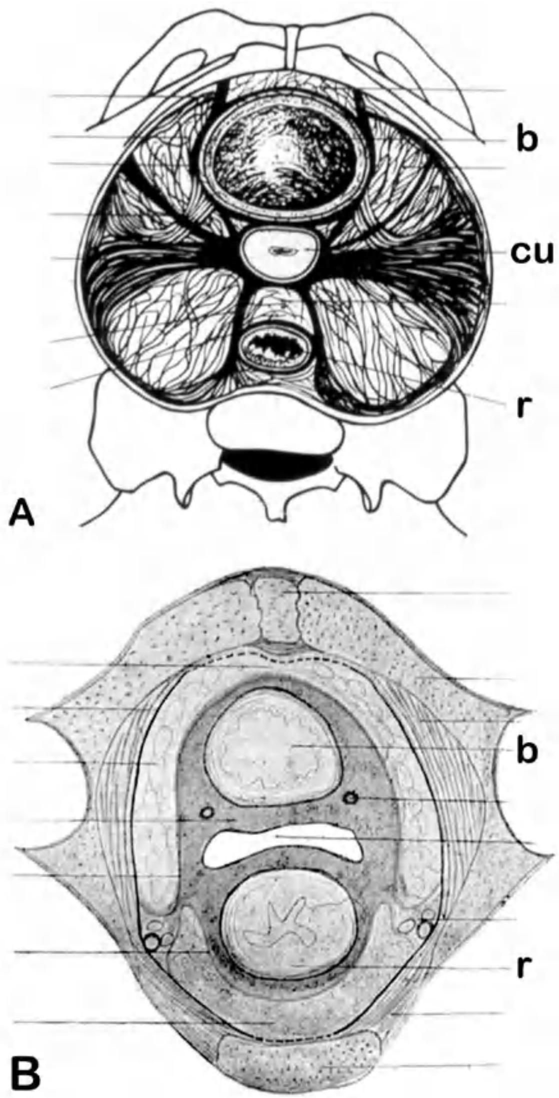
The pelvic floor constitutes the caudal border of the human's visceral cavity. It is characterized by a complex morphology because different functional systems join here. Since a clear understanding of the pelvic floor region is crucial for both male and female pelvic surgery and for fundamental mechanisms of urogenital dysfunction and treatment, we have focused on a morphological concept of this region that is in accordance with actual clinical concepts.

The tissues comprising the pelvic floor region are striated muscles closely correlated to the smooth muscular layers of the pelvic organs as well as different kinds of connective tissue. The anatomy and physiology of all components of the pelvic floor are currently of clinical interest: Uterine or genital prolapse as well as sphincter defects, e.g. caused by damages during vaginal delivery, may be the reason for urinary or fecal incontinence in elderly female (Sultan et al. 1993). A keen knowledge of the morphological relationships of the prostate region is essential to prevent impotence and urinary incontinence, which frequently follow radical prostatectomy in the male (Herschhorn 1999). Due to the amount of important structures within the narrow cavity of the lesser pelvis, it is extremely difficult for all the pelvic surgeons to perform minimal invasive techniques. Nevertheless, in the near future these techniques have to be established quite similar to any other region.

Modern imaging techniques are used for the diagnosis of pelvic floor or sphincter disorders. Furthermore, they are employed to determine the extent of pelvic diseases and the staging of pelvic tumors. In order to be able to recognize the structures seen on ultrasound, CT, and MRI as well as on dynamic sonography and MRI, a detailed knowledge of the relationship of the anatomical entities within the pelvic floor region is required.

Most morphological descriptions of the pelvic floor region have been derived from dissectional or operative studies in the adult (DeLancey 1994; Gasparri and Brizzi 1961; Hafferl 1969; von Hayek 1969; Pernkopf 1941; Richter and Frick 1985). The results of these studies mainly emphasize the common idea of supportive connective tissue structures for each pelvic organ, of a common visceral or "endopelvic" fascia and of markable sexual differences relating the subdivision into connective tissue compartments (Fig. 1A, B). These studies do not provide any evidence for the developmental differentiation of the pelvic connective tissue nor of the pelvic floor muscles. As we suppose that the knowledge of the development of all these structures is necessary for the understanding of the subdivision of the adult pelvic floor region, we studied both human fetal and adult specimens. By means of this study we are able to test the following hypotheses: (1) In general the subdivision of male and female pelvic connective tissue is identical, (2) an endopelvic visceral fascia does not exist,

Fig. 1A, B Schematic drawings of the pelvic connective tissue, its subdivision, and compartments. **A** Ligaments and compartments in the female pelvis according to Tandler (1923). **B** Ligaments and compartments in the male pelvis according to Waldeyer (1899). (For definitions of abbreviations used in the legends, see list of abbreviations on page IX)




(3) striated muscles are supportive structures of the pelvic floor, and (4) sexual differences are found in the morphology of these muscles.

The *Terminologia Anatomica* (1998) contains a mixture of old and new terms describing the different structures of the pelvic floor. Throughout our review we will try to use actual anatomical terms as far as possible, we will compare them with clinical terms and, most importantly, we will define them exactly (see Table 1).

# 2 Morphological Approaches for a Spatial Insight into the Anatomy of the Pelvic Floor

In order to compare the results of our morphological studies with the planes of modern imaging techniques, both fetal and adult specimens were studied in undisturbed transparent sections of the entire pelvis. To gain the spatial insight into the pelvic floor anatomy that is most important for the operating surgeon, we produced computer-assisted three-dimensional reconstructions of our sections and thus accomplished dissectional impressions.

## 2.1 Macroscopic Dissections

Lateral dissection of the pelvis according to a protocol derived from Pernkopf (1941) was carried out in the pelves of two fetuses (23-week-old female and 25-week-old male) and two newborn children. The preparations were used to demonstrate the position of the inferior hypogastric plexus, the fat pad within the anterior compartment, as well as the so-called puboprostatic or pubovesical ligaments. The external anal sphincter and the levator ani muscle were carefully dissected in four embalmed specimens of adult pelves from outside.

## 2.2 Sections of Fetal Pelves

Pelvic floor anatomy was studied in seven newborn children and 79 fetuses, which were all obtained following legal abortion or miscarriage, and which showed no signs of maceration or macroscopic abnormality. The fetuses and newborn children had been fixed by immersion and stored in a 4% formaldehyde solution for at least 3 months. The crown-rump length (CRL) of the fetuses ranged between 34 and 351 mm, corresponding to a gestational age of 9–37 weeks after conception (Patten 1968).

The fetal pelves and the pelves of the newborn children were subjected to plastination histology (Fritsch 1988), and had therefore been impregnated with the epoxy resin BIODUR E 12 (Heidelberg, Germany). The embedded blocks were serially sectioned with a diamond-wire saw (Well, Mannheim, Germany) either in the transverse, coronal (= frontal) or sagittal plane. The thickness of these sections ranged from 300–700 $\mu$m.

After mounting and polishing, the sections were stained with azure II/methylene blue and counterstained with basic fuchsin (Fritsch 1989). The stained sections were examined and photographed with a macroscope (Wild/Leica, Stuttgart, Germany) at magnifications of ×4–80.

## 2.3
## Sections of Adult Pelves

The sectional anatomy of the adult pelves was studied in 11 (6 female and 5 male) specimens from persons who were 58–81 years old. The pelves were frozen at −80°C and then serially cut into sections in the transverse, sagittal, or coronal plane with a bandsaw; the thickness of the sheets ranged between 3–5 mm. The sawdust was carefully removed from the sheets, which were then dehydrated with acetone at −25°C for 5 weeks, defatted in methylene chloride at room temperature for 2 weeks, and then impregnated with an epoxy resin mixture (von Hagens et al. 1987). Finally, the sheets were put into a chamber composed of glass plates, filled with epoxy resin, and cured at 50°C.

## 2.4
## Three-Dimensional Reconstructions

Specimens subjected to plastination histology were scanned directly at a resolution of 1,200 dpi at 256 colors (HP ScanJet 5100 with transparency device; Hewlett Packard). The images were stored in an uncompressed TIFF-format. For further processing in Paint Shop Pro 5.03 (Jasc Software Inc.), the images were stacked and aligned manually using different layers in one file. After trimming of the whole layered image, each layer was saved to a separate file again. Each individual file was processed by isolating and coloring the structures, the spatial arrangement of which are to be shown. For color calibration, a common color table was used. These files were then imported to Spyglass Slicer 1.0 (Spyglass, USA). This program was used to create three-dimensional reconstruction, where the covering (hiding) structures were set nearly transparent (alpha 0.10), others semi-transparent (alpha 0.50) and decisive structures opaque.

## 2.5
## Magnetic Resonance Imaging

In order to obtain morphological and functional images of the pelvic floor, 52 healthy volunteers (44 female, 8 male; mean age 26.9 years; range of age 20–51 years) were examined using Magnetic Resonance Imaging (MRI).

Functional cine MRI of the pelvic floor was performed on two 1.5-T superconductive magnet units (Magnetom Vision, Magnetom Sonata; Siemens Corp., Erlangen, Germany) according to a previously published protocol (Lienemann et al. 1997).

The examination was performed with the patient lying head first, supine, with slightly opened legs. We used a body-array-surface coil. Run-out was prevented with absorbent tissues. No premedication was utilized.

Pulse sequences for the acquisition of morphological images included T2-weighted turbo spin-echo sequences [TR 3500–3800 ms, TE 99 ms, matrix 308×512, two acquisitions, FOV (field of view) 370–250 mm] of the pelvis in axial, coronal, and sagittal orientation. With the exception of the sagittal orientation (3 mm), the slice thickness was 5 mm. In six individuals axial images of the anal sphincter complex were acquired with a slice thickness of 1 mm.

For the functional part, the bladder was emptied prior to the examination. Opacification of the vagina was achieved by using sonography gel. The rectum was filled with approximately 200 ml sonography gel until the patient expressed an urge to relieve the bowels.

For the functional examination, the urethral complex as seen on the axial image was used as a reference point for the sagittal single-slice True-FISP sequence (TR 5.8 ms, TE 2.5 ms, flip angle 70°, matrix 197×256, FOV field view 270 mm, a total of 30 measurements with one image every 1.2 s, in-plane resolution 1.02 mm). In addition, the protocol included an axial single slice True FISP-sequence at the level of the inferior rim with the pubic bone.

During the examination the volunteers were asked to relax the pelvic floor muscles, contract them slowly, and then relax again. Then the patient was asked to increase the intra-abdominal pressure by straining. Defecation was attempted in all cases. This cycle was repeated twice to a maximum of four times.

The functional imaging sequences were evaluated in a cine loop. The overall time of examination varied between 20 and 30 min.

# 3 Subdivision

The anatomy of both the male and female pelvis and perineum shows a lack of conceptual clarity. These regions are best understood when they are clearly described and subdivided according to functional and clinical requirements: The actual clinical subdivision discerns an *anterior*, a *middle*, and a *posterior* compartment. Whereas an anterior and posterior compartment may be found in the male as well as in the female, a middle compartment can only be found in the latter. The term "compartment" is routinely used by radiologists and all surgeons operating on the pelvic floor. This term is not identical with the term "space." According to former literature, a lot of spaces are supposed to be arranged in the region of the pelvic floor: retrorectal, pararectal, rectoprostatic, rectovaginal, retropubic, paravesical, etc. (Lierse 1984; Pernkopf 1941; Waldeyer 1899). From the point of view of the surgeon, "spaces" are empty (Richter and Frick 1985). They are only filled with loose connective tissue and neither contain large vessels nor nerves. Some years ago, we proposed to drop the term "space" and to speak of compartments instead, taking into account that a compartment may be filled by different tissue components (Fritsch 1994).

In this review, we first present the posterior compartment and then the anterior one. This is in accordance with the viewpoint of the radiologists and with the course of the vessels and nerves. An "extra" middle compartment that is characteristic for the female is presented in detail at the end of this review.

What is our common knowledge about the borders of the different pelvic compartments and what do we know about their content?

## 3.1 Posterior Compartment

The borders of the posterior compartment are the skeletal elements of the sacrum and the coccyx dorsally. They are completed by the anococcygeal body (see Table 1/1.) dorsocaudally and by the components of the levator ani muscle laterally and caudally. The rectoprostatic or rectovaginal fascia constitutes an incomplete border ventrocranially. The ventrocaudal border is composed by the perineal body (see Table 1/2.). The only organ of the posterior compartment is the anorectum (see Table 1/4.).

## 3.2
## Anterior Compartment

The borders of the anterior compartment are the pubic symphysis ventrally, the components of the levator ani muscle laterally, and the perineal membrane (see Table 1/3.) caudally. In the female, a distinct border between the anterior and middle compartment cannot be found dorsally. In the male, however, the border between the anterior and posterior compartments is composed of the rectoprostatic fascia. The contents of the anterior compartment are different in the male and in the female. Whereas bladder, prostate with urethra, seminal glands, and the pelvic parts of the ductus deferens are situated in the male's anterior compartment, it only contains bladder and urethra in the female.

## 3.3
## Middle Compartment

The borders are the components of the levator ani muscle laterally and the perineal body caudally. No distinct borders can be described ventrally, whereas the rectovaginal fascia constitutes the dorsal border. The middle compartment contains the female genital organs that are arranged in a more or less coronal plane. In more detail, the ovaries, the uterine tubes, the uterus, and the vagina are situated in this compartment.

## 3.4
## Perineal Body

The perineal body is part of the perineum. It is situated between the genital organs and the anus and may be considered as a central or meeting point because a number of different structures join here.

# 4 Compartments

## 4.1
## Posterior Compartment

### 4.1.1
### Connective Tissue Structures

In macroscopic dissection of embalmed cadavers it is nearly impossible to distinguish subcompartments within the connective tissue of the posterior compartment. Our comparative study of adult and fetal pelves shows that two subcompartments can be distinguished within the posterior compartment:

A small presacral subcompartment (see Table 1/5.) is situated in front of the sacrum and coccyx. It is bordered by the caudal segments of the vertebral column dorsally and ventrolaterally; it is clearly demarcated by the pelvic parietal fascia (Fig. 2A–D), which is called presacral fascia (see Table 1/6.) at this position. In fetuses, the presacral compartment contains loose connective tissue that is replaced by adipose tissue in the adult. The subcompartment is predominated by large presacral veins.

The major part of the posterior pelvic compartment is filled by the anorectum and its accompanying tissues, constituting the perirectal "sub"compartment (see Table 1/7.). As we have shown (Fritsch 1990), this perirectal tissue is identical with the rectal adventitial tissue, which develops along the superior rectal vessels. In the adult, it mainly consists of adipose tissue subdivided by several connective tissue septa (Fig. 3A). Within this perirectal tissue the supplying structures of the rectum are enclosed: the superior rectal vessels, stems and branches, the branches of the variable medial rectal vessels, rectal nerves and rectal lymphatics, vessels, and nerves. The localization of these lymphatic nodes is strikingly different from that of the other lymph nodes of the posterior compartment that are situated laterally in the neighborhood of the iliac vessels (Nobis 1988; Stelzner 1998).

The rectal adventitia develops from a layer of condensed mesenchymal tissue, which—later on—forms a dense connective tissue in fetuses (Fig. 3B, C). In the newborn child it is remodeled by small fat lobules occurring between the connective tissue lamellae. The outer lamella covers the perirectal subcompartment and is called "rectal fascia" (Fritsch 1990) or "Grenzlamelle" (Stelzner 1989, 1998) (see Table 1/8.). It constitutes the morphological border of the perirectal subcompartment (Fig. 3D). The craniocaudal extent of the perirectal subcompartment depends on the branching pattern of the superior rectal vessels; thus, the perirectal compartment is broad laterally and dorsally and it is rather thin ventrally where it is only composed of some

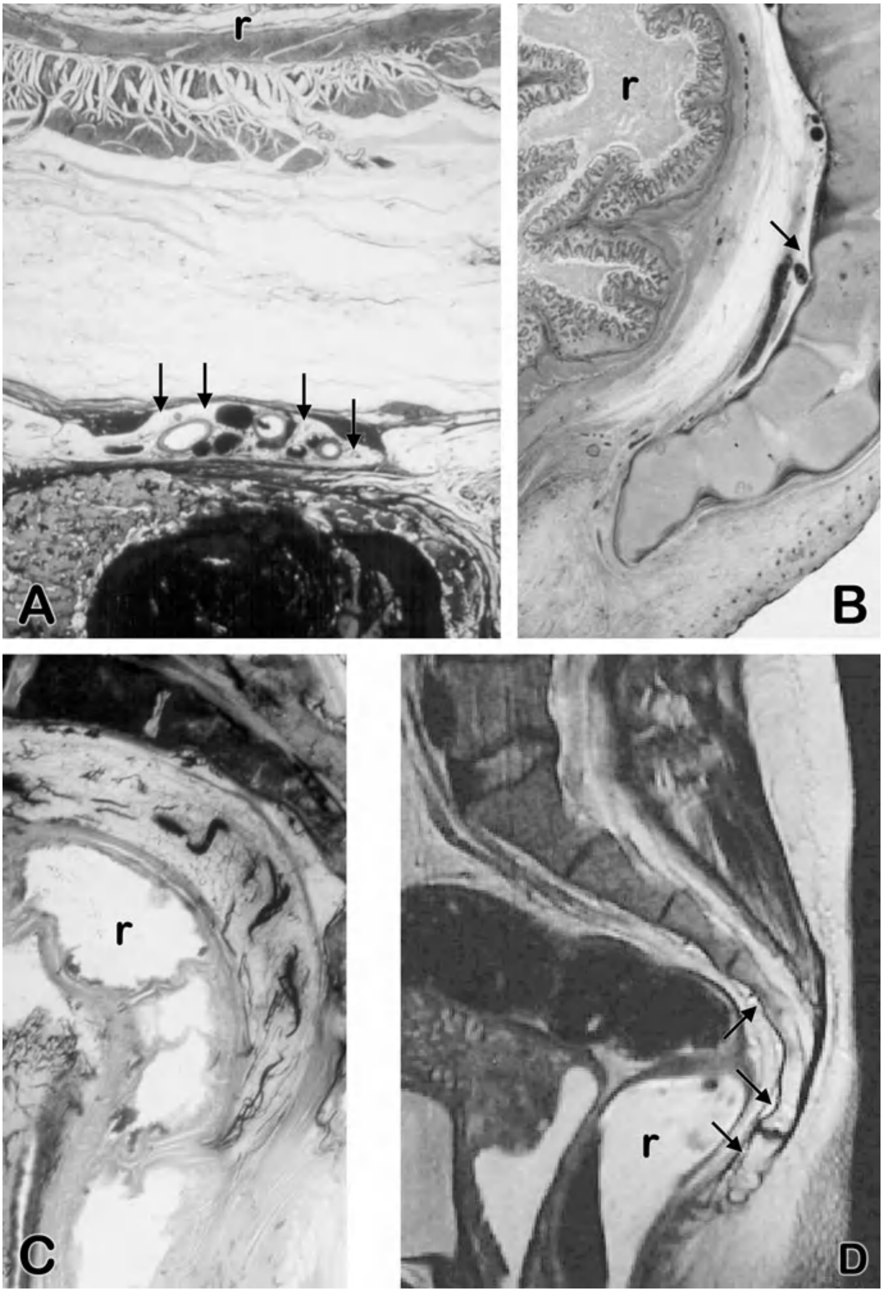



**Fig. 2A–D** Presacral space (*arrows*). **A** Axial section (500 $\mu$m) of an adult male. ×4. **B** Sagittal section (400 $\mu$m) of a 24-week-old female fetus. ×9. **C** Sagittal section (5 mm) of an adult female. ×0.45. **D** Mid-sagittal MR image of an adult female

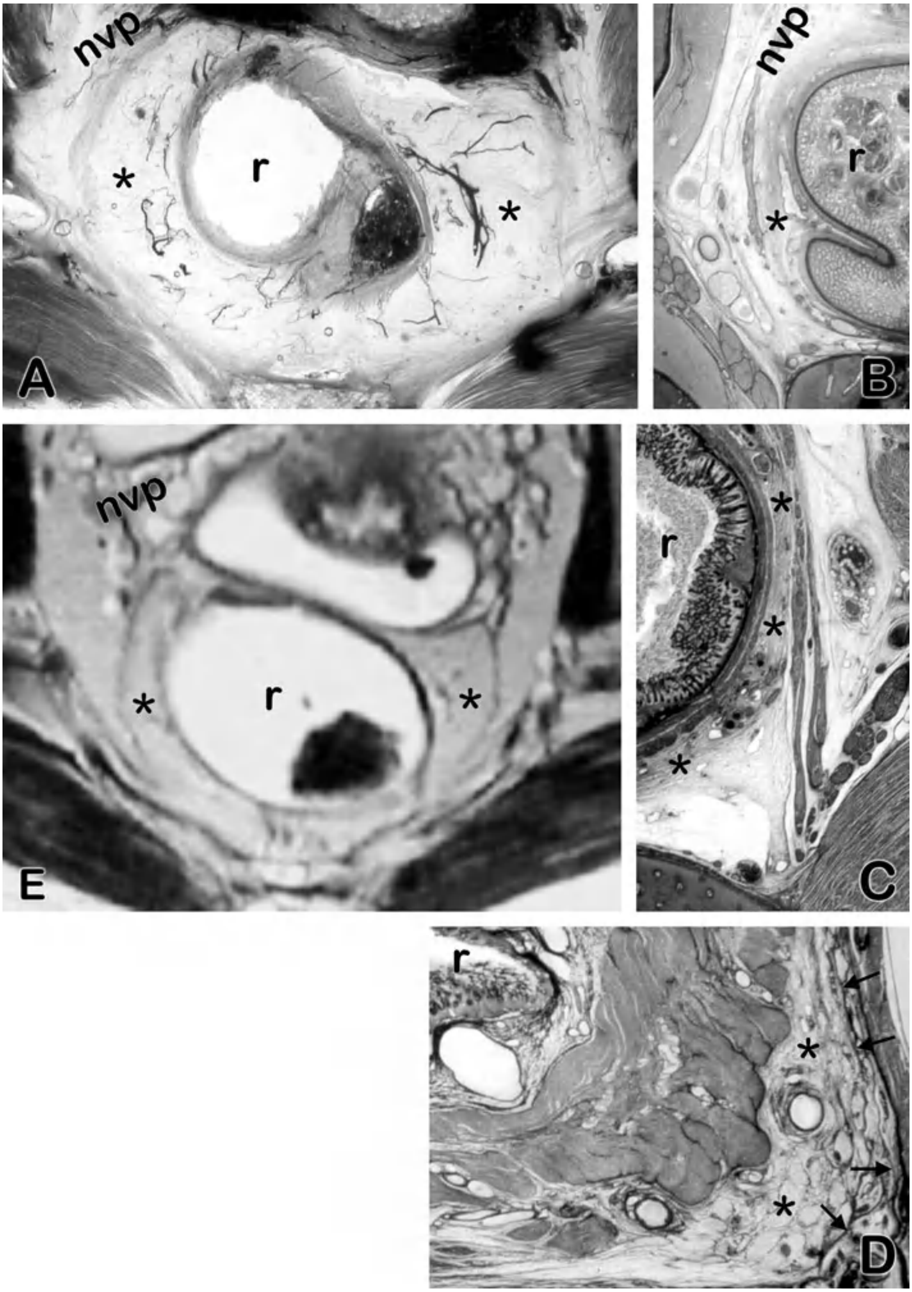



**Fig. 3A–E** Perirectal tissue (*asterisks*). **A** Axial section (5 mm) of an adult female. ×0.45. **B** Axial section (500 $\mu$m) of a 24-week-old male fetus. ×5. **C** Axial section (400 $\mu$m) of a 24-week old female fetus. ×5. **D** Axial section (400 $\mu$m) of a newborn male specimen. The *arrows* point to the rectal fascia. ×10. **E** Axial MR image of an adult female connective tissue lamellae. As can be seen in sagittal sections, the extent of the perirectal subcompartment decreases in size in a craniocaudal direction (Fig. 2C).

What is situated outside the rectal fascia and therefore outside the perirectal subcompartment? Dorsally, the presacral subcompartment is loosely attached to the perirectal compartment (see Sect. 1). Laterally, the supplying structures (autonomic nerves and branches of the iliac vessels) of the urogenital organs constitute a nerve—vessel plate (Fig. 3B,C). The latter is accompanied by connective tissue and fills the remaining space between the perirectal compartment and the lateral pelvic wall. In the male, the nerves of the inferior hypogastric plexus (see Table 1/9.) are directly attached to the rectal fascia laterally (Fritsch 1989), whereas in the female the uterosacral ligament (see Table 1/10.) is situated between the rectal fascia and the inferior hypogastric plexus (Fig. 3A, E; Fritsch 1992).

Ventrally, the border of the perirectal compartment differs in a craniocaudal direction. In the male, the perirectal subcompartment borders on the anterior compartment, i.e., on the peritoneum of the rectovesical pouch and on the rectovesical fascia covering the seminal glands, and on the prostate. There is only a small distance between the ventral rectal wall and the seminal glands or the prostate. It is commonly accepted that a rectoprostatic fascia or fascia of Denonvilliers (see Table 1/11.) (Denonvilliers 1836, 1837 according to citation in Wesson 1922) is situated between the organs of the posterior compartment and of the anterior one (Fig. 4A). The fascia develops locally by differentiation of mesenchyme and is composed of collagenous fibers and smooth muscle bundles in the adult. Thus, the rectoprostatic fascia represents a kind of circumscribed septum between rectum and prostate that incompletely separates the two compartments (Fig. 4B, C). Laterally, the septum is neighbored to the inferior hypogastric plexus, but it does not have any connections to the lateral pelvic wall. A rectoprostatic fascia can already be found in middle-aged fetuses where several thin connective tissue lamellae can be discerned within the fascia: One part of them belongs to the prostate, the other to the rectal adventitia where smooth muscle bundles and nerves are intermingled. In adult specimens these lamellae seem to have fused and thus it is quite difficult for the surgeon to find a plane of cleavage (Stelzner 1998) between them.

In the female the perirectal subcompartment borders on the middle compartment, i.e., on the peritoneum of the recto-uterine pouch level with the cervix uteri and the fornix vaginae and on the posterior wall of the vagina more caudally. As we have recently shown (Ludwikowski et al. 2002) a two-layered rectovaginal fascia (see Table 1/12.) develops in the female and is identical to the male's rectoprostatic fascia (Tobin and Benjamin 1953). Level with the anorectal flexure, additional bundles of longitudinal smooth muscles are situated at the anterior rectal wall and directly borders on the rectovaginal fascia ventrally (Fig. 4D). The smooth muscle bundles are accompanied by nerves, some of them crossing the midline. They are found in the male as well as in the female (Fig. 4A, D), they are connected to the smooth muscle layer of the rectal wall. Caudally these additional smooth muscle bundles are attached to the connective tissue of the perineal body (Fig. 4E).

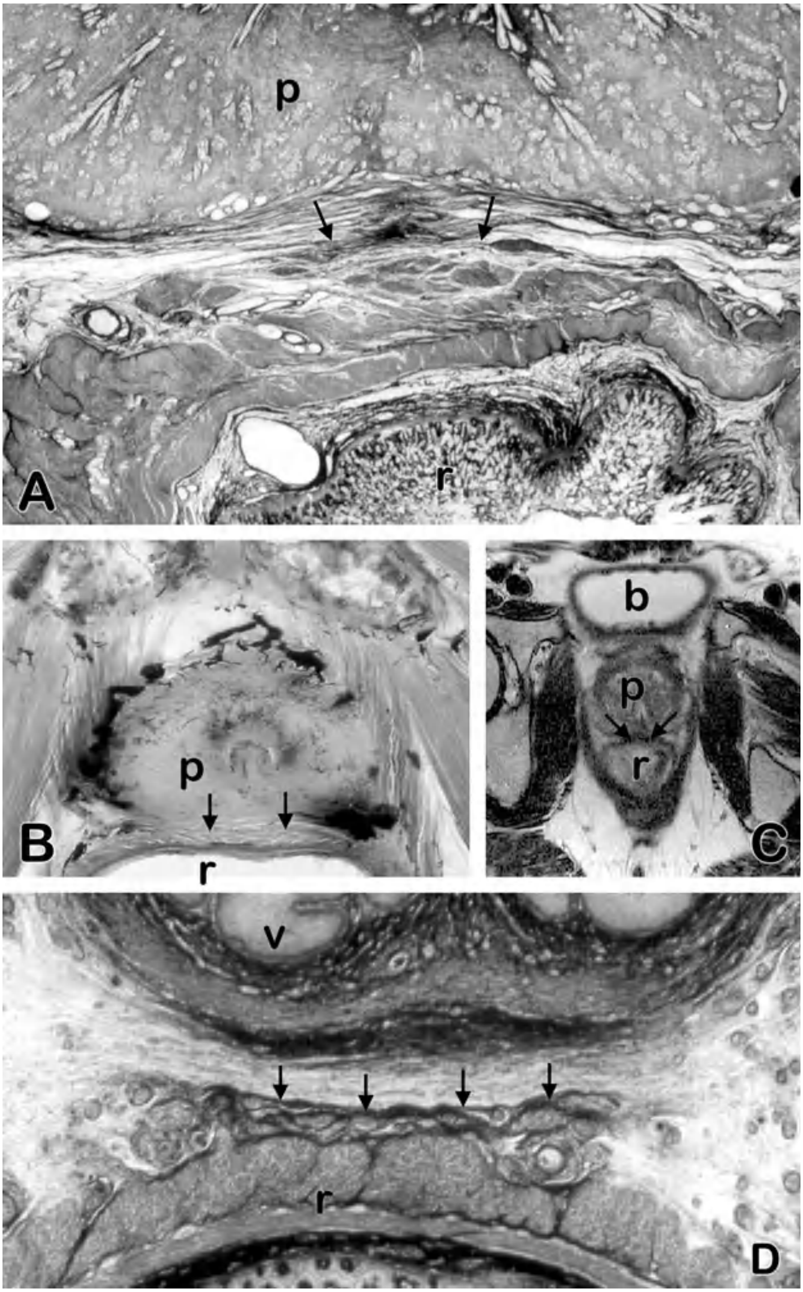



**Fig. 4A–D** Rectoprostatic (**A–C**) and rectovaginal (**D**) fascia (*arrows*). **A** Axial section (400 $\mu$m) of an adult male. ×10. **B** Axial section (3 mm) of an adult male. ×1.1. **C** Axial MR image of an adult male. **D** Axial section (400 $\mu$m) of a 24-week-old female fetus. ×28

### 4.1.2 Muscles

Within the posterior pelvic compartment all components of the levator ani muscle are to be found: The pubococcygeus muscles and the iliococcygeus muscles constitute an irregular plate and insert into the coccyx, where they overlap each other in a staggered arrangement (Fig. 5A–C). The inferior component, the puborectalis muscles, do not insert into any skeletal structure. Behind the rectal wall the fiber bundles of each puborectalis muscle criss-cross, thus constituting a muscular sling around the anorectal flexure (Fig. 6A, B). In the craniocaudal direction, the pubococcygeus muscle and the puborectalis muscle are more or less continuous. In sectional anatomy they can be differentiated by the different directions of their fiber bundles, those of the pubococcygeus taking a slightly descending course, those of the puborectalis exclusively situated in the horizontal plane. The different components of the levator ani muscle can already be distinguished in early fetal life (Fritsch and Fröhlich 1994). Sexual differences found in the levator ani muscle of the adult are already marked in late fetal life: The levator ani constitutes a thick and well-developed muscle in the male fetus whereas it is thinner and already intermingled with connective tissue in the female fetus (Fig. 6C, D). This is particularly true for its puborectalis portion.

The puborectalis muscle is continuous with the external anal sphincter caudally (Fig. 7A, B). The macroscopic distinction between both muscles is provided by the anococcygeal body. The puborectalis has no skeletal attachment, but the deep portion of the sphincter ani externus is indirectly fastened to the coccyx by the anococcygeal body.

The sphincter ani externus is the outer part of the anal sphincter complex (see Table 1/13.), the other components of which are the smooth internal sphincter and the longitudinal muscle layer of the anorectum; the latter is interposed between the sphincters. Whereas macroscopically the external anal sphincter presents itself as a continuous sheet covering the anal canal (Fig. 8A), it can be subdivided into a deep, anorectal portion and a superficial, subcutaneous portion in sectional anatomy (Fig. 8B). This deep portion is a clearly demarcated layer of circularly arranged striated muscle fibers; the superficial portion is characterized by an intermingling of the striated muscles fibers with the smooth longitudinal muscle. The form of the external anal sphincter can best be studied in three-dimensional reconstructions of histological or anatomical orthogonal sections (Fritsch et al. 2002): At a level above the perineum where the external anal sphincter is continuous with the puborectalis muscle dorsally (Fig. 8C), it is missing in the midline ventrally, but it is thickened ventrolaterally where it becomes part of the anterior compartment in the male and the middle compartment in the female. At the level of the perineum the external anal sphincter is complete ventrally (Fig. 8D), but it turns inwards and forms a muscular continuum with the smooth internal sphincter and the longitudinal muscle dorsally (Fig. 8E). As can be seen from the fetal sections, sexual differences in the anal sphincter complex are already present prenatally: The sphincter complex as a whole is thicker in the male than in the female, the anterior portion is thick in the female and thinner and more elongated in the male.

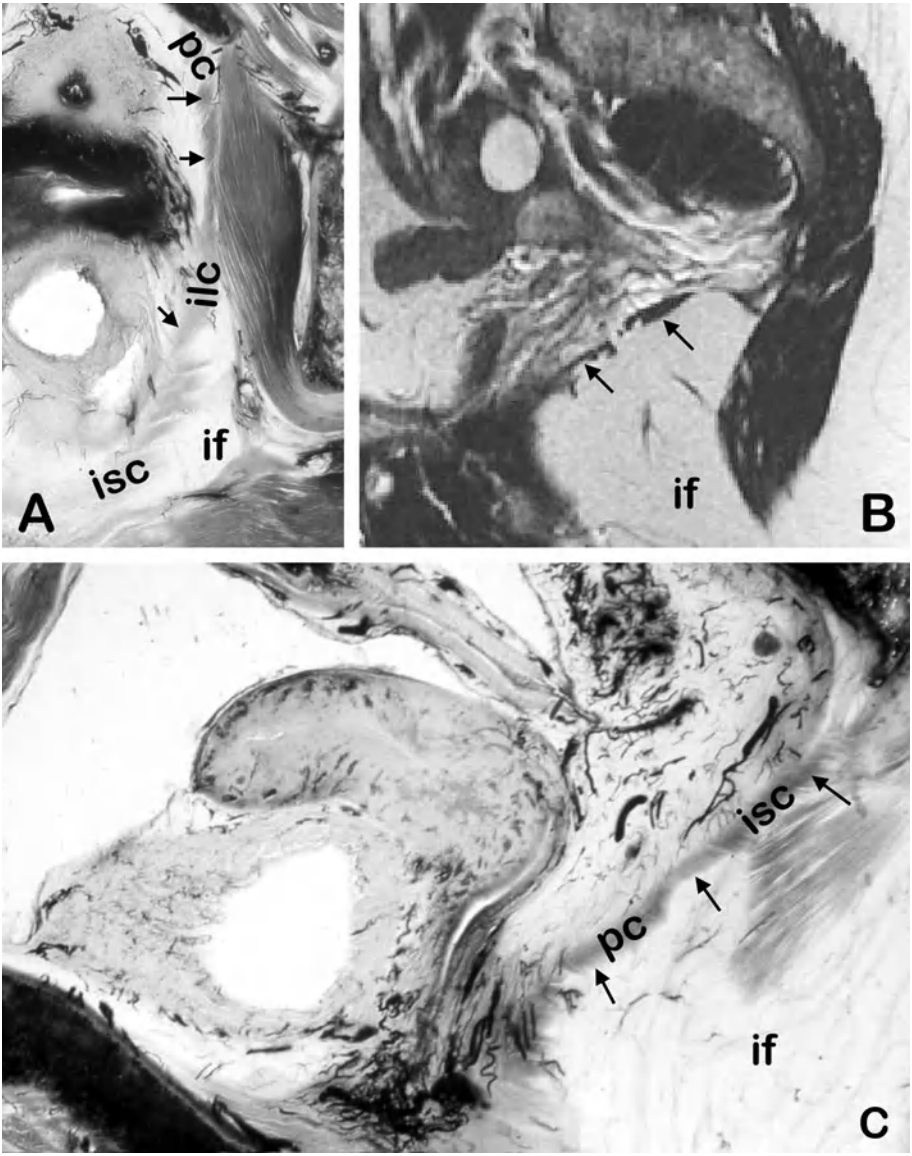



**Fig. 5A–C** Levator ani muscle (*arrows*). **A** Axial section (5 mm) of an adult female. ×0.6. **B** Parasagittal MR image of an adult female. **C** Sagittal section (5 mm) of an adult female. ×1.0. *ilc*, Iliococcygeal muscle; *isc*, ischiococcygeal muscle; *pc*, ubococcygeal muscle; *if*, ischioanal fossa

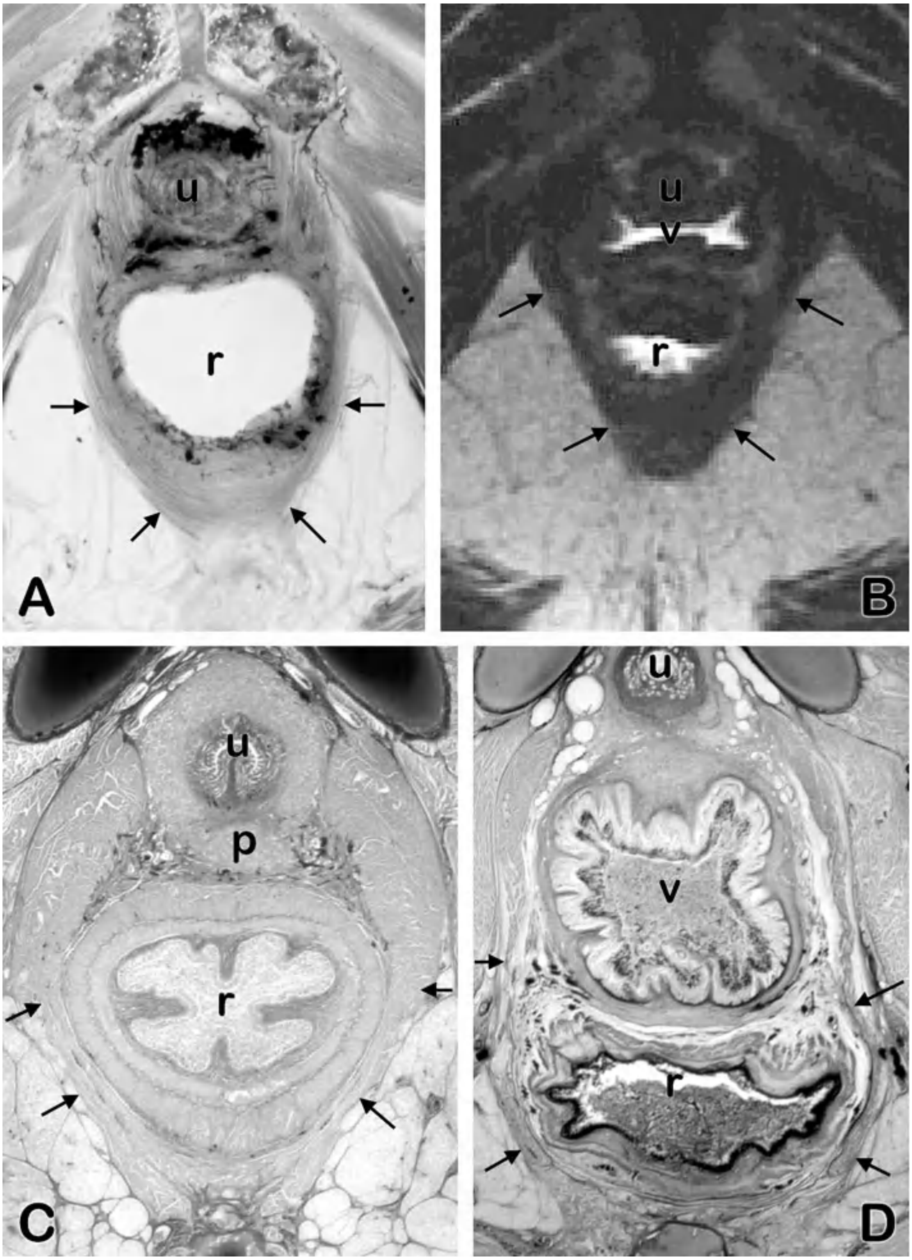
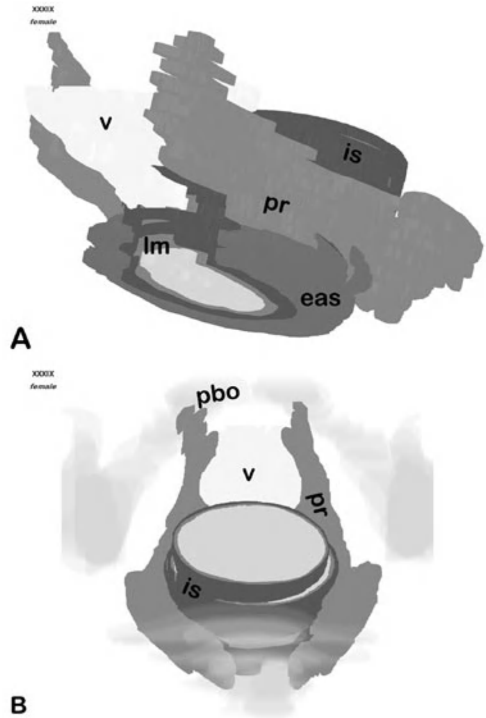



**Fig. 6A–D** Puborectalis muscle (*arrows*). **A** Axial section (3 mm) of an adult male. ×0.8. **B** Axial MR image of an adult female. **C** Axial section (400 $\mu$m) of a male newborn specimen. ×5. **D** Axial section (400 $\mu$m) of a female newborn specimen. ×4

Fig. 7A, B Computer-assisted reconstructions of a female fetus. A Oblique ventrolateral view. B Descending dorsoventral view




## 4.1.3 Reinterpreted Anatomy, Function and Fundamentals in Neuroanatomy

The posterior compartment is predominated by the rectum and its surrounding connective tissue. The morphological demarcation of this compartment is formed by the rectal fascia. In CT the rectal fascia may be discriminated as a slightly hyperdense sheath (Grabbe et al. 1982; Roediger and Tucker 1986) and in MRI it is visible as a thin, hypointense structure. According to our results the macroscopic borders of the perirectal compartment are clearly demarcated only in the adult female, where the sacrouterine ligaments constitute the lateral borders and where the posterior border is marked by the pelvic parietal fascia. The perirectal adipose tissue constitutes functional fat that adapts to the different filling volumes of the rectum and constitutes a gliding sheath for the movements of that organ. In contrast to prior literature (Richter 1998; Pernkopf 1941) we did not find any ligament or even ligamentous structures bounding the rectum to the lateral pelvic wall. Thus, there is neither a "rectal stalk" nor a dense "paraproctium."

From a morphological point of view, the surrounding tissue of the rectum has to be called rectal adventitia and not mesorectum (Heald 1995). Under the assumption that a "meso" is a duplication of the peritoneum, the term "mesorectum" is falsely used by the surgeons, because a "meso" cannot be found in the neighborhood of the mostly extraperitonally situated rectum in the adult.

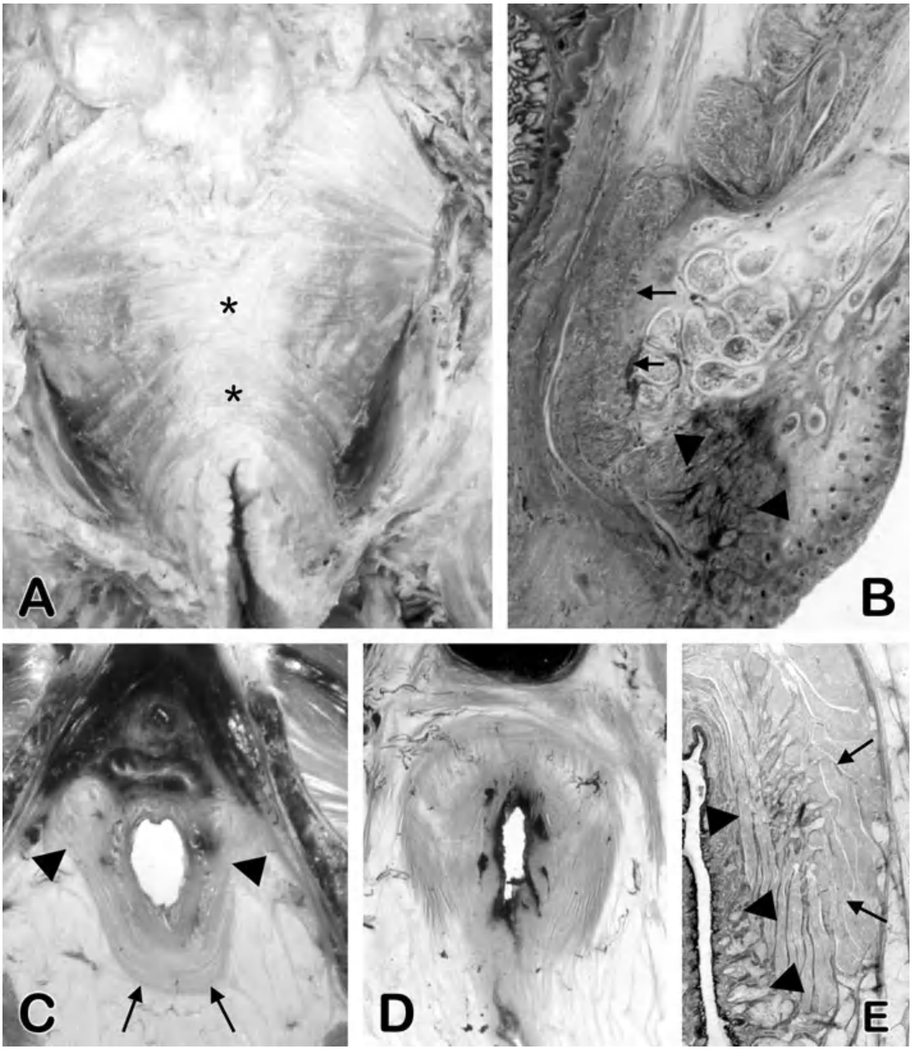



**Fig. 8A–E** Anal sphincter complex. **A** Macroscopic preparation of an adult female with anococcygeal body (*asterisks*). **B** Sagittal section (500 $\mu$m) of a 20-week-old female fetus with deep (*arrows*) and superficial (*arrowheads*) portion. ×10. **C** Axial section (5 mm) of an adult female, fusion of the external sphincter (*arrow*) and the puborectalis (*arrowhead*). ×0.6. **D** Axial section (3 mm) of an adult male, with the ventrally circular portion at the perineum. ×1.1. **E** Axial section (400 $\mu$m) of a male newborn specimen with the muscular continuum of external (*arrows*) and internal sphincter (*arrowheads*). ×130

It is obvious from former studies that there are similarities as to the source of innervation between fecal and urinary continence system. The external anal sphincter is innervated by the pudendal nerve and the puborectalis muscle is innervated by both the pudendal nerve and by branches of the sacral plexus (Roberts et al. 1988). According to Schroeder (1981), the nucleus, which is present in the ventral horn of the segments S2 -and S3 and called Onuf's nucleus (see Table 1/14.) (Onufrowicz 1901), is a good candidate as a source for the innervation of the striated anal and urethral sphincters in man. Both the internal anal sphincter and the longitudinal muscle layer are innervated by the autonomic nervous system. In contrast to the well-examined innervation of the smooth muscle system of the urinary tract, little is known about this part of the anal sphincter complex. Efferent fibers of the sympathetic division (Th6–L2) and efferent fibers of the parasympathetic division (S2–S4) are involved and approach the anorectum via inferior hypogastric plexus. Yamamoto et al. (1978) have found groups of neurons within Onuf's nucleus in animals that are responsible for the innervation of the smooth muscle sphincter. They have shown that it is difficult to distinguish those parts of Onuf's nucleus responsible for the smooth sphincter from the parts that are responsible for the striated sphincters. In contrast to the detailed knowledge of the extrinsic and intrinsic innervation of the colon (Wedel et al. 1999), little is known about the interaction of extrinsic and intrinsic innervation of the anorectum, especially on the initial process responsible for defecation and refilling. We suppose that the additional smooth muscle bundles and their nerves that are situated at the anterior rectal wall include receptors for the filling status of the rectum. It would make sense that such structures are situated at the anterior rectal wall because during filling the rectum can easily be widened in a lateral and dorsal direction but not in a ventral direction. As these bundles are connected to the longitudinal muscle layer of the rectal wall, they may be part of a dilatator similar to the puboprostatic or pubovesical ligaments in front of the urethra (see Sect. 4.2.3).

As to the anorectal continence, we have learned to distinguish between the maintenance of continence at rest where type I or slow fibers of the external sphincter are involved and the maintenance of continence during stress conditions where type II or fast fibers of the external anal sphincter are involved (Lierse et al. 1993). The external anal sphincter has capacity for both functions but the distribution differs during the developmental process. According to Beersiek et al. (1979), type I fibers predominate in the external anal sphincter and in the puborectalis of the adult. In newborn infants, type I fibers constitute only 40% of these muscles (unpublished data of J Steinfeld and W Lierse 1990; in: R Schäfer and P Enck 1997). According to our results, the external sphincter, the internal sphincter and the longitudinal muscle bundles form a morphologically intimately connected sphincter complex: Level with the perineum the external sphincter turns in to become continuous with the internal sphincter and both are enclosed by the longitudinal muscle bundles; furthermore, all parts of the sphincter complex are innervated by the pudendal nerve. Thus, our results support the physiological considerations of Schäfer and Enck (1997) who proposed that the type I fibers of the external sphincter intimately cooperate with the internal sphincter muscle.

### 4.1.4
### Surgical and Obstetric Relevance

Anal sphincter-saving operations are obviously preferred to permanent stomas after resections for rectal cancer or mucosal ulcerative colitis. In this context, the clinical relevance of our findings concerning the surrounding tissue of the rectum is enormous (Stelzner 1989, 1998). As we have pointed out regarding the developmental origin of the rectal adventitia and fascia as well as the structures enclosed herein, we have found the explanation for the actual surgical procedure: The rectal fascia is the most important structure during operation of the rectum (Fritsch 1990, 1996; Heald 1995). It is possible for the surgeon to dissect the rectal fascia and thus to peel off the rectum and the surrounding adipose tissue with all lymph nodes and vessels (Stelzner 1998). There are three critical entities neighboring the rectal fascia: Dorsally, there is the presacral compartment with its large veins. A blood-sparing technique is necessary in this region to prevent copious bleeding; it would be better, if possible, not to touch this compartment. Ventrally, level with the rectovaginal or rectoprostatic fascia, it is important for the surgeon to separate the lamellae of this fascia and not to cut the smooth muscle bundles and the nerves of the inferior hypogastric plexus. Laterally, the nerves of the inferior hypogastric plexus and the iliac vessels are directly attached to the rectal fascia. If blood supply and/or innervation is disturbed, patients may have problems with rectal and urinary continence, constipation by stenosis, as well as erection in the male (Burnett and Wesselmann 1999; Heald 1988; Lepor et al. 1985; Long and Bernstein 1959; Maas et al. 1998; Stelzner 1977; Stelzner et al. 1989; Walsh and Schlegel 1988). This is the reason why—if possible—a small part of the ventral rectal wall should be left in cases of rectal excision (Stelzner et al. 1989).

In order to get the best functional results, it is very important for the surgeon to be well informed about the exact anatomy of the anal sphincter complex. Sphincter lesions are described after the use of staplers (Jehle et al. 1995). As this instrument is often used in anorectal operations, it should be pointed out that according to our results both the internal as well as the in-turned external sphincter can be damaged (Fritsch et al. 2002).

The most common reason for fecal incontinence in woman is childbirth with injury to the sphincter. External sphincter injuries occur in 6%–30% of woman (Sultan et al. 1993). It should be differentiated between complete or incomplete sphincter disruptions. Incomplete disruptions can be treated by biofeedback training. The results obtained by this treatment are sufficient. Complete sphincter disruptions are seldom apparent. Undoubtedly they need surgical intervention. Different techniques are used. Sphincteroplasty (suturing the muscular defect) is performed isolated or combined with surgery for urinary continence (Halverson et al. 2001). The same authors propagating this method showed one year later that years after sphincter repair (overlapping anal sphincter repair) more than half of the patients are incontinent to liquid or solid stool (Halverson and Hull 2002). In severe fecal incontinence a new prosthetic device, the Action artificial anal sphincter, was implanted. Continence was improved in 75%, but early infection, rectal erosion, and difficulties evacuating with developing obstructed defecation are major concerns in this operation (Altomare et al. 2001).

Gracilis plasties (a new circular muscle is placed around the anal canal) have been performed for 50 years. Though Pickrell's gracilis muscle transposition often results in building up a scar and never results in normal continence, acceptable continence can be achieved in selected patients (Han et al. 1995).

In order to improve the results, the gracilis plasty it is combined with a neuromuscular stimulator. Continence should be maintained by active muscle contraction and perfectly controllable sphincter function is described in a case report (Baeten et al. 1988). Nevertheless, the literature is unanimous. Cases with good results are always combined with intensive biofeedback. An explanation for this might be the redevelopment of the correct composition of type I and type II fibers and that the plasty is incomplete, because the smooth sphincter muscle is not included.

Despite different etiologies and surgical approaches, anterior levatorplasty and sphincteroplasty yielded similarly successful results in patients with fecal incontinence. Although a marked symptomatic improvement was seen in both groups, no associated physiological alterations could be detected. The reason for the improvement is thus unclear, but it may result from a stenosing effect in the anal canal.

Up to now, in children the artificial rectal sphincter and sphinctero-plasties have not been recommended. In children with anal atresia the so-called posterior anorectoplasty according to Pena (Pena 1997) is recommended. During this operation the distal part of the gut is torn through more or less incomplete sphincter anlagen. In doing so, the author recognized that the external sphincter is not a complete circular muscle. Thus he recommended a strictly midline preparation and an intraoperative electro-stimulation to identify the muscle fibers and to achieve the best functional outcome. Our morphological investigation (Fritsch et al. 2002) supports the fact that the external anal sphincter is not a totally circular muscle. We have thoroughly described the parts of the sphincter complex in order to help the surgeon to identify these structures and if possible, to reconstruct them in a meticulous way.

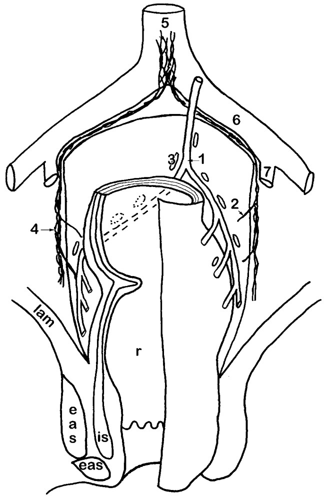
Until now, no plastic operation for rectal sphincter repair can really be recommended. An alternative method is daily enemas, which are performed by rectal enemas or using the Malone antegrade continence enema (Malone et al.1990; Griffiths and Malone 1995).

Rectoceles are hernial protrusions of the anterior rectal wall and the posterior vaginal wall into the vagina and/or throughout the vaginal introitus. It occurs with laxity of the connective tissue in advancing years, multiparity, poor bowel habits, perineal relaxation and increased intra-abdominal pressure in constipation (Khubchandani et al. 1983; Zbar et al. 2003). Rectoceles are usually associated with scarring and shortening of the anterior anal sphincter mechanism, and the perineal body is thinned. This may be the source of constipation, anal pain, and bleeding. The size of the rectocele does not correlate with symptoms and it is often diagnosed in a population without symptoms. Trauma or obstetrical injuries weaken the rectovaginal fascia. Pelvic denervation, secondary to a vaginal approach for hysterectomy, may contribute to formation of rectoceles and paradoxical sphincter contraction with elevated mean resting rectal pressure at rest. The etiology of rectoceles is different and should be clearly defined before treating. Pelvic floor outlet obstructions should be treated before a rectocele repair is done. Associated cystoceles or enteroceles, sphincter defects, should be corrected in the same operation. For this, different approaches are described: transvaginal, transrectal, transperineal, transabdominal, or combinations of these, but all of them result in a change of the rectovaginal fascia. In the successful repair of a rectocele, the rectovaginal fascia and its repair seem to be the key structure (Richardson 1993; Cundiff et al. 1998). The outcome of the operations depends on the surgeon's familiarity with the operation and associated defects and symptoms (Lawler and Fleshman 2002).

### 4.1.5
### Important Vessels, Nerves and Lymphatics

1. Superior rectal artery
2. Rectal nerves
3. Rectal lymph nodes
4. Inferior hypogastric plexus
5. Superior hypogastric plexus
6. Common iliac artery
7. Internal iliac artery

(Veins have a corresponding course)




## 4.2
## Anterior Compartment

### 4.2.1
### Connective Tissue Structures

When dissecting along the lateral and ventral wall in embalmed cadavers, it is easy to isolate the bladder, including the embedding tissues and all the adjacent structures. During dissection, no lateral stalks are found that might be responsible for the fixation of the bladder or the urethra. Ventrally, a cord can be identified. It takes an ascending course from the pubic bone to the neck of the bladder and is thicker in the male, where it is usually called puboprostatic ligament (see Table 1/15.) and thinner in the female, where it is called pubovesical ligament (see Table 1/16.) (Fig. 9A, B). It is connected to the tendinous arch of the pelvic fascia (see Table 1/18.). Together, both structures incompletely subdivide the retropubic region into a prevesical subcompartment and a preurethral subcompartment. From the comparative sectional study of fetal and adult pelves we learned the detailed composition of the connective tissue structures within the anterior compartment:

With the exception of its neck and its posterior wall, the bladder is covered by adipose tissue (Fig. 9C). The latter constitutes a semicircular pad that fills the gap between the lateral pelvic wall and the ventral and lateral wall of the bladder. The fat pad is not subdivided by ligaments or any other dense connective tissue septa, but sometimes may be crossed by variable branches from the obturator vessels. It develops in situ (Fig. 9D) from a large paravisceral fat pad (see Table 1/19.) in human fetuses (Fritsch and Kühnel 1992) and neither contains large vessels, nerves, nor lym-

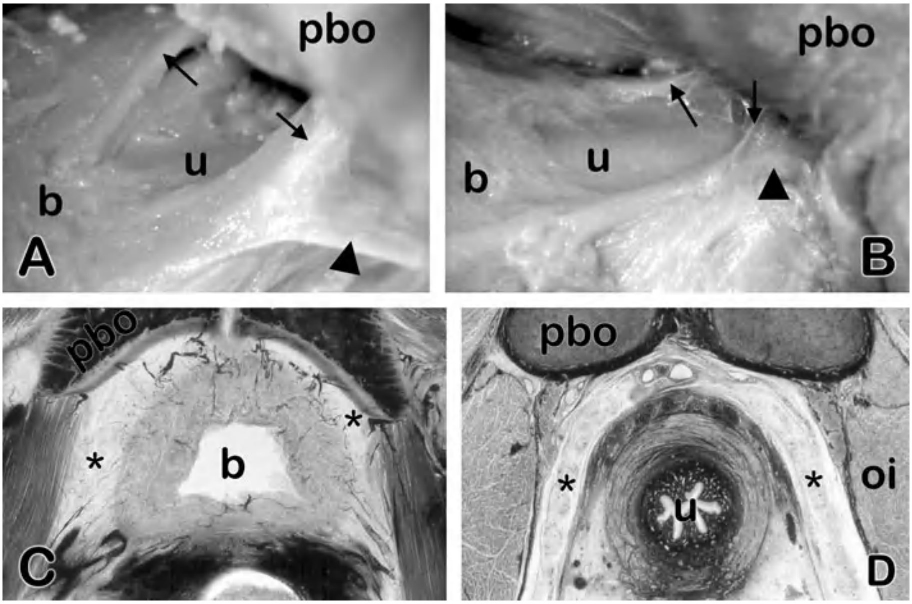



**Fig. 9A–D** Anterior compartment. **A** Macroscopic preparation of a male newborn specimen with the puboprostatic ligament (*arrow*) and the tendinous arch (*arrowhead*). ×6. **B** Macroscopic preparation of a 23-week-old female fetus with the pubovesical ligament (*arrow*) and the tendinous arch (*arrowhead*). ×9. **C** Axial section (5 mm) of an adult female with the paravisceral fat pad (*asterisks*). **D** Axial section (400 $\mu$m) of a 24-week-old female fetus with the developing paravisceral fat pad (*asterisks*). ×8

phatics. The latter derive from the internal iliac vessels and join the dorsolateral edge of the bladder, the seminal glands, and the prostate. Their branches, which are always accompanied by a sheath of dense connective tissue, embrace the bladder, urethra, and prostate. Thus nerves, vessels, and lymphatics are directly situated at the lateral and dorsal wall of the bladder and medially to the fat pad. Ventrocranially, both fat pads join in the midline. Their dorsal edge abuts at the perirectal compartment and their caudal border abuts the levator ani laterally and the pubovesical or puboprostatic ligament ventrally. Thus, they are not part of the preurethral subcompartment that is filled by connective tissue accompanying the deep dorsal vessels of the penis or the clitoris.

Within the anterior compartment two structures are found that are composed of dense connective tissue: the tendinous arch of the pelvic fascia that originates from the pubic bone and that is connected to the pelvic parietal fascia covering the levator ani muscle on its visceral side (superior fascia of the pelvic diaphragm); the semicircular fibrous sheath that covers the ventral and lateral wall of the bladder, the urethra, and the prostate. As the sheath is strong ventrally it can be considered as an incomplete ventral vesical, prostatic or urethral fascia. Whereas the ventral vesical fascia has absolutely no fixation to the lateral pelvic wall, at a level of the urogenital hiatus the ventral urethral fascia, but not the urethra (Ludwikowski et al. 2001), is attached to the fascia of the levator ani muscle laterally (Fig. 10A). Thus, within the

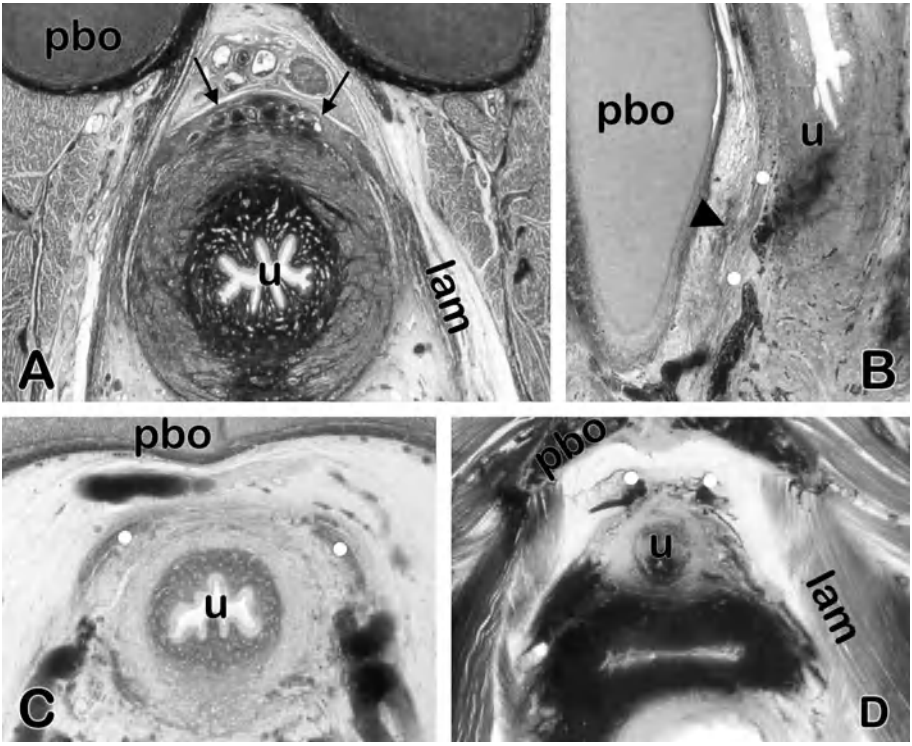



**Fig. 10A–D** Anterior compartment and the so-called ligaments of the urethra. **A** Axial section (400 $\mu$m) of a 24-week-old female fetus with the semicircular urethral sheath (*arrows*). ×12. **B** Sagittal section (500 $\mu$m) of a 13–14-week-old female fetus with the pubovesical ligament (*white spots*) and the origin of the tendinous arch (*arrowhead*). ×25. **C** Axial section (400 $\mu$m) of a 17-week-old female fetus with the pubovesical ligaments (*white dots*). ×12. **D** Axial section (5 mm) of an adult female with the pubovesical ligaments (*white dots*). ×7.5

hiatus a fibrous bridge connects the fasciae of the levator ani muscles of both sides. To summarize: the fibrous structures of the anterior compartment build up a hammock-like (DeLancey 1994) construction for bladder, prostate, and urethra. These findings can most clearly be shown in fetuses and are matching but not so evident in the adult. It is important to know that there is absolutely no kind of a lateral bony fixation for bladder, prostate, or urethra. In a dorsocranial direction, the ventral fascia of bladder, prostate, and urethra is continuous with the connective tissue sheath of the internal iliac vessels. Ventrally, the hammock-like construction is indirectly fixed to the pubic bone by means of the tendinous arch and by the so-called puboprostatic or pubovesical ligament (Fig. 10B–D). The latter is composed of cholinergic innervated smooth muscle cells (Wilson et al. 1983) and is connected to the vesical neck cranially (see Sect. 1).

An additional fibrous structure can be found to close the hiatus ventrally: A plate of dense connective tissue fills the space between pubic bone and urethral sphincter, thus constituting the perineal membrane (Fig. 11A).

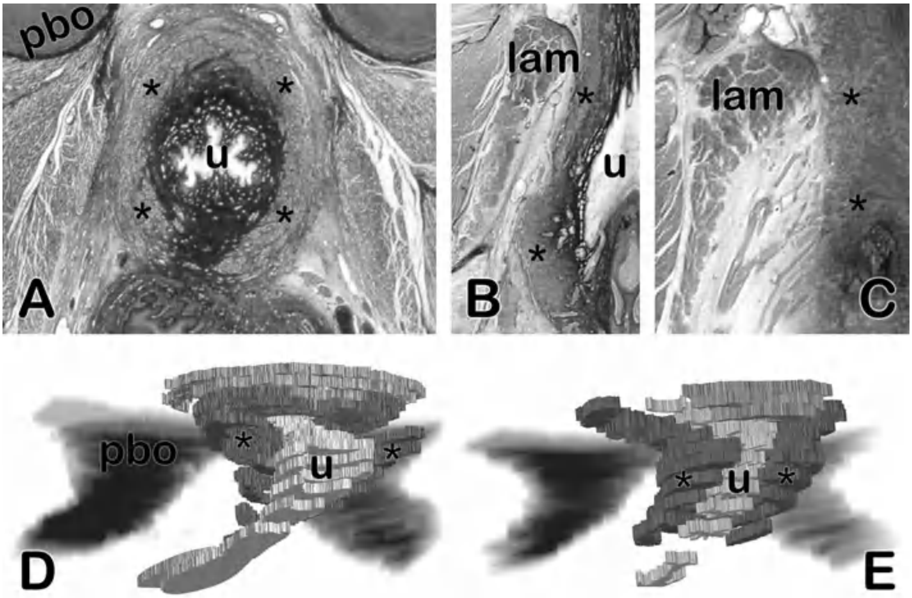



**Fig. 11A–E** External urethral sphincter (*asterisks*). **A** Axial section (400 $\mu$m) of a 24-week-old female fetus, embedded in the transverse perineal membrane. ×9. **B** Axial section (500 $\mu$m) of a 20-week-old male fetus just before leaving the urogenital hiatus. ×22.5. **C** Axial section of the same fetus (*b*) when leaving the urogenital hiatus. ×12. **D** Computer-assisted three-dimensional reconstruction of a male fetus. **E** Computer-assisted three-dimensional reconstruction of a female fetus

The male's cavernous nerves are clinically important structures that are in close contact to the connective tissue structures and the muscles of the anterior compartment. As has already been reported some years ago (Fritsch 1989) there are two pathways for these nerves to leave the pelvic cavity: Some of them run between the fascia of the levator ani muscle and the urethra, whereas others enter into the urethral external sphincter (Fig. 11B).

### 4.2.2
### Muscles

The striated muscles of the anterior compartment are the ventral parts of the levator ani muscle (see Table 1/17.), i.e., the pubococcygeus and puborectalis muscle of each side. As they are covered by the superior fascia of the pelvic diaphragm, they are clearly separated by the adjacent organs (Figs. 10A, D, and 11A, B) and the external urethral sphincter. As has been reported previously (Ludwikowski et al. 2001), this muscle is horseshoe- or omega-shaped during fetal development and incompletely covers urethra or prostate (Fig. 11C, D). The dorsal ends of this muscle are connected by a plate of dense connective tissue that is broad in the male and small in the female, where it is firmly attached to the ventral wall of the vagina (Figs. 10D, 11A). Whereas most of the fibers of the external urethral sphincter run semicircular, the most caudal fibers nearly run in a transverse plane. This portion predominates in the male and therefore has been considered as the male's deep transverse perineal muscle (Oelrich 1980).

As has been described above, smooth muscles are found outside the walls of the urogenital organs constituting parts of the so-called puboprostatic or pubovesical ligament in front of the ventral wall of the urethra.

### 4.2.3
### Reinterpreted Anatomy, Function and Fundamentals in Neuroanatomy

The extent of the fat pad described here is identical with the anterior portion of the paravisceral space as reported by Gasparri and Brizzi (1961). These authors described a large paravisceral compartment along the urogenital organs that is separated by the uterine vessels in the female. It is true that in the female the uterine vessels constitute the border between the anterior and posterior compartment, but nevertheless they separate the paravisceral fat pad and the perirectal subcompartment. The difference between our opinion and that of Gasparri and Brizzi (1961), though obviously slight, is of great clinical importance with respect to lymphatic and surgical pathways that are quite different within the two compartments. This issue demonstrates well that the interpretation regarding the subdivision of the pelvic connective tissue is incomplete without knowing its developmental and functional differentiation. It is obvious that the main function of the semicircular, paravisceral fat pad is to constitute a gliding pad for the bladder (Kux and Fritsch 2001). The fat pad accompanies the bladder whenever it is moving.

Function and innervation of the external urethral sphincter, the pubovesical and puboprostatic ligaments have been extensively described by Dorschner et al. (2001). According to their studies, the external urethral sphincter is composed of both a striated and a smooth muscular part and thus forms an urethral sphincter complex similar to what we have pointed out for the anal sphincter complex. There is no doubt about the function of the external urethral sphincter that is part of the urinary continence system. Furthermore, it is generally accepted that, similar to the anal sphincter complex, there are different fiber types within the striated part of the external urethral sphincter (Ho et al. 1997; Schroeder and Reske-Nielsen 1983), but as to the data about distribution of fast and low twitch fibers we are cautious when interpreting these data because they are taken from different specimens, from different places within the muscle itself, and from muscles of different age and of different sex.

Dorschner et al. (2001) pointed out the fact that the smooth muscle bundles of the puboprostatic or pubovesical ligaments are continuous with longitudinal muscle fibers of the neck of the bladder, which they call dilatator urethrae. Maybe again there is a similarity to the anorectum, where we also found smooth muscle bundles and autonomic nerves outside the ventral wall, which we think work in functional coactivity to the longitudinal internal bundles. Nevertheless, it seems certain that the function of the so-called puboprostatic or pubovesical ligaments which receive a presumptive cholinergic innervation (Wilson et al. 1983) is not fixing the urethra to the pubic bone but maintaining its position relative to the bone during micturition (Gosling et al. 1999). In contrast, the contraction of the levator ani muscle and the external urethral sphincter leads to a narrowing of the preurethral space and to an ascending movement of the urethra as can be seen in dynamic MRI (Fielding et al. 1998; Sprenger et al. 2000).

Whereas Oelrich (1980) pointed out the existence of a deep transverse perineal muscle in the male, Dorschner et al. (2001) completely deny the existence of a deep transverse perineal muscle and thus of the urogenital diaphragm as a similar portion does not exist in the female.

In order to clarify, we propose to compare the male and female situation in our preparations: The short female urethra is covered by the external urethral sphincter, which ends level with its orifice where it still consists of semicircular running bundles. The intrapelvic part of the male's urethra is also covered by the external urethral sphincter. Level with the perineum the bundles of this muscle take a more and more transverse course, running from left to right and thus constituting the so-called deep transverse perineal muscle. It seems to be easy to explain this sexual difference by the different function of the urethra at this level; whereas the female urethra has to be opened and closed at this level, the male urethra has to be secured to the bones additionally, as it changes its direction afterwards and proceeds into the penis.

### 4.2.4 Urological and Obstetric Relevance

As the supplying structures for the female's urological organs and the male's urogenital organs are situated at the medial border of the paravisceral fat pad, the latter constitutes an ideal surgical pathway. It must be taken into account, however, that whenever the fat pad is damaged, the prevesical space may undergo fibrous obliteration and thus distension and retraction of the urinary bladder may severely be impaired and ejaculation may become painful in the male (Kux and Fritsch 2001).

Due to our results that in principle support the hammock hypothesis of DeLancey (1994), an operative "refixation" of the urethra and the bladder neck should take into account an ascending dorsocranial traction (nerve guiding plate) as well as a descending ventrocaudal traction (tendinous arch of the pelvic fascia). Though there are innovative ideas as to the surgical reconstruction of the female urinary tract (Ulmsten 2001) they are not performed according to the morphological needs, because they mostly consider only one part of the so-called fixation system. Different sling techniques are performed by using different kinds of materials. In most techniques the urethra is torn in a dorsocranial direction. In the first years after operation patients are continent, but some years later the operation results in an urethral obstruction.

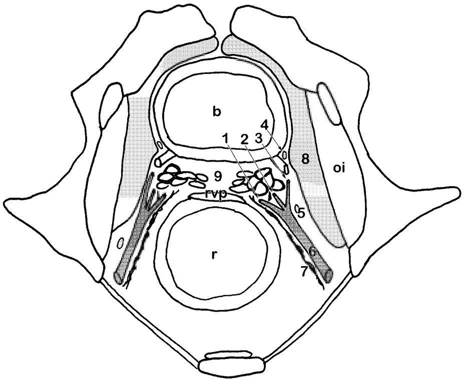
In cases of urogenital sinus malformation, a secure procedure can be performed using a perineal approach. The procedure is called total urogenital sinus mobilization (TUM), because the urethra is not fixed to the pubic bone. Level with the bladder neck, the pubovesical ligament should be protected to obtain urinary continence (Pena 1997; Ludwikowski et al. 1999).

To avoid postoperative impotence due to nerve damage of the cavernous nerves in the male, an effort is made to preserve these nerves during pelvic, urethral, or penile surgery. As their topography was not clear in the adult, it has extensively been studied in human fetuses (Walsh and Donker 1982; Fritsch 1989); the results of these studies have been compared with the relationships in the adult male (Lepor et al. 1985; Paick et al. 1993) and finally they have been used to improve operation techniques in male pelvis.

### 4.2.4.1
### Important Vessels, Nerves and Lymphatics in the Male

1. Inferior vesical artery
2. Artery to the deferent duct
3. Superior vesical artery
4. Vesical lymph nodes
5. Internal iliac lymph nodes
6. Internal iliac artery
7. Inferior hypogastric plexus
8. Paravesical fat pad
9. Seminal gland

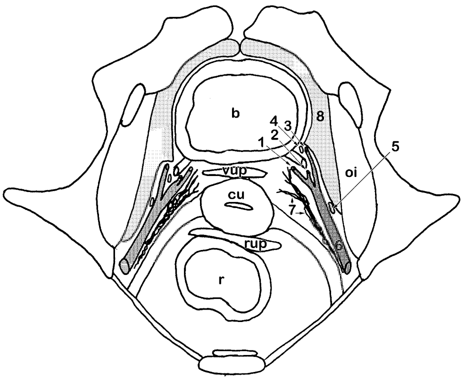
(Veins have a corresponding course)




### 4.2.4.2
### Important Vessels, Nerves and Lymphatics in the Female

1. Inferior vesical artery
2. Branches to the ureter
3. Superior vesical artery
4. Vesical lymph nodes
5. Internal iliac lymph nodes
6. Internal iliac artery
7. Inferior hypogastric plexus
8. Paravesical fat pad

(Veins have a corresponding course)



## 4.3
## Middle Compartment

### 4.3.1
### Connective Tissue Structures

In macroscopic dissections of the adult female pelvis it is impossible to isolate ligaments fastening the cervix uteri or the vagina to the lateral pelvic wall and thus separating the middle compartment from the anterior or the posterior one laterally. In a refined macroscopic dissection performed with a binocular dissecting microscope it is possible—as well as in any other part of the pelvic subperitoneal tissue—to isolate connective tissue septa within the adipose tissue surrounding uterus and vagina (DeBlok 1982). Our study of female fetal and adult pelvic sections reveals the true nature of the connective tissue structures surrounding uterus and vagina. The only connective tissue belonging to the middle compartment accompanies the vessels of uterus and vagina, thus running parallel to the lateral walls of these organs. In fetuses, the connective tissue is still loose and without a differentiated structure; in the adult it mainly consists of adipose tissue with regular connective tissue septa (Fig. 12A–D) and it is continuous with the broad ligaments (see Table 1/20.) laterally. As can clearly be seen in fetuses, the paracervical connective tissue abuts the paravesical adipose tissue laterally and the paravaginal connective tissue abuts the pelvic parietal fascia caudally (Fig. 12A, B). As shown in fetuses (Fritsch 1992), the broad ligaments themselves are part of the recto-uterine and the vesico-uterine fold (see Table 1/21., 1/23.) that tangentially cover the anterior and posterior uterine walls. Apart from dense subperitoneal connective tissue that covers the recto-uterine pouch (see Table 1/22., Fig. 12E) and mainly consists of collagenous fibers, no supportive ligaments are found for the female fetal uterus. In the adult, this condensation of subperitoneal connective tissue has developed to the uterosacral ligaments (see Table 1/10.). They are visible in the transparent sections as well as on MRI and form semicircular cords varying in thickness individually. They originate from the lateral margin of the cervix uteri and the vaginal vault and are directed dorsocranially, where they are connected to the pelvic parietal fascia covering the sacrospinous ligaments. As they are part of the recto-uterine ligaments, they cover the perirectal tissue laterally. Our study undoubtedly confirmed the existence of the round ligaments as well as their course and their components. However, ligamentous structures constituting cardinal or transverse ligaments (see Table 1/25.; Kocks 1880; Mackenrodt 1895) that are supposed to fasten the cervix uteri and the vaginal vault with the lateral pelvic wall can not be found in the adult pelvis. Our findings that have been taken from anatomic sections of elder specimens unrestrictedly correlate with the results of the MRI taken from young adult female pelves (Fig. 13A, B).

Subperitoneally, the middle compartment and its organs abut the anterior compartment ventrally. This area is predominated by the dense connective tissue bridge intimately connecting the ventral vaginal wall with the dorsal urethral wall (Fig. 12B; see also anterior compartment).

Dorsomedially, the middle compartment abuts the posterior compartment. The border between these compartments is demarcated by the rectovaginal fascia (see also posterior compartment), that is composed of dense connective tissue, elastic fi-

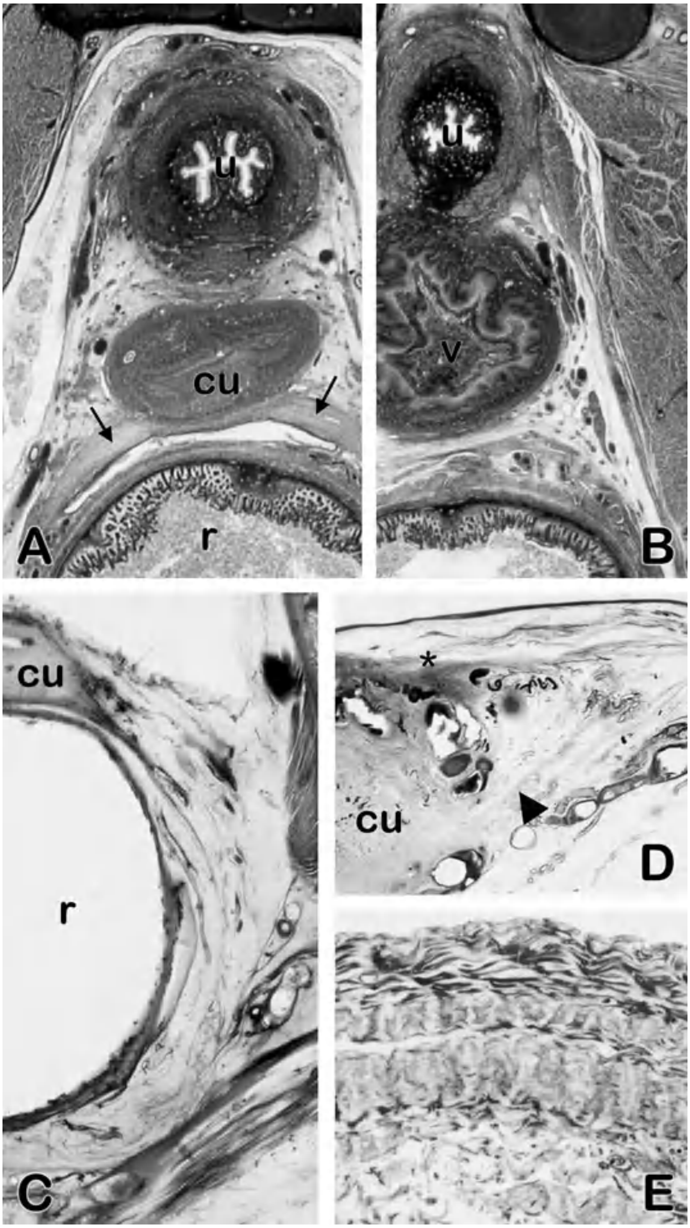



**Fig. 12A–E** Paracervical and paravaginal tissue. **A** Axial section (400 $\mu$m) of a 24-week-old-female fetus at a level with the recto-uterine pouch covered by dense connective tissue (*arrow*). ×8. **B** Axial section (400 $\mu$m) of the same fetus at a level with the vagina embedded in loose paravaginal tissue. Vagina and urethra are intimately connected. ×8. **C** Axial section (3 mm) of an adult female with the paracervical tissue. ×0.8. **D** Enlargement of an axial section (3 mm) of the same specimen with origin of the round ligament (*asterisk*) and the uterosacral ligament (*arrowhead*). ×3.5. **E** Enlargement of (*a*) with parallel oriented connective tissue fibers constituting the subperitoneal part of the uterosacral ligament. ×40

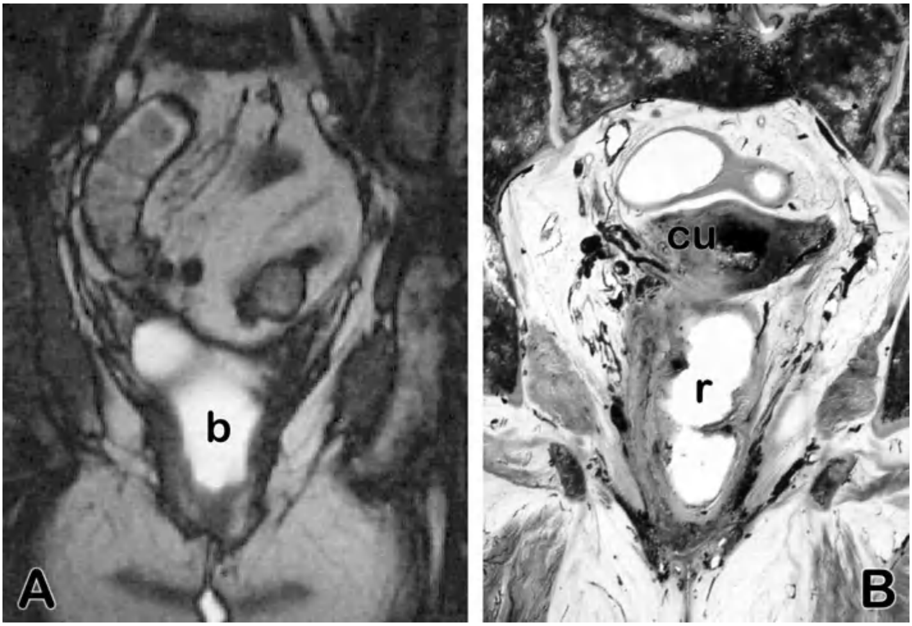



**Fig. 13A, B** Subperitoneal connective tissue and nerve vessel guiding plate. **A** Coronal section (3 mm) of an adult female with pararectal and paracervical tissue. ×0.4. **B** Coronal MR image of an adult female with paravesical and paracervical tissue

bers (Richardson 1993), and smooth muscle cells that belong to the longitudinal layer of the rectal wall.

### 4.3.2 Muscles

The middle compartment does not have any specific striated muscles. The lateral vaginal wall comes in close contact to the puborectalis portion of the levator ani muscle. Both structures are always separated by the superior fascia of this muscle (Fig. 6B).

### 4.3.3 Reinterpreted Anatomy, Function and Fundamentals of Neuroanatomy

Surgical techniques for the fixation of uterus and vagina are numerous. They all depend on the idea that there are sheath-like condensations within the pelvic cavity that are commonly called fascia. Moreover, these fasciae are thought to act as supportive structures for the uterus and vagina and thus they need to be reconstructed during operation. We think this point is one of the most critical to discuss within this review:

Our reinterpreted anatomy of the connective tissue surrounding uterus and vagina is:

- In accordance with some papers (Berglas and Rubin 1953; Koster 1933; Uhlenhut and Nolley 1957), we do *not* find any visceral fascia covering uterus and vagina. Both organs are accompanied by adventitial connective tissue. The rectovaginal fascia develops in situ (Ludwikowski et al. 2002) and is connected to the uterosacral ligaments, to the longitudinal muscular layer of the rectum and to the perineum (see posterior compartment and perineal body).

- As has clearly been summarized by Bastian and Lassau (1982) various ligaments are supposed to exist in the pelvis of the adult female. Our results show that—apart from the uterosacral and the round ligaments—no ligaments of the uterus can be found in conventional anatomical specimens, sections or by MRI. We showed, however, that the paracervical and paravaginal region contains adipose tissue, numerous vessels, nerves, and connective tissue septa. *All together these components may be confounded with a ligamentous structure* especially in the elder female. The connective tissue septa have carefully been described by new morphological approaches (De Blok 1982b; DeLancey 1996) but they have been overinterpreted as to their functional meaning. There is no doubt that some of these connective tissue septa are connected to the fascia of the levator ani muscle and the contraction of this muscle is directly transferred to the septa and thus to the vagina, too. However, due to their morphological characteristics they are not supposed to act as supportive structures.

Our results are still in disagreement with the classical descriptions in clinical and anatomical textbooks. We are aware of the fact that the variability of nomenclature is misleading, too. Nevertheless, it is morphologically true that if at all we speak of a fixation of the uterus it is only fulfilled by the uterosacral ligaments running in a dorsocranial direction. These ligaments are connected to the pelvic parietal fascia level with the sacrospinous ligaments, thus producing an upward traction for the whole uterovaginal complex.

### 4.3.4
### Obstetric Relevance

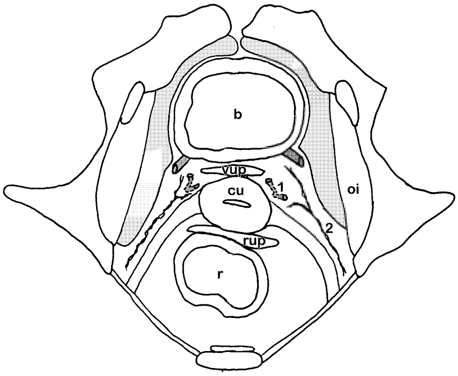
There are various surgical procedures to reconstruct the so-called supportive ligaments in patients with genital prolapse. Due to our morphological data, in the case of prolapse it only makes sense to carry out a sacrospinous fixation of the uterovaginal complex (Niemen and Heinonen 2001; Thakar and Stanton 2002), taking into account that the pudendal vessels and the pudendal nerve are not injured during operation (Occelli et al. 2001). We are not able to answer the question whether such a fixation should be performed at the time of transvaginal hysterectomy (Cruikshank 1991), but we propose to not confine this technique to patients with an intact pelvic floor function. Based upon our morphological data, we would prefer a laparoscopic approach that bears a tremendous potential for the treatment of all aspects of urogenital organ and pelvic floor pathology by the same route without disturbing the pelvic floor itself (Wattiez et al. 2001).

In case of cervical carcinoma, a new technique has been developed, total mesometrial resection (TMMR), that allows nerve preservation and thus preservation of the adjacent organs and the pelvic floor (Höckel et al. in press).

## 4.3.5
## Important Vessels, Nerves and Lymphatics

1 Uterine artery
2 Inferior hypogastric plexus

(Veins have a corresponding course)



# 5 Perineal Body

## 5.1
## Connective Tissue Structures and Muscles in the Male

The perineal body separates urogenital and anal hiatus. In the male it is situated between the rectum and urethra (prostate), i.e., between the posterior and anterior compartments. Within the region of the perineal body, the skin is firmly attached to the underlying connective tissue. This becomes obvious in macroscopic dissection as well as in histological sections. As can already be seen in early fetal life, the male's perineal body consists of dense connective tissue (Fig. 14A). It does not possess its own musculature, but numerous muscles originate or insert within the dense perineal body. The external anal sphincter is attached to it dorsally and the deep transverse perineal muscle, including the bulbourethral glands, abut the ventral portion of the perineal body (Fig. 14B, C). As has already been pointed out above (see posterior compartment), the additional smooth rectal muscle bundles that are situated in the rectoprostatic fascia are integrated and attached to the connective tissue of the perineal body (Fig. 14D). Apart from muscular structures, the cavernous nerves come in close contact to the perineal body. They pass just above its intrapelvic side (Fig. 14E) when leaving the pelvic cavity beside the membranous part of the urethra.

## 5.2
## Connective Tissue Structures and Muscles in the Female

In the female, the perineal body is situated between the rectum and vagina, i.e., between the posterior and middle compartments. The female's perineal body is smaller than the male's, but it also consists of dense connective tissue. Apart from the deep transverse perineal muscle that does not exist in the female (Oelrich 1983), the muscular structures that are attached to the female's perineal body are the same as in the male. As the region of the female's perineal body is of high clinical interest with regard to birth damage and/or episiotomies (Woodman and Graney 2002), it will thoroughly be described according to the gynecologist's point of view, i.e., from outside (inferior) to the inside (superior): Level below the orifice of the vagina the external anal sphincter is attached to the perineal body (Fig. 15A), whereas level with the orifice of the vagina and above the internal sphincter abuts the perineal body and thus indirectly to the dorsal wall of the vagina (Fig. 15B). At these levels the external sphincter embraces the anal canal, the perineal body, and the dorsal wall of the vagina laterally. Cranially it is connected to the puborectalis muscle (Fig. 15C, D).

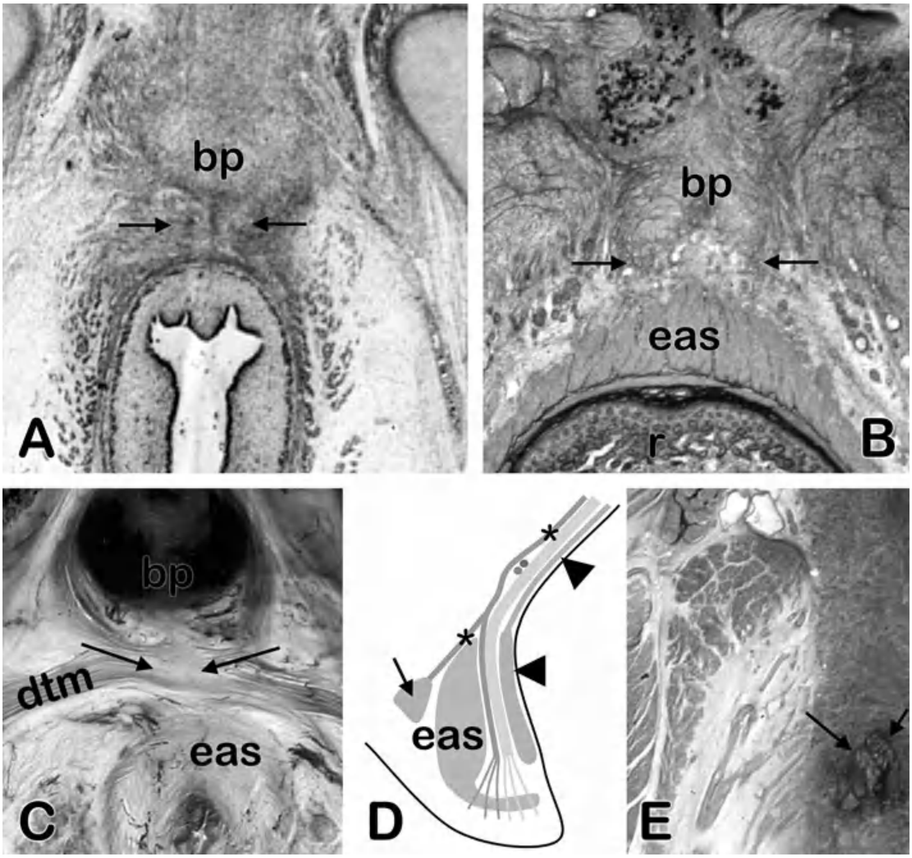



**Fig. 14A–E** Perineal body (*arrows*). **A** Axial section (300 $\mu$m) of a 9-week-old male fetus. ×36. **B** Axial section (400 $\mu$m) of a male newborn specimen. ×8. **C** Axial section (3 mm) of an adult male. ×2. **D** Schematic drawing of the sagittal plane pointing out the ventral anorectal wall (*arrowheads*) and the different muscle layers including the additional longitudinal muscle cells (*asterisks*). **E** Axial section (500 $\mu$m) of a 20-week-old male fetus just before leaving the urogenital hiatus. ×12

The infralevatoric side of the perineal body is connected with connective tissue septa of the ischioanal fossa (DeBlok and DeJong 1980) which are also connected to the inferior fascia of the levator ani muscle (Janssen et al. 2001)

## 5.3 Reinterpreted Anatomy, Function and Fundamentals of Neuroanatomy

A detailed knowledge concerning the anatomy of the perineal body has become of interest since transperineal or even dynamic transperineal ultrasound (Beer-Gabel et al. 2002) are carried out. With the help of this technique, the infralevatoric viscera, the soft tissues, and the puborectalis can be viewed and defined.

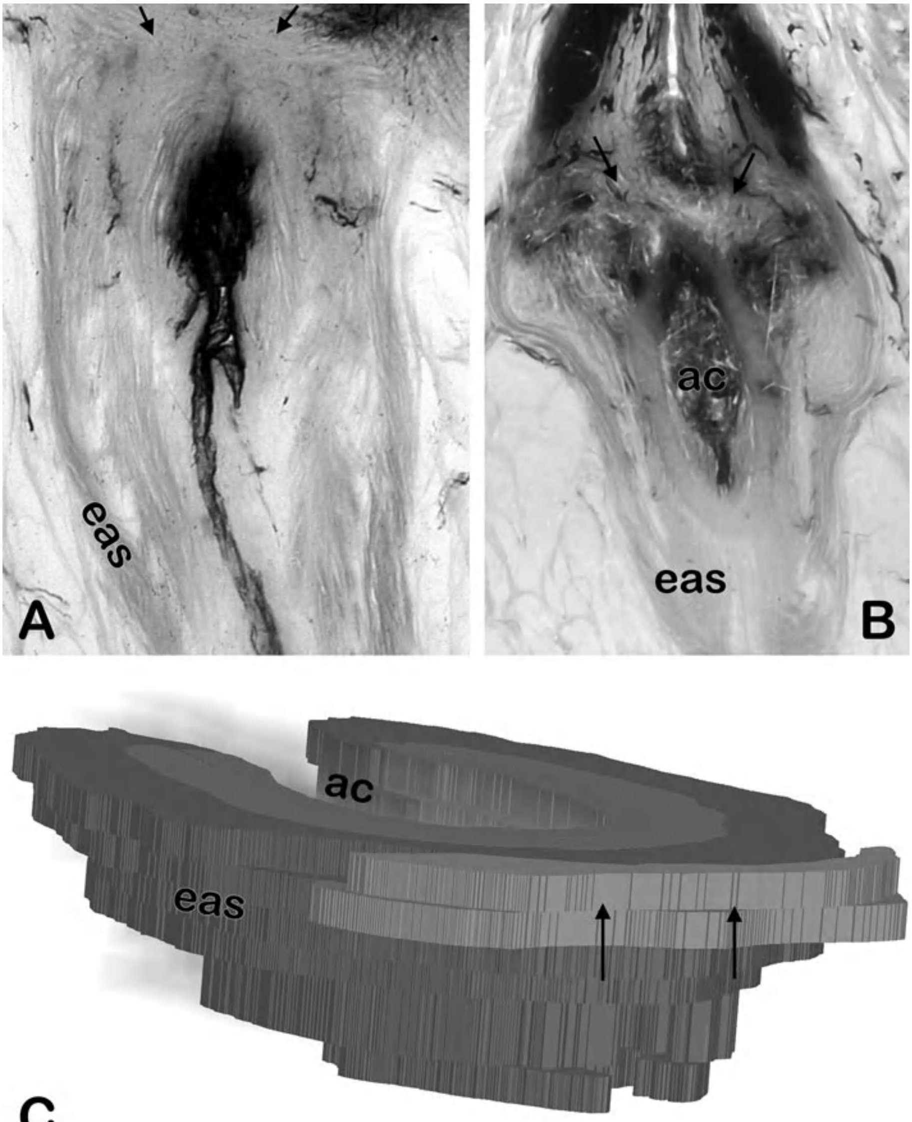



**Fig. 15A–C** Perineal body (*arrows*) and attached muscles. **A** Axial section (5 mm) of an adult female at a level with the anal cleft. ×2.2. **B** Axial section of the same specimen (**A**) at a level with the vaginal hiatus. ×1.2. **C** Computer-assisted reconstruction in an oblique view from the right side

For a long time there has been no doubt as to the fibrous components of this region. As, however, defined in the current *Terminologia Anatomica* (1998) the perineal body should be a fibromuscular rather than a tendinous structure. We do absolutely not agree with this opinion. The perineal body itself is a fibrous structure, but it is intermingled with all originating and inserting muscles. It has to be considered

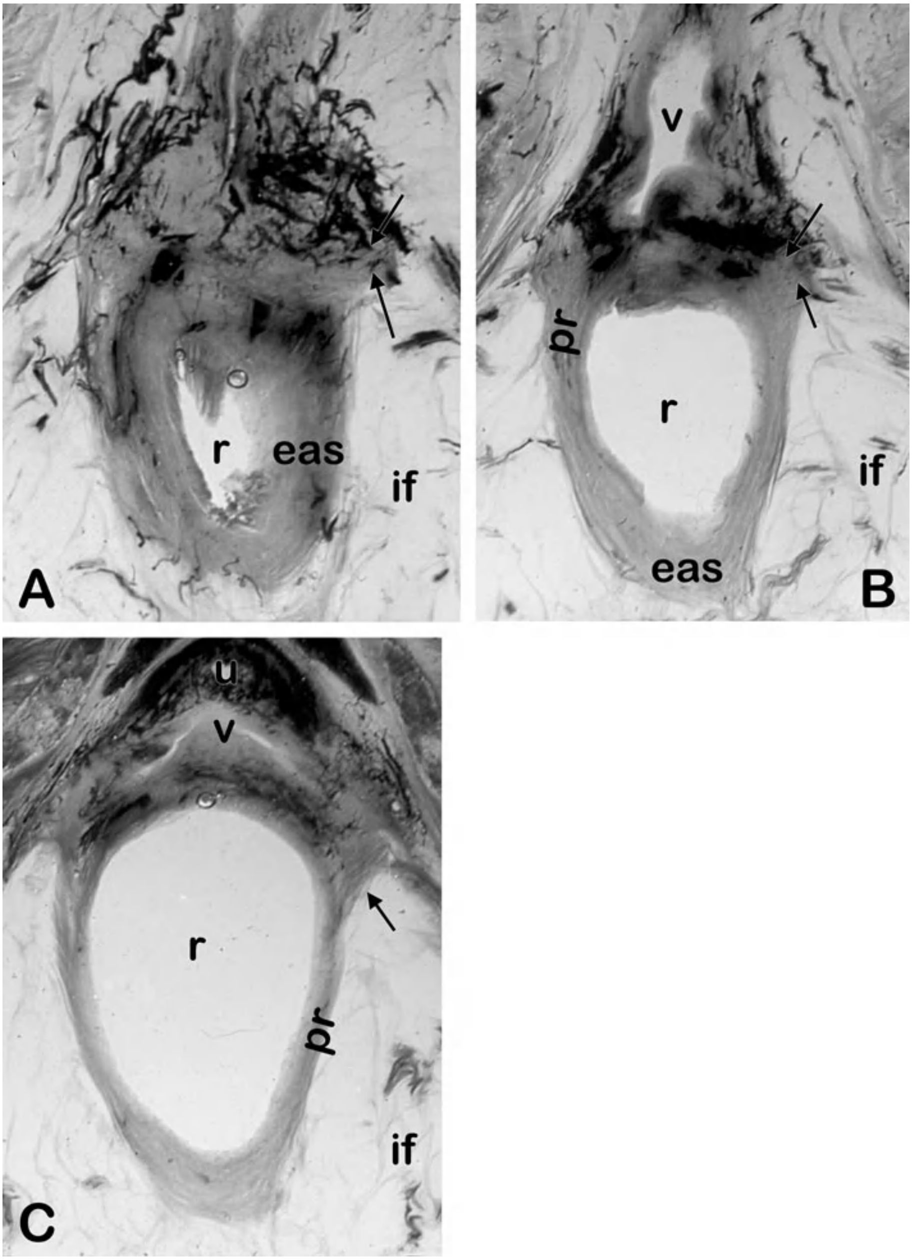



**Fig. 16A–C** Scar (*arrows*) of an old perineal rupture in axial sections (4 mm) of an adult female. **A** At a level with the perineum. ×0.8. **B** At a level with the fusion of external anal sphincter and puborectalis muscle. ×0. **C** At a level with the rectal ampulla. ×0.8

as a tendinous center for all the muscles that do not have a bony origin or attachment. There is no doubt that it is an important region for absorbing part of the intrapelvic (intra-abdominal) pressure. A stretched or even destroyed perineal body may be a cause for urogenital or rectal prolapse (Zbar et al. 2003).

## 5.4 Surgical, Urological, and Obstetric Relevance

From a morphological as well as from a functional point of view there is a need for discussion if and how a surgical approach through an intact perineal body should be performed.

Twenty years ago, an appeal was made by urologists to be careful when operating at the perineum, after they learned to avoid injury at the cavernous nerves passing in the neighborhood of the perineal body and the membranous part of the urethra (Lepor et al. 1985; Walsh et al. 1983; Fritsch 1989).

The discussion of pelvic floor damage during vaginal delivery and/or after episiotomies has been fueled by the remarkable statistics of Sultan et al. (1993), who showed that episiotomies do not prevent tearing. We think that the indication for episiotomies should be clearly defined by an international committee and it should be restricted to special cases, because perineal damage may occur not only spontaneously but also iatrogenically through the execution of an episiotomy. It is absolutely not old-fashioned to protect the perineum during vaginal delivery by hands-on methods.

We recommend not carrying out median and lateral episiotomies and being careful with the mediolateral ones: As can be seen from a pathological specimen in Fig. 16A–C, a perineal tear and/or a lateral episiotomy has led to a scar of the perineal body and the external anal sphincter. The connective tissue septa of the ischioanal fossa are irregular (Fig. 16A). At the border between the infralevatoric and levatoric levels, it becomes visible that the vaginal wall is slightly displaced, the puborectalis is rather thin, and the ischioanal fossa is not symmetric with the contralateral side (Fig. 16B), a diagnosis that still remains on supralevatoric levels (Fig. 16C). A refined and functional surgical treatment of perineal tears seems to be necessary to avoid such situations. As modern imaging techniques allow a fast and reliable control, it is the gynecologist’s task to improve their surgical treatment.

# 6 Summary and Conclusions

The study presented here comparing cross-sectional anatomy of the fetal and the adult pelvic connective tissue with the results of modern imaging techniques and actual surgical techniques shows that the classical concepts concerning the subdivision of the pelvic connective tissue and muscles need to be revised.

According to clinical requirements, the subdivision of the pelvic cavity into anterior, posterior, and middle compartments is feasible. Predominating connecting tissue structures within the different compartments are:

*Paravisceral fat pad* within the anterior compartment (Fig. 17, I), *rectal adventitia or perirectal tissue* within the posterior compartment (Fig. 17, II), and *uterosacral ligaments* within the middle compartment. The *nerve-vessel guiding plate* can be found in all of these compartments; it starts within the posterior compartment and it ends within the anterior one. It constitutes the morphological border between the anterior and posterior compartments in the male. This border is supplied by the *uterosacral ligaments* in the female. Whereas in gross anatomy no further border is discernable between anterior and posterior or middle compartment, the *rectal fascia* (hardly visible in embalmed cadavers) demarcates the rectal adventitia and is one of the most important pelvic structures for the surgeon.

In principle, the outlined subdivision of the pelvic connective tissue is identical in the male and in the female; facts that become clear from early human life and that

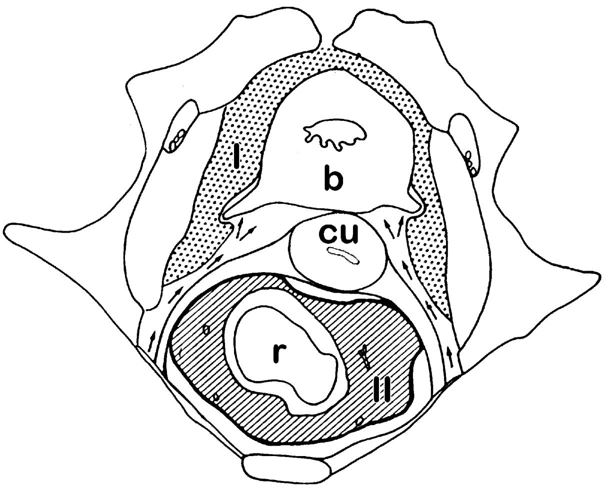
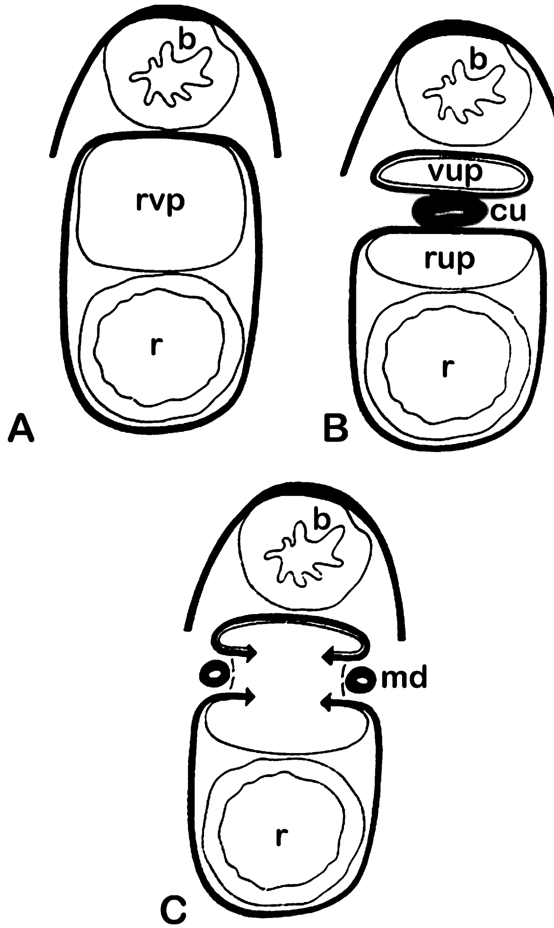



**Fig. 17** Pelvic connective tissue compartments in a schematic drawing of the female pelvis: The large fat pad (*I*) fills the anterior compartment, the perirectal tissue (*II*) predominates the posterior one. The perirectal tissue has completely been removed in case of rectal cancer

Fig. 18 Hypothesis on the development of the two peritoneal pouches in the female pelvis in correlation to the situation in the male




are already established during this period (Fig. 18). The uterus is interposed between the bladder and rectum and subdivides the pelvic peritoneum into two pouches thus establishing the only real difference between male and female pelvic cavity. The preferential direction of the pelvic connective tissue fibers is not changed by the interposition of the uterovaginal complex.

The pelvic floor muscles are composed of the portions of the *levator ani muscle*, *the muscles of the cavernous organs* and *the deep transverse perineal muscle in the male*. The latter does *not exist* in the female. We have clearly shown that the different muscles can already be found in early human life and that they are *never* intermingled with the muscular walls of the pelvic organs. The levator ani muscle of the female, however, is intermingled with connective tissue long before the female sexual hormones exert influence. We have also shown that the distinct sexual differences within the pelvic floor muscles as well as within the sphincter muscles can already be found in early human life. Both the external urethral and the external anal sphincter muscles *are not completely circular*. The external anal sphincter is intimately connected with the internal sphincter as well as with the longitudinal muscle. Whereas the innervation and function of the urethral sphincter muscles are mostly clear, cloacal development, innervation, and function of all parts of anal sphincter complex are not completely clarified.

As to the support of the pelvic viscera, we believe that intact pelvic floor muscles, an undisturbed topography of the pelvic organs, and an undisturbed perineum are of more importance than the so-called pelvic ligaments. Our hypothesis points to the fact that *the support of pelvic viscera is multistructural*. Thus in pelvic surgery, a lot of techniques have to be revised with the aim to preserve or to reconstruct all the structures mentioned. This is a multidisciplinary task that can only be solved by cooperation of morphologists, urologists, gynecologists, and coloproctologic surgeons or by creating a multidisciplinary pelvic floor specialist.

**Table 1** Synonyms used for the sensory circumventricular organs

| Term | Figure | *Terminologia Anatomica* (TA) | | Clinical term | Definition | Renaming (according to our results) | Existence |
|---|---|---|---|---|---|---|---|
| | | English | Latin | | | | |
| 1. Anococcygeal body | 19 | Anococcygeal body; anococcygeal ligament | Corpus anococcygeum; lig. anococcygeum | – | *TA*: The term *corpus*, rather than *ligamentum*, is used in TA because it is a stratified nonligamentous structure in which fleshy muscle attachments underlie a tendon | Not necessary | + |
| 2. Perineal body | 20 | Perineal body | Corpus perineale; centrum perinei | – | *TA*: The perineal body is fibromuscular rather than tendinous and quite unlike the *centrum tendineum* of the diaphragm<br>*Our opinion*: The perineal body itself is tendinous, nevertheless it can not be compared with the flat centrum tendineum of the diaphragm | Though tendinous, not necessary | + |
| 3. Perineal membrane | 21 | Perineal membrane | Membrana perinei | – | Dense connective tissue between external urethral sphincter (and transverse perineal muscle in male) and pubic bone | Not necessary | + |
| 4. Ano-rectum | 22 | Rectum and anal canal | Rectum et canalis analis | Ano-rectum | *Our opinion*: The clinical term includes both, the rectum and the anal canal not taking into account that they are of different origin | Necessary to pick up in TA | + |
| 5. Presacral compartment | 23 | – | – | – | *Our opinion*: Small space between presacral fascia and sacral and coccygeal vertebrae containing vessels | Necessary to pick up in TA | + |
| 6. Presacral fascia | 23 | Presacral fascia | Fascia presacralis | – | Caudal part of the parietal pelvic fascia | | + |
| 7. Perirectal compartment | 24 | – | – | Mesorectum | *Our opinion*: Compartment filled by the rectal adventitia including nerves, vessels, lymph nodes | Necessary to pick up in TA | + |

**Table 1** (continued)

| Term | Figure | *Terminologia Anatomica* (TA) | | Clinical term | Definition | Renaming (according to our results) | Existence |
|---|---|---|---|---|---|---|---|
| | | English | Latin | | | | |
| 8. Rectal fascia, or “Grenzlamelle” | 25 | – | – | – | *Our opinion*: Outer connective tissue lamella of the rectal adventitia, bordering the perirectal compartment | Necessary to pick up in TA | + |
| 9. Inferior hypogastric plexus | 26 | Inferior hypogastric plexus; pelvic plexus | Plexus hypogastricus inferior; plexus pelvicus | Pelvic plexus | Autonomic nerve plexus within the recto-uterine or recto-vesical fold | Exclusively into the old and clinical term: *pelvic plexus* | + |
| 10. Uterosacral ligament | 27 | Uterosacral ligament or recto-uterine ligament | Lig. rectouterinum | – | Dense connective tissue running from the edges of the cervix uteri to the region of the sacrospinous ligament | Exclusively into *uterosacral ligament* | + |
| 11. Rectoprostatic fascia | 28 | Rectoprostatic fascia; rectovesical septum (male) | Fascia rectoprostatica; septum rectovesicale | – | *Our opinion*: Plate of dense connective tissue, smooth muscle cells and nerves, locally arranged between rectum and prostate | Exclusively into the term *rectoprostatic septum* | + |
| 12. Rectovaginal fascia | 28 | Rectovaginal fascia; rectovaginal septum (female) | Fascia rectovaginalis; septum rectovaginale | – | *Our opinion*: Plate of dense connective tissue, smooth muscle cells and nerves, locally arranged between rectum and vagina | Exclusively into the term *rectovaginal septum* | + |
| 13. Anal sphincter complex | 29 | – | – | – | Includes all muscle layers of the anal canal: internal (smooth) sphincter, longitudinal (smooth) muscle, external (striated) sphincter | Necessary to pick up in TA | + |

**Table 1** (continued)

| Term | Figure | *Terminologia Anatomica* (TA) | | Clinical term | Definition | Renaming (according to our results) | Existence |
|---|---|---|---|---|---|---|---|
| | | English | Latin | | | | |
| 14. Onuf's nucleus | 30 | – | – | – | Onuf's nucleus (Onufrowicz, 1901): a – sexually dimorphic – longitudinally oriented group of small somatic motor neurons in the ventral horn of the sacral spinal cord (S2–S4), slightly medially to the lateral motor nucleus; axons from Onuf's nucleus are known to innervate the rhabdosphincter of the bladder, the bulbocavernosus muscle, and also the vagina in female. The neurotransmitters serotonin and norepinephrine are in high concentration in Onuf's nucleus | | + |
| 15. Puboprostatic ligament | 31 | Pubovesical ligament, medial puboprostatic ligament, pubovesicalis, puboprostatic ligament, lateral puboprostatic ligament; puboprostaticus | Lig. pubovesicale, lig. mediale puboprostaticum, m. pubovesicalis, lig. puboprostaticum, lig. laterale puboprostaticum; m. puboprostaticus | – | Most confusing structure! *Our opinion*: There is only one structure, running from the pubic bone to the vesical neck. It mainly consists of smooth muscle cells intermingled with strands of dense connective tissue | Exclusively into the term *pubovesical muscle* | + |
| 16. Pubovesical ligament | 31 | Medial pubovesical ligament, pubovesicalis, lateral pubovesical ligament | Lig. mediale pubovesicale, m. pubovesicalis, lig. laterale pubovesicalis | – | Most confusing structure! *Our opinion*: there is only one structure, running from the pubic bone to the vesical neck. It mainly consists of smooth muscle cells intermingled with strands of dense connective tissue | Exclusively into the term *pubovesical muscle* | + |

**Table 1** (continued)

| Term | Figure | *Terminologia Anatomica* (TA) English | *Terminologia Anatomica* (TA) Latin | Clinical term | Definition | Renaming (according to our results) | Existence |
|---|---|---|---|---|---|---|---|
| 17. Levator ani muscle | 32 | Levator ani | M. levator ani | – | Muscle that constitutes the main part of the pelvic diaphragm and is composed of the Mm. pubococcygei, iliococcygei, and puborectales of each side | | + |
| 18. Tendinous arch of the pelvic fascia | 33 | Tendinous arch of the pelvic fascia | Arcus tendineus fasciae pelvis | – | *Our opinion*: This structures originates from the pubic bone laterally, it is connected with the superior fascia of the pelvic diaphragm laterally and with the pubovesical ligament medially. It may falsely be called Lig. laterale puboprostaticum or Lig. laterale pubovesicale | | + |
| 19. Paravisceral fat pad | 34 | – | – | – | *Our opinion*: Fat pad at the lateral side of the bladder that develops in situ. Functionally necessary for the movements of bladder | Necessary to pick up in TA | + |
| 20. Broad ligament | 35 | Broad ligament of the uterus | Lig. latum uteri | – | Peritoneal fold between the uterus and the lateral wall of the pelvis | | + |
| 21. Recto-uterine fold | 36 | Recto-uterine fold | Plica recto-uterina | – | Peritoneal fold passing from the cervix uteri on each side of the rectum to the posterior pelvic wall | | + |
| 22. Recto-uterine pouch | 36 | Recto-uterine pouch | Excavatio rectouterina | Space of Douglas | Deep peritoneal pouch situated between the recto-uterine folds of each side | | + |
| 23. Vesico-uterine fold | 37 | Vesico-uterine fold | Plica vesicouterina | – | Peritoneal fold between bladder and uterus on each side | | + |
| 24. Vesico-uterine pouch | 37 | Vesico-uterine pouch | Excavatio vesicouterina | – | Slight peritoneal pouch between the vesico-uterine folds of each side | | + |

**Table 1** (continued)

| Term | Figure | *Terminologia Anatomica* (TA) | | Clinical term | Definition | Renaming (according to our results) | Existence |
|---|---|---|---|---|---|---|---|
| | | English | Latin | | | | |
| 25. Transverse cervical ligament or cardinal ligament | 38 | Transverse cervical ligament,<br>Cardinal ligament | Lig. transversum cervicis, lig. Cardinale | Cardinal ligament | Connective tissue structures that should extend from the side of the cervix to the lateral pelvic wall<br>*Our opinion*: The cardinal ligament does not exist | Necessary to omit | ∅ |

**Fig. 19** See Table 1/1.

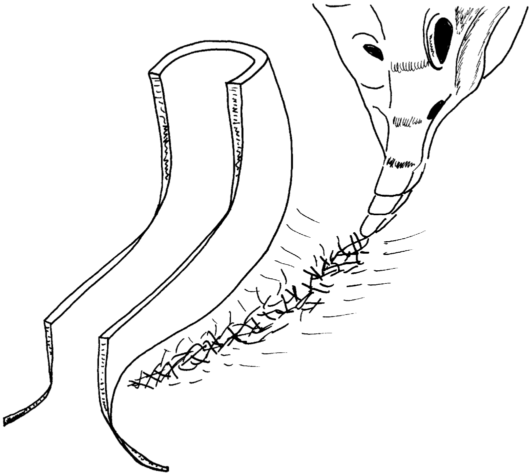


**Fig. 20** See Table 1/2.

Fig. 21 See Table 1/3.

Fig. 22 See Table 1/4.

Fig. 23 See Table 1/5., 6.

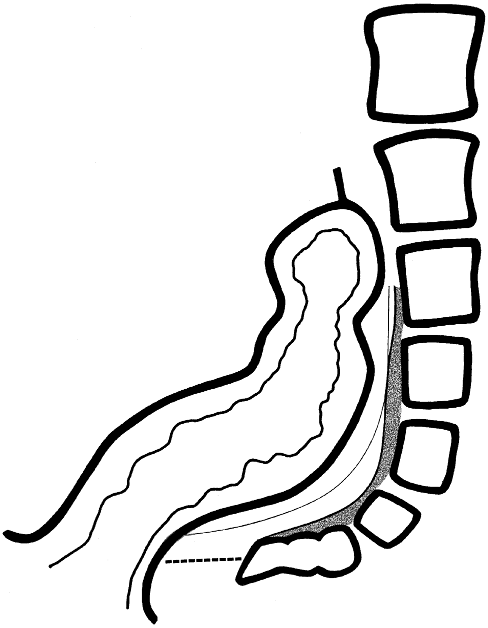


Fig. 24 See Table 1/7.

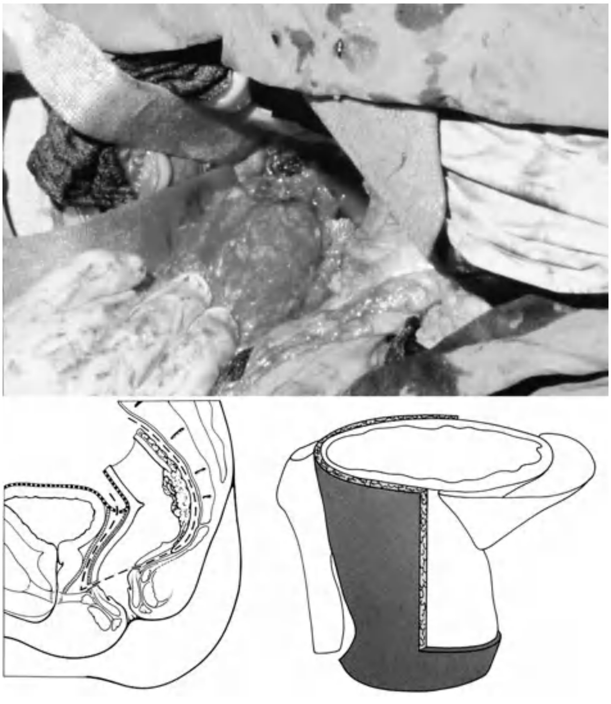


**Fig. 25** See Table 1/8.

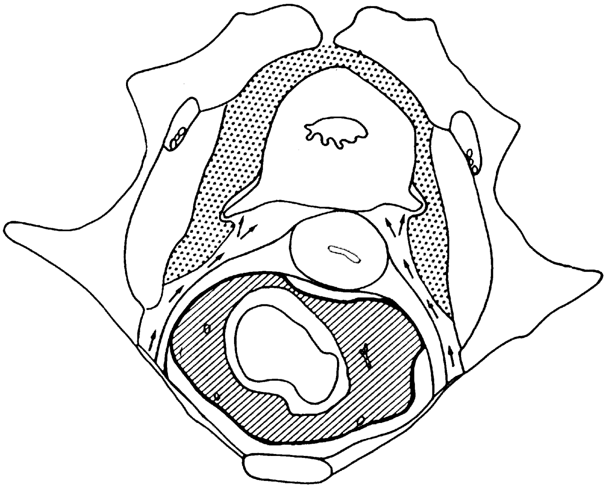


**Fig. 26** See Table 1/9.

**Fig. 27** See Table 1/10.

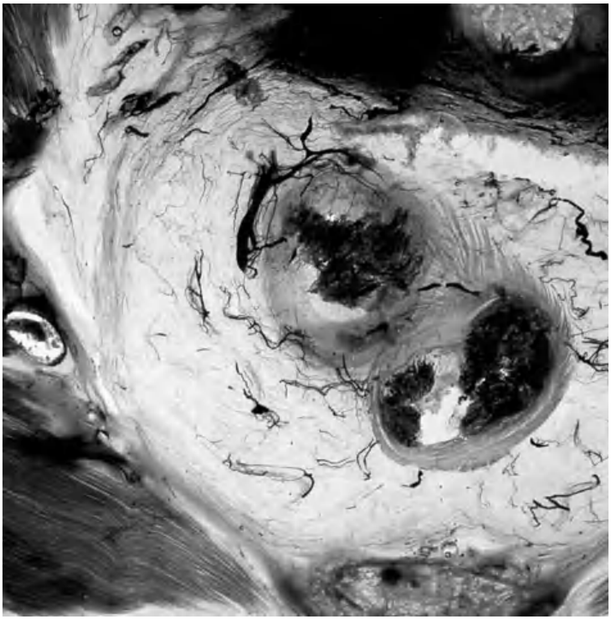


**Fig. 28** See Table 1/11., 12.

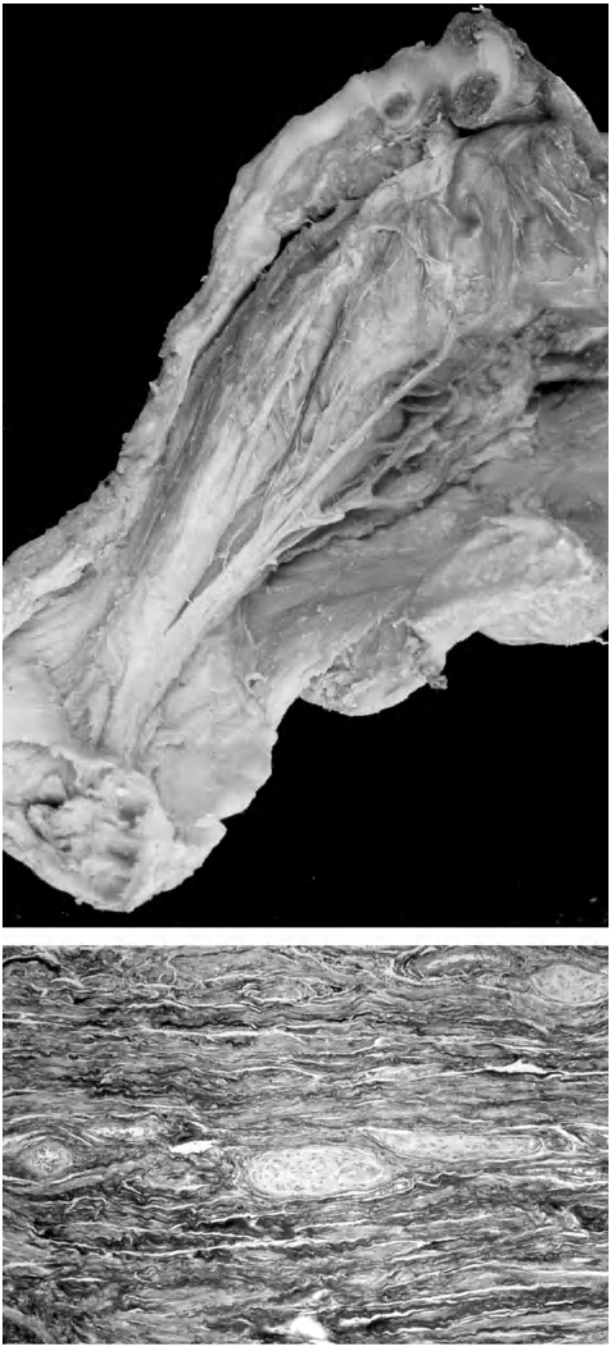
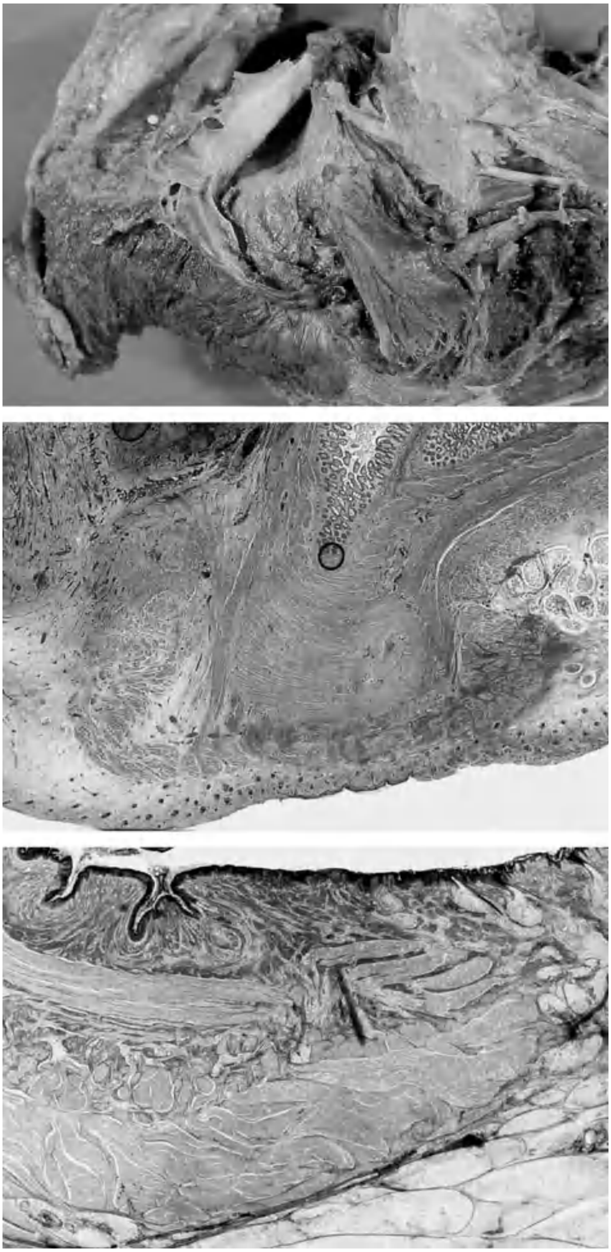


**Fig. 29** See Table 1/13.



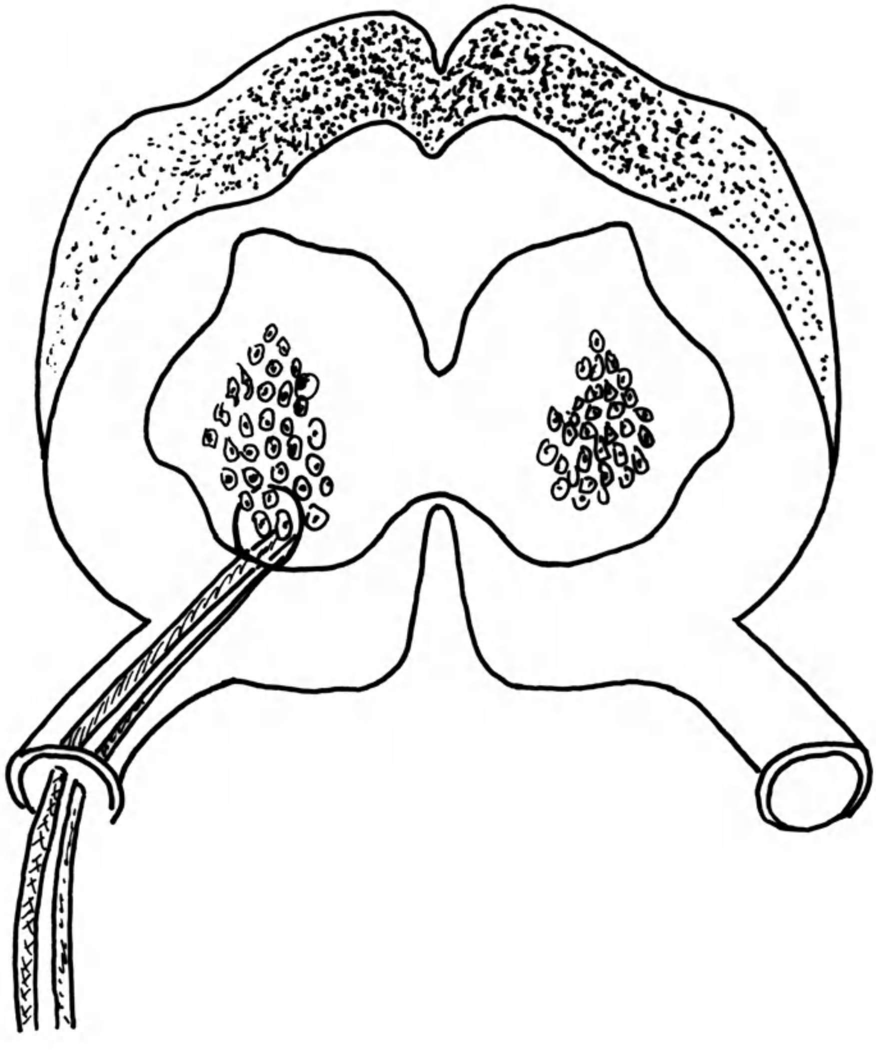


Fig. 30 See Table 1/14.

Fig. 31 See Table 1/15.

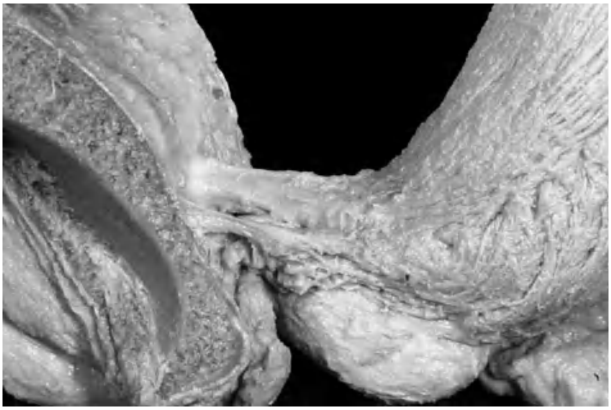


Fig. 32 See Table 1/17.

**Fig. 33** See Table 1/18.

**Fig. 34** See Table 1/19.

Fig. 35 See Table 1/20.

Fig. 36 See Table 1/21., 22.

**Fig. 37** See Table 1/23., 24.

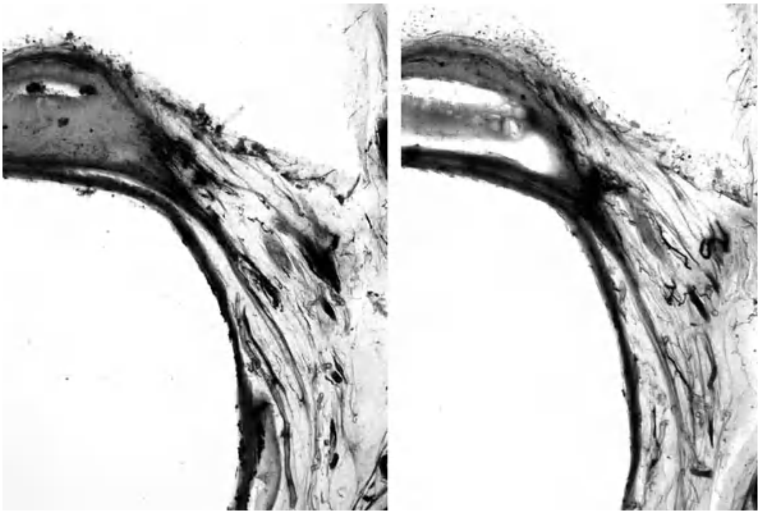


**Fig. 38** See Table 1/25.

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