2 Gross and Laparoscopic Anatomy of the Lower Tract and Pelvis

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Introduction

An overview of the gross and laparoscopic anatomy of the lower urinary tract should summarize both long-standing anatomic knowledge and current scientific findings. In few fields has the anatomic understanding grown as much as urology, especially concerning anatomy of the lower urinary tract. Whereas the gross anatomy is already well known, now research is increasingly contributing to our understanding of the microscopic level. This concerns especially the detailed anatomy and topography of the sphincter mechanism of the urinary bladder, the routing and function of the neural structures in the pelvis and, for example, the anatomic structure of the pelvic floor. The transmission of these new findings in combination with traditional anatomic knowledge into urological practice, including the growing field of laparoscopic surgery, is essential to maintain and improve the success of treatments for our patients. The following chapter gives a clear, detailed and informative summary of the anatomy of the lower urinary tract, especially considering of laparoscopic and endoscopic surgery.

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The History of the Study of the Urological Anatomy

The historiography of urology goes back to 1000 BC in Egypt. The first description of a bladder catheter made of bronze dates to this time, and bladder stone surgery also seems to have been practiced. The prostate was first described by Herophilus of Chalcedon in 300 BC. Human cadaver sections enabled this first glimpse.

After the widespread rejection of anatomical studies up to the Middle Ages, detailed descriptions of human anatomy began to emerge again with the work of Leonardo da Vinci (1452–1519), Andreas Vesalius (1514–1564) from Brussels and their successor Eustachi (1500–1574). The anatomy of the urogenital tract was mainly revealed by Étienne de la Rivière of Paris with the description of the seminal vesicles, Marcellus Malpighi (1628–1694) with the exploration of renal functioning and Lorenzo Bellini (1643–1704) with the identification of the renal tubuli. The progress of microscopic examinations further advanced the basic anatomical knowledge. In 1684, Mery described the existence of the bulbourethral glands, which was later attributed to Cowper.

The founder of the study of the pathology of the urogenital tract was Giovanni Battista Morgagni (1682–1771) with his work “De sedibus et causis morborum.” Giovanni Battista

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Morgagni is considered the first to describe prostatic hyperplasia.

One of the milestones in urology—urological endoscopy—goes back to Phillip Bozzini of Frankfurt who invented the first endoscope using candlelight in 1806. This made possible the exploration of the internal anatomical details of a living individual [1].

Topographic Anatomy of the Anterior Abdominal Wall

The increasing significance of laparoscopic procedures, especially for intrapelvic and prostatic surgery, necessitates a detailed understanding of the topographic anatomy of the anterior abdominal wall. Figure 2.2 illustrates the different structures in addition to a laparoscopic view of the male pelvis (Fig. 2.1) at the beginning of robotic-assisted radical prostatectomy. Beside topographic knowledge of specific anatomic landmark physiologic movement of intraabdominal structures, e.g. pulsation of arteries or undulated contraction of the ureters, and manipulation with introduced catheters (bladder neck visualisation during robot-assisted prostatectomy by catheter pull) help to identify relevant structures to proceed with surgery.

Five tissue folds subdivide the anterior abdominal wall. The former embryonic urachus forms the median umbilical ligament between the urinary bladder and the umbilicus. On both sides lateral to the median umbilical ligament, the remnants of the fetal umbilical arteries shape the medial umbilical ligaments/folds—the space in between is called the supravesical fossa. During cystectomy, the medial umbilical ligaments are the main structures to identify and control the superior vesical pedicle including the superior vesical artery. The inferior epigastric vessels underlie the lateral umbilical ligaments/folds. These structures have important significance regarding hernia classification. Medial to the lateral umbilical fold, the medial inguinal fossa represents the passage of direct inguinal hernias. The lateral inguinal fossa corresponds to the deep inguinal ring—the entry to the inguinal canal. An indirect inguinal hernia accompanies the components of the spermatic cord through the inguinal canal into the scrotum. In paediatric urology the Prentiss maneuver requires comprehensive knowledge of the inguinal canal and the course of inferior epigastric vessels to fascilitate adequate orchidopexy in boys with short spermatic cord.

The external iliac vessels and the iliopsoas muscle leave the pelvis below the inguinal ligament, which connects the anterior superior iliac spine to the pubic tubercle. The lacunar ligament is located directly medial to the external iliac vein connecting the inguinal ligament to the superior pubic ramus and represents the caudal

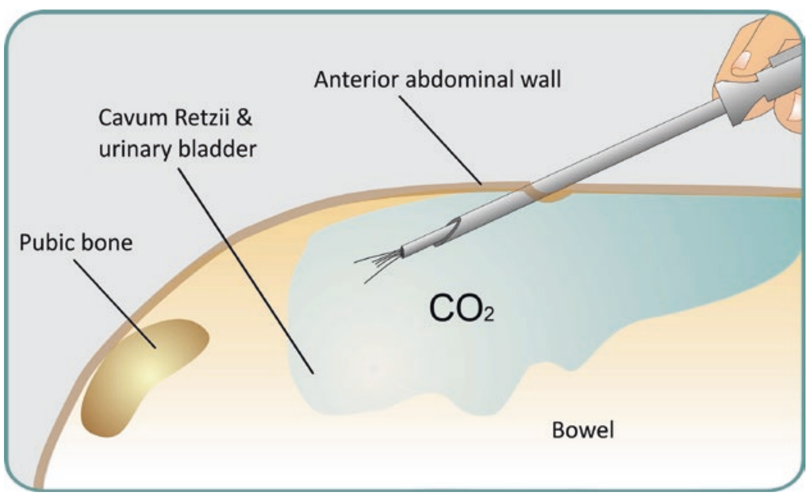

Fig. 2.1 The drawing illustrates the laparoscopic line of sight during pelvic or prostate surgery (illustrated by P.M. Weber, University Hospital of Tuebingen)

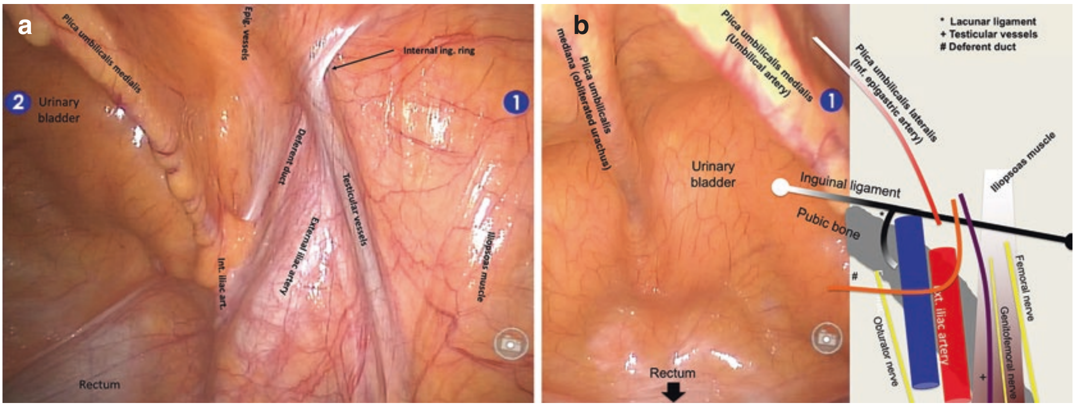

Fig. 2.2 (**a**) Laparoscopic view into the male pelvis with annotated anatomic landmarks. (**b**) Topographic anatomy of the male pelvis. Left: laparoscopic view at the beginning of robotic-assisted laparoscopic prostatectomy. Right: draft of the anatomical structures of the inguinal region in addition to the left intraoperative view (Reprinted from Amend et al. [55] with permission from Springer Nature)

extent during lymphadenectomy for prostate or bladder cancer. Lateral to the external iliac vessels the genitofemoral nerve dividing into two branches, the femoral nerve (laterally adjacent to the psoas major muscle) and the lateral femoral cutaneous nerve are at risk to be damaged during lymphadenectomy depanding on the extend of surgery (Fig. 2.2) [2, 3].

Female Pelvis

A plain promontorium and wide-open iliac wings characterize the female pelvic bone. The peritoneal pelvic cavity harbours the urinary bladder, the ureters, the uterus, the vagina, the ovaries, the Fallopian tubes and the rectum. The uterus, in between the urinary bladder and the rectum, leads to varying peritoneal conditions, starting from the anterior abdominal wall. The parietal peritoneum covers approximately the upper half of the urinary bladder, the uterus, the adnexa and the anterior wall of the rectum. Thereby the parietal peritoneum forms two parts of the abdominal cavity: the rectouterine excavation (Douglas' fold) and the vesicouterine excavation. A vaginal manipulator helps to expose these pelvic spaces during laparoscopic surgery. The peritoneal fold between the uterus/cervix and the pelvic wall is called the ligamentum latum or broad ligament, although these structures lack some of the typical features of a ligament in the anatomical sense. The uterine artery, the uterine venous plexus and parts of the distal third of the ureters are included in the broad ligament. Ovaries and the Fallopian tubes are also joined to the broad ligament by a peritoneal duplication. The ovaries receive their blood supply through the suspensory ligament (often also called infundibulopelvic ligament), and they are connected to the uterus by the (proper) ovarian ligament, which is part of the broad ligament and includes a secondary blood supply called ovarian branches of the uterine artery. At least, the round ligaments represent connections between the deep inguinal rings and the uterine horns. Embryogenetic, the round ligament corresponds to the gubernaculum testis in males.

The rectouterine folds mark the borders of the rectouterine pouch—they consist of fibrous tissue and smooth muscle fibers, and also include the inferior hypogastric plexus (Fig. 2.3).

The pelvic fascia with its parietal and visceral layer covers the borders of the subperitoneal space; the clinical synonym is "endopelvic fascia". The endopelvic fascia also forms the superior layer of the fascia of the pelvic and urogenital diaphragm. The urinary bladder is attached to the pubic bone/symphysis pubis via the pubovesical ligaments (analogous to the puboprostatic ligaments in male humans, see also below) with lateral connections to the superior layer of the fascia

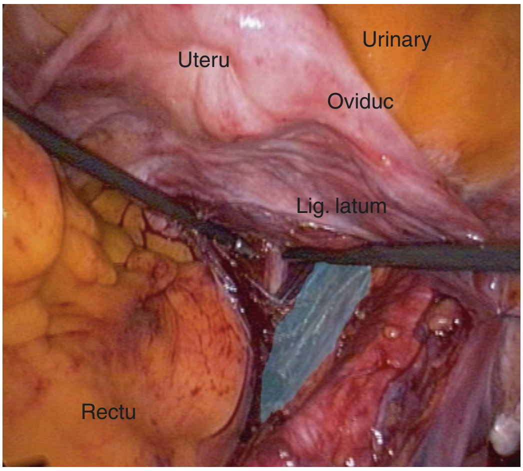

Fig. 2.3 Laparoscopic view into the female pelvis. The right rectovaginal fold is marked lucent blue

of the pelvic diaphragm. Between the different subperitoneal organs, connective and fatty tissue fills the resulting spaces (presacral, prevesical, paracervical, parametrial). The stability of the uterus and the cervix is guaranteed by the recto-uterine (synonym, sacrouterine) ligament and the topography of the other pelvic organs. The cardinal ligaments (synonym, transverse cervical ligaments) on the base of the broad ligament, joining the cervix and the lateral pelvic wall, are not there at birth but are shaped throughout a lifetime by the increasingly compact and strong connective tissue. They increasingly support the topographical position of the cervix [2, 4–6].

Male Pelvis

In contrast to the female pelvis, in male humans the pelvic bone is narrower and marked by a more protruding promontorium, resulting in a heart-shaped pelvic entry. The pelvis accommodates the urinary bladder, the ureters, the prostate, the seminal vesicles, the deferent ducts and the rectum. The parietal peritoneum also covers the pelvic organs starting from the anterior abdominal wall to the anterior rectal wall. Between the urinary bladder and the rectum, the deepest point of the abdominal cavity forms the rectovesical excavation. On both sides the rectovesical fold confines the excavation and includes the inferior hypogastric plexus. The deferent ducts shape the paravesical fossa by raising a peritoneal fold.

The subperitoneal space in front of and lateral to the urinary bladder is clinically called the cavum retzii. A look at the existing literature concerning the anatomical conditions of the subperitoneal fascias, especially the prostate-surrounding tissue and the formation of the so-called Denonvilliers' fascia, demonstrates an inconsistent presentation and nomenclature. The following explanations will outline the most usually published anatomical findings and interpretations. The pelvic fascia in males also consists of two parts: a parietal layer, which covers the lateral wall of the pelvis, and a visceral layer covering the pelvic organs. The tendinous arch represents the transition between the parietal and visceral part. Often the visceral layer is clinically indicated as the endopelvic fascia, especially with regard to radical prostatectomy and nerve-sparing procedures. Whether the prostate is actually separated by its own prostatic fascia is under discussion. The absence of the fascia in the apical region of the prostate and the formation of the so-called puboprostatic ligaments by the endopelvic fascia suggest that the visceral layer of the pelvic fascia (=endopelvic fascia) and the fascia of the prostate (periprostatic fascia) correlate. Generally, the periprostatic fascia is described as a multilayered structure, which incorporates neurovascular structures, fatty and fibrous tissue. Interindividual and prostate aspect depended variations (fusion of fascias and prostate capsule) are common, especially with regard to the prostate gland size. The puboprostatic ligaments between the anterior aspect of the prostate and the pubic bone/symphysis pubis do not represent ligamentous structures in the proper sense. In fact, the puboprostatic ligaments are characterized by an aggregation of the pelvic fascia. Possibly muscle fibers (smooth or striated) also contribute to the configuration of the so-called puboprostatic ligaments. Especially in large prostates the correct identification of the dissection plane between the anterior prostate aspect and the puboprostatic ligaments may be difficult.

Similarly, there is a lack of clarity regarding Denonvilliers' fascia. The anatomical nomenclature utilizes the description rectoprostatic fascia or septum. It represents a membranous separation between the rectum and the prostate/urinary bladder. The fascia emerges from two layers of a peritoneal cul-de-sac, ranging from the deepest point of the rectovesical excavation to the pelvic floor. Recent examinations report the termination of the Denonvilliers' fascia located at the junction of the prostate and the dorsal (fibrous) part of the rhabdosphincter. In addition, the presence of smooth muscle fibers inside the fascial layers has been reported. There has been extensive discussion about the possibility of surgical separation of both layers during radical prostatectomy. Currently it is evident that microscopically the rectoprostatic fascia consists of two formerly peritoneal layers, which often cannot be divided bluntly. It is assumed that authors illustrating techniques of fascia separation are referencing to the space between Denonvilliers' fascia and the rectal fascia propria (a part of the visceral layer of the pelvic fascia = endopelvic fascia). Furthermore, adhesions between Denonvilliers' fascia and the prostatic capsule, primarily at the base of the seminal vesicles, have been identified. These individual findings have to be taken into account for precise retro-prostatic preparation with regard to positive surgical margins during prostatectomy independent of the surgical approach. Periprostatic neural and vascular structures are focused on below [2, 4, 6–16].

Pelvic Floor

Two fibromuscular layers are responsible for the closure of the inferior pelvic aperture: the pelvic diaphragm and the urogenital diaphragm. It has to be emphasized at this point that the term urogenital diaphragm is not part of the anatomic nomenclature. Particularly the presence of a deep transverse perineal muscle was under extensive discussion, whereas recent studies confirm that a deep transverse perineal muscle is present.

The pelvic diaphragm consists of the levator ani muscle and the coccygeus muscle (M. ischiococcygeus). The levator ani muscle in turn consists of the following structures, which are named according to their origins and insertions: the pubococcygeus muscle, iliococcygeus muscle and puborectalis muscle. A superior and inferior fascia covers the levator ani muscle, the superior layer being part of the parietal layer of the pelvic fascia as described above. The levator ani muscle forms an archway-shaped opening for the anus and urethra in males, and the anus, vagina and urethra in females. Interestingly, the levator ani muscle thickness has been reported smaller and the steepness inside the pelvis greater comparing males to females. This might be dedicated to the general form of the bony pelvis and the physical necessities during pregnancy. The innervations for the striated muscles derive principally from the sacral plexus (S3 and S4); some nerve fibers reach the puborectal muscle via the pudendal nerve located in the pudendal canal. Even though the contributions of the shape topography and the contraction of the pelvic diaphragm to anal continence seem to be proven, it is still unclear to what extent these anatomical structures also affect urinary continence. Recent publications have reported the muscular independence between the pelvic diaphragm and the striated external urethral sphincter, whereas an association by connective tissue forming a tendinous connection starting from the inferior part of the external urethral sphincter in females could be demonstrated. Especially because of these interactions, authors suggest the necessity of an intact pelvic diaphragm for urinary continence.

The relevance of the rectourethralis muscle in males is regularly discussed with respect to post-prostatectomy urinary continence. Special incontinence tapes aim to repair the assumable posterior loss of the external urinary sphincter complex after prostatectomy, which is naturally guaranteed by muscular and fascial dorsal structures (Denonvilliers' fascia, rectourethralis muscle). Recent studies characterized the rectourethral muscle as the anterior branch of longitudinal fibers of the anterior smooth muscle component of the rectum, which directs through the deep transverse perineal muscle to the perineal body. The posterior branch of rectal longitudinal smooth muscles passes between the internal and external anal sphincter to the perineum (Fig. 2.4).

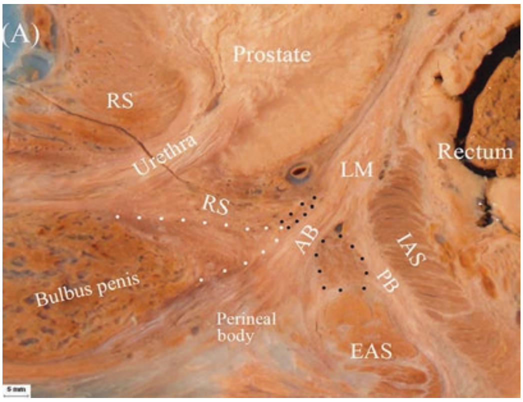

Fig. 2.4 Sagittal cross-section of celloidin fixed male human pelvic floor: deep transvers perineal muscle marked with black dots. Connective tissue of the penile bulb marked with white dots (*RS* rhabdosphincter, *LM* longitudinal muscle of the rectum, *AB* anterior bundle of LM, *PB* posterior bundle of LM, *EAU* external anal sphincter). (Reprinted from Zhai et al. [13] with permission from Elsevier)

Considering the urogenital diaphragm, the exact anatomical and histomorphological composition is still undefined. Almost all anatomical atlases report that the urogential diaphragm consists of the deep transverse perineal muscle (less developed in females) with a superior and inferior urogenital fascia. Additionally, the superficial transverse perineal muscle inserting at the perineal body (=central tendon of perineum), the striated external urethral sphincter and the surrounding connective tissue complete the traditional view of the urogenital diaphragm. In addition, as described above, smooth muscle fibers originating from the anterior rectal wall integrate into or perforate the urogenital diaphragm (rectourethralis muscle). With reference to the discussions of the existence of a deep transverse perineal muscle, prevailing descriptions in literature and also recent studies of human cadavers report the presence of the deep transvers perineal muscle (Fig. 2.4). The urogenital diaphragm is described as layers of connective tissue embedding the external urethral sphincter in conjunction with the perineal body, the deep transvers perineal muscle, the structures of the inferior pubic bone and the superficial transverse perineal muscle. Whether these findings about the muscular structures of the urogenital diaphragm are possibly due to age-related fatty degeneration of muscular tissue is under discussion and remains unexplained. The main vascular and neural structures—the internal pudendal artery and the pudendal nerve—are located directly below the urogenital diaphragm. The internal pudendal artery is a branch of the internal iliac artery and the pudendal nerve originates from the sacral plexus (S2-4). Both structures surround the sacrospinous ligament and follow the inferior pubic bone inside the pudendal canal as described below. The bulbourethral glands (Cowper's glands) are located laterally to the membranous urethra at the level of the urogenital diaphragm. They could be visible during deep urethral repair, perineal prostatectomy or gender reassignment surgery. The urethral sphincter mechanism is described out below [2, 6, 13, 17–26].

Urinary Bladder

The urinary bladder is a muscular, distensible organ for urine collection and controlled micturition. Macroscopically the urinary bladder is divided into the apex, corpus, fundus and collum. The average filling volume ranges between 300 and 500 cm^3. The mucosa is only loosely adherent to the subjacent muscular layers, except for the trigone where a direct adhesion to the submucosal layers can be found. A fold raised between the obliquely passing ureters on both sides forming the ureteral orifices characterizes the trigone.

The urinary bladder wall is structured as follows: mucosa (transitional cells), submucosa, detrusor muscle (three layers), and surrounding adipose and connective tissue. The detrusor muscle is subdivided into an external and internal longitudinal muscle layer, as well as an interjacent circular layer. The bladder neck, including the trigone, consists of two muscular layers. A specialized circular smooth muscle could not be found. The longitudinal muscle fibers in conjunction with the extending longitudinal fibers of both ureters extend below the bladder neck and reach the muscular layers of the urethra. In male humans these structures reach to the point of the seminal colliculus. Therefore, a closure of the bladder neck to maintain continence, even in case of damage of the rhabdosphincter (e.g. traumatic urethral injury), or to ensure antegrade ejaculation is possible.

The blood supply of the urinary bladder generally derives from two main branches of each of the internal iliac arteries: the superior vesical artery and the inferior vesical artery—often named the superior and inferior vesical pedicle during surgery. The superior vesical artery descends from a common branch with the former umbilical artery, which is part of the medial umbilical ligament (landmark for the superior vesical pedicle during cystectomy). The inferior vesical artery arises from a common branch of the middle rectal artery. Prostatic branches generally derive from the inferior vesical artery. Varying distinct venous plexuses on both sides of the vesical base secure the blood drainage of the urinary bladder. These venous vessels communicate extensively with the prostatic venous plexus in male and the vaginal venous plexus in female humans. Both, the thin venous vessel wall (especially in case of neoplastic vascularization) and the numerous venous interconnections might result in demanding vascular control during radical surgery.

Organs of the pelvis, in contrast to other regions, present a widespread field of lymph node drainage. The urinary bladder drains its lymph fluid through external iliac lymph nodes, internal iliac lymph nodes, lymph nodes in the obturator fossa and common iliac lymph nodes (Fig. 2.5).

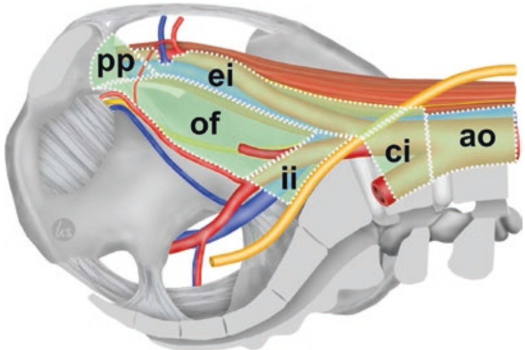

Fig. 2.5 Areas of lymphadenectomy for pelvic surgery: post pubic (pp), external iliac (ei), obtorator fossa (of), internal iliac (ii), common ilica (ci), aortal (ao). (Reprinted from Schilling et al. [28] with permission from Wiley-Blackwell)

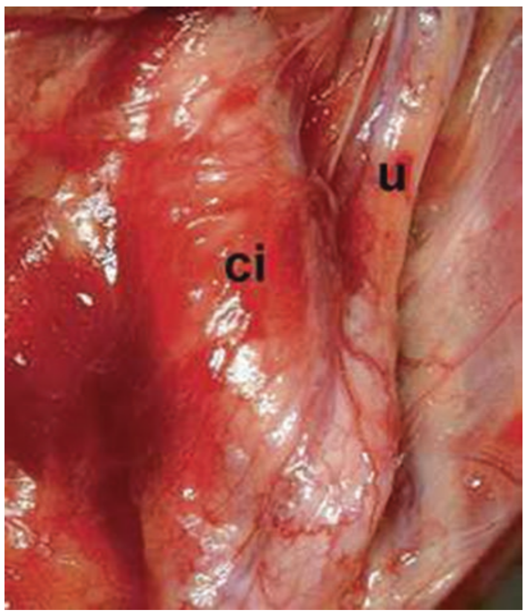

Fig. 2.6 Nerve course of the sympathetic fibers deriving from the superior hypogastric plexus (*ci* common ilica artery, *u* ureter). (Reprinted from Schilling et al. [28] with permission from Wiley-Blackwell)

A complex neural system facilitates the correct functioning of the urinary bladder as a storage and drainage system. Interactions between independent reflex pathways and arbitrary actions are necessary for a precise process. Both the autonomous and the somatic nervous system contribute to carrying out the tasks of bladder filling and emptying.

Anatomic nerve fibers reach the urinary bladder (and adjacent organs) through the inferior hypogastric plexus (=pelvic plexus). The inferior hypogastric plexus thus comprises the parasympathetic and sympathetic nerve tracts. Anatomically the inferior hypogastric plexus derives from the singular superior hypogastric plexus, which reaches the pelvis proximally and medial to the crossing of the distal ureter and the common iliac artery on both sides (Fig. 2.6). The inferior hypogastric plexus is part of the bilateral rectouterine or rectovesical fold beside the pouch of Douglas (Fig. 2.3). The plexus extends laterally to the rectum, the vagina (in females), the bladder neck and the seminal vesicles (in males) in a sagittal direction. The continuing course of nerve fibers along the prostate is described in the next chapter. An allocation of nerve fibers within the plexus to innervated targets seems to be possible. Roughly, the anterior part is responsible for urogenital innervations, and the posterior part serves the rectum.

The sympathetic fibers of the inferior hypogastric plexus originate from the superior hypogastric plexus, which is fed by nerve fibers from the lumbar sympathetic trunk condensed in 2–3 lumbar splanchnic nerves, as well as from sacral splanchnic nerves, which derive straight from the sacral part of the sympathetic trunk.

Sympathetic excitation generally results in inhibition of the detrusor muscle and stimulation of the smooth muscle sphincter cells, which leads to a filling of the urinary bladder. The parasympathetic fibers derive from the sacral spinal cord (S2-S5) and reach the inferior hypogastric plexus via pelvic splanchnic nerves exiting from the foramina of the sacral bone. Sensory afferent nerve fibers of the urinary bladder (and most probably of the proximal urethra as well) run along the parasympathetic nerves. Contraction of the detrusor muscle is mediated through the parasympathetic nervous system. The pudendal nerve is part of the somatic nervous system and innervates the striated parts of the external urethral sphincter. The pudendal nerve courses in the pudendal canal (Alcock's canal) at the bottom of the inferior pubic bone after the distribution of the lumbosacral plexus (S2–4). The variation of an intrapelvic nerve branching off the pudendal nerve prior to entering the pudendal canal and running on the inside of the levator muscle has been described. Stimulation results in increased contraction of the external urethral sphincter and adjacent segments of the levator ani muscle. Complex interconnections on different sections of the central nervous system, including Onuf's nucleus (located in the sacral part of the spinal cord), the periaqueductal grey, the pontine micturition center and the frontal lobe of the cerebrum, are involved in the process of filling and emptying. For example, it could be demonstrated that pelvic floor training for stress urinary incontinence not only influences the competence of the sphincteric mechanisms, but the training also results in restructuring of supraspinal central nervous system components [2, 4, 27–32].

Prostate, Seminal Vesicles and Deferent Ducts

The prostate is often compared to a chestnut of about 20 g. With the base aligned to the urinary bladder and the apex proximate to the external urinary sphincter, the prostate incorporates the prostatic urethra with a length of about 3 cm.

As a result of benign prostatic hyperplasia sizes up to 300 g are possible, which influences topography to the adjacent organs and structures (periprostatic nerves, striated and smooth muscle of the sphincter complex) as well as the distribution of the subsequently described prostatic zones.

McNeal defined the different zones of the prostate based on histopathological analysis: the peripheral zone, the central zone, the transitional zone and the anterior fibromuscular zone. This definition has to be separated from the macroscopic classification into lobes.

The ejaculatory ducts are paired tubes formed on each side by fusion of the deferent duct and the duct of the seminal vesicle. The orifices of the ejaculatory ducts are located on the seminal colliculus (also called the verumontanum). 15–30 orifices of ducts of the prostate glands are located beside the seminal colliculus.

The seminal vesicles are located lateral to the deferent ducts. Dorsally and laterally fibers from the inferior hypogastric plexus engulf the vesicles. The space between Denonvillier's fascia dorsally and the fascia covering the posterior wall of the bladder is called the spatium urovesicale (urovesical space). Recent studies describe smooth muscle fibers merged longitudinally into the Denonvillier's fascia, which connect the urinary bladder to the prostate at the entry of the ejaculatory ducts. This so-called vesicoprostatic muscle has to be identified and dissected during radical prostatectomybladder (neck preparation) (Fig. 2.7). Branches of the inferior vesical

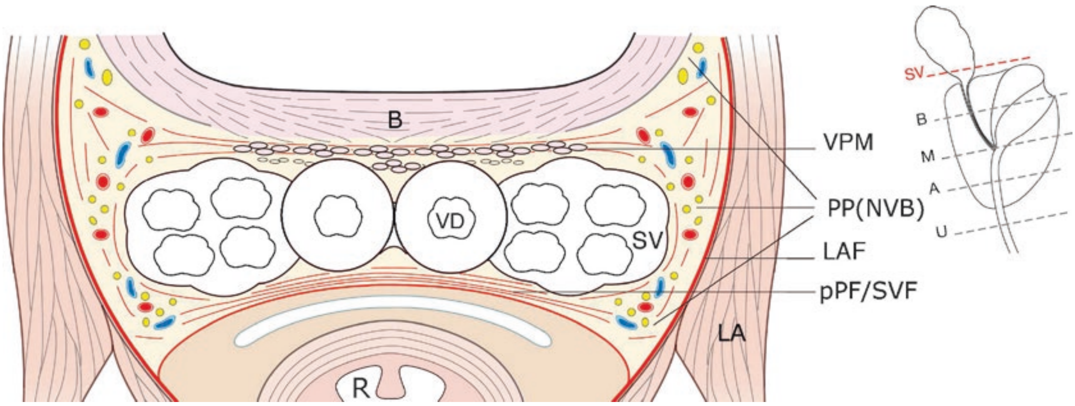

Fig. 2.7 Axial cross-section of the pelvis at the level of seminal vesicles (SV) illustrates the relation of deferent duct (VD), seminal vesicle, bladder (B), neurovascular bundle (NVB) and rectum (R) to the posterior pelvic fascia (synonymic seminal vesical fascia (SVF) or Denonvilliers' fascia), the vesicoprostatic muscle (VPM) and the levator ani fascia (LAF). (Reprint of Walz et al. [16] with permission of Elsevier)

artery, the middle rectal artery and the artery of the vas deferens usually reach the seminal vesicle at its tip.

The deferent duct is characterized by a dilatation prior to the confluence with the duct of the seminal vesicle called the ampulla. The deferent duct is accompanied by one or two separate arteries (arteries of the vas deferens), which derive from the inferior vesical artery. These arteries play an important role (beside additional cremasteric arteries) to ensure testicular blood supply during two-staged Fowler-Stephens procedure to treat cryptorchism with intraabdominal testis and the need to divide the main testicular vessels.

The inferior vesical and the middle rectal artery contribute to the blood supply of the prostate. The main vessels enter the prostate on both sides at the dorsolateral aspect close to the base of the prostate. Smaller vessels perforate the prostate capsule directly. Venous drainage moves from the surrounding prostatic venous plexus.

Accessory pudendal arteries can be found in about 25% of the patient population undergoing radical prostatectomy. An accessory pudendal artery is defined as a vessel starting above the level of the levator ani muscle, running down to the penile structures below the symphysis pubis and the pubic bone, respectively. Some authors subdivide the accessory arteries into lateral (alongside the anterolateral aspect of the prostate) and apical (inferior and lateral to the puboprostatic ligaments) accessory pudendal arteries. The extent of their contribution to the erectile function of the penis is still under investigation and discussion.

The puboprostatic complex includes the puboprostatic ligaments, the prostatic venous plexus and their correlation to the prostate and the external urethral sphincter. The puboprostatic ligaments formed by the endopelvic fascia, first described by Young, are described above. The prostatic venous plexus communicates extensively with the distinct venous plexus of the urinary bladder cranially and the superficial/deep dorsal veins of the penis. The proper name (Santorini's plexus) refers to their initial discovery by Giovanni Domenico Santorini in 1724. The venous plexus is imbedded in the fibrous structure of the so-called puboprostatic ligaments. The puboprostatic plexus directly covers the anterior elevated part of the external urethral sphincter (see also following chapter). The proximate neighborhood of sphincter structures, periprostatic nerves continuing beside the urethra and big venous vessels explains the risk of functional damage by an uncontrolled dissection of the Santorini's plexus.

The description of the anatomic affiliations of pelvic lymph nodes to the drainage field was originally based on lymphographic studies.

Recent findings are the results of sentinel lymph node studies. The injection of ^{99m}Tc-labeled nanocolloid into the prostate facilitates the identification of sentinel lymph nodes either by surgery or by radiological imaging (Fig. 2.8). The lymph nodes of the obturator fossa, the external iliac lymph nodes, the internal and finally the common iliac lymph nodes are responsible for the drainage of the prostate gland (Figs. 2.8 and 2.9).

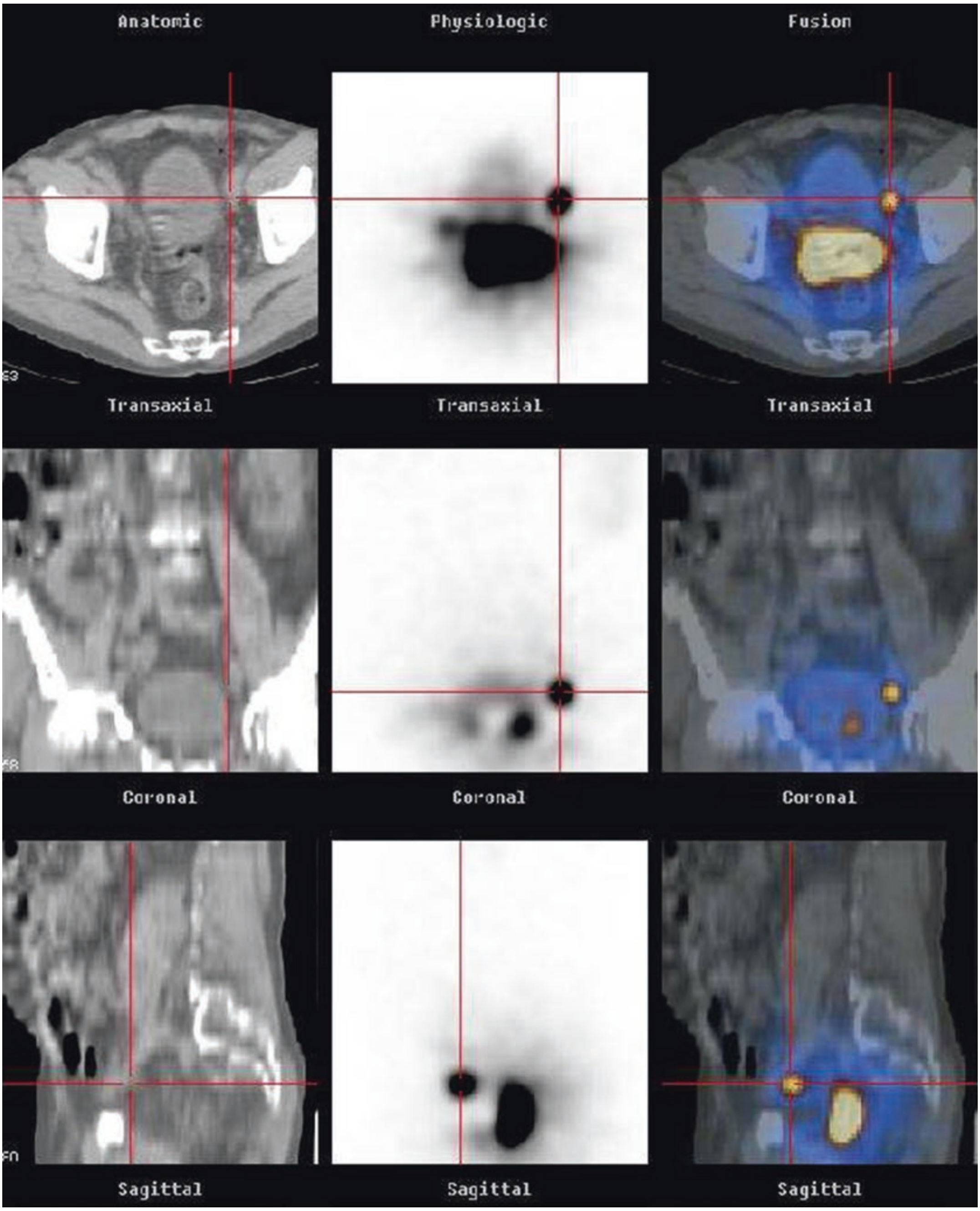

Fig. 2.8 Radiological image of sentinel lymph nodes after injection of ^{99m}Tc-labeled nanocolloid into the prostate. Left column: CT scan images, middle column: SPECT images, right column: CT/SPECT fused images. Sentinel lymph node located inside the red indicator

Although oncological aspects are still the main concern of every radical prostatectomy treating prostate cancer, quality of life aspects including erectile function as well as continence have become important. The existence of the endopelvic fascia equipollent to the visceral layer of the pelvic fascia has been outlined above. Most authors would agree that the neurovascular structures are located between the prostate surface with its fibromuscular capsule and the visceral layer of the pelvic fascia, which extends to Denonviellers' fascia at the dorsolateral aspect of the prostate (Fig. 2.10). Some studies describe a merger between the different parts of the multilayered fascia as described above. Whether nervous tissue can also be found in the fold between the visceral and the parietal layer of the pelvis remains unclear. In 1985, Donker, Walsh et al. were the first to extensively describe the neurovascular bundle. The technique of nerve-sparing radical prostatectomy and cystectomy was adapted regarding these anatomical findings. Especially the course of these periprostatic nerves has resurfaced as a focus of academic interest the last decade. The entry of the inferior hypogastric plexus into the pelvis and its location lateral to the seminal vesicles, including the convergent fibers of the sacral splanchnic nerves (sympathetic) and pelvic splanchnic nerves (parasympathetic), has been referred to above. Furthermore, the presence of somatic nerves with a percentage of about 5% has been detected. This might explain in conjunction with the confirmation of sensory fibers, responsible for innervation of the membranous/proximal penile urethra, that uni- or bilateral nerve-sparing also influences post-prostatectomy continence (Fig. 2.10).

In contrast to a separate dorsolateral nerve bundle, several authors reinvestigated the anatomy and described different nerve dispersions. The periprostatic nerves proceed divergently especially in the mid-part of the prostate; therefore, a varying amount of nerve tissue can be found also in the anterior and anterolateral aspect of the prostate in addition to the known accumulation in the dorsolateral course (Figs. 2.11 and 2.12). Characteristically the nerve fibers converge towards the apex located at the posterior

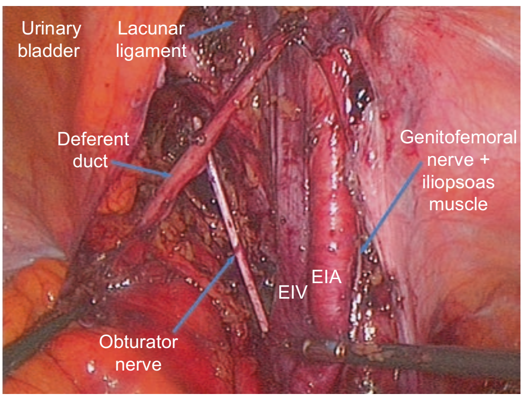

Fig. 2.9 Situs after laparoscopic lymphadenectomy for prostate cancer; EIV: external ilic vein, EIA: external iliac artery. The lacunar ligament as the distal extent of lymphadenectomy

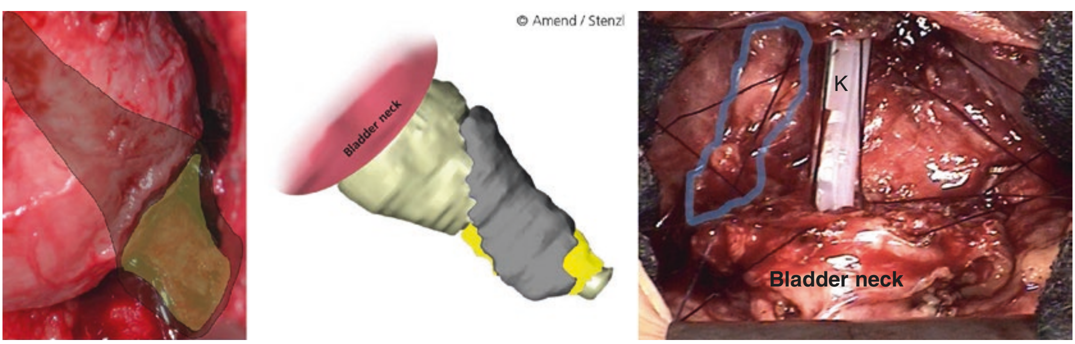

Fig. 2.10 Retropubic radical prostatectomy. Left: prostate after apical preparation with isolated membranous urethra (yellow shade). The grey shade outlines the area of the rhabdosphincter. Right: nerve-sparing procedure on left side (marked in blue) and partial nerve-sparing procedure on right side before anastomosis (K: transurethral catheter)

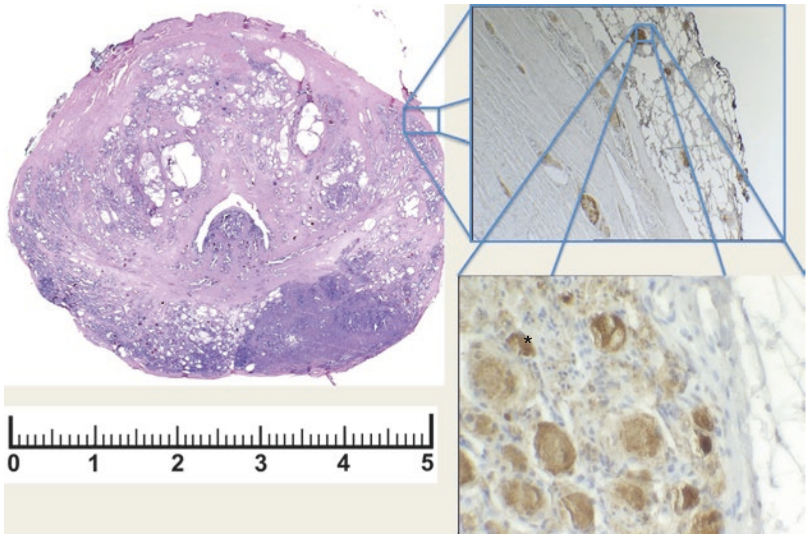

Fig. 2.11 Whole mounted horizontal section (left side, HE staining) of the prostate (∗prostate carcinoma). Staining with protein-gene-product (PGP) 9.5 antibodies illustrates the existence of nerve fibers anterior-lateral [42]

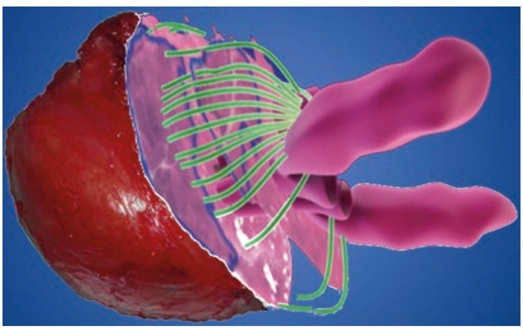

Fig. 2.12 3D reconstructions of nerve courses (right side: green lines) based on prostate specimens (left side) and whole mounted sections (middle part)

and posterolateral side of the apex and the urethra, respectively. In addition, parts of the periprostatic nerves leave the craniocaudal course and enter into the prostate for innervations. Initial investigations demonstrated the correlation of neural impulses routed through the nerve fibers on the anterior aspect of the prostate and erectile function. Beside the description of somatic periprostatic nerves additional emerging studies clarified the different nerve quantities surrounding the prostate gland. Relevant portions of parasympathetic and sympathetic fibers have been found anterolaterally at the level of the prostate base with subsequent condensation to a posterolateral course at the prostatic apex. The data supports a higher release of the periprostatic tissue for nerve-sparing with emphasis to the prostatic base-if the oncologic situation justifies this approach (Fig. 2.13) [2, 4, 7–12, 16, 19, 30, 33–50].

Urethra

Male Urethra

The urethra is subdivided into four different parts: the intramural part (=pre-prostatic urethra) at the bladder neck, the prostatic urethra, the membranous urethra and the spongy urethra surrounded by the corpus spongiosum. Transitional cells in large sections characterize the mucosa. The distal part near the navicular fossa is marked by a stepwise transition over stratified columnar cells to stratified squamous cells. The muscle layer is divided into an inner longitudinal, a middle circular and an inconsistently described outer longitudinal stratum. The bulbourethral artery, a branch of the internal pudendal artery entering at the level of the penile bulb, supplies the spongy urethra.

Female Urethra

The female urethra is about 3–5 cm long. The histology is equivalent to the male urethra.

Aspects of the urethral closure mechanisms are focused on in the following paragraph.

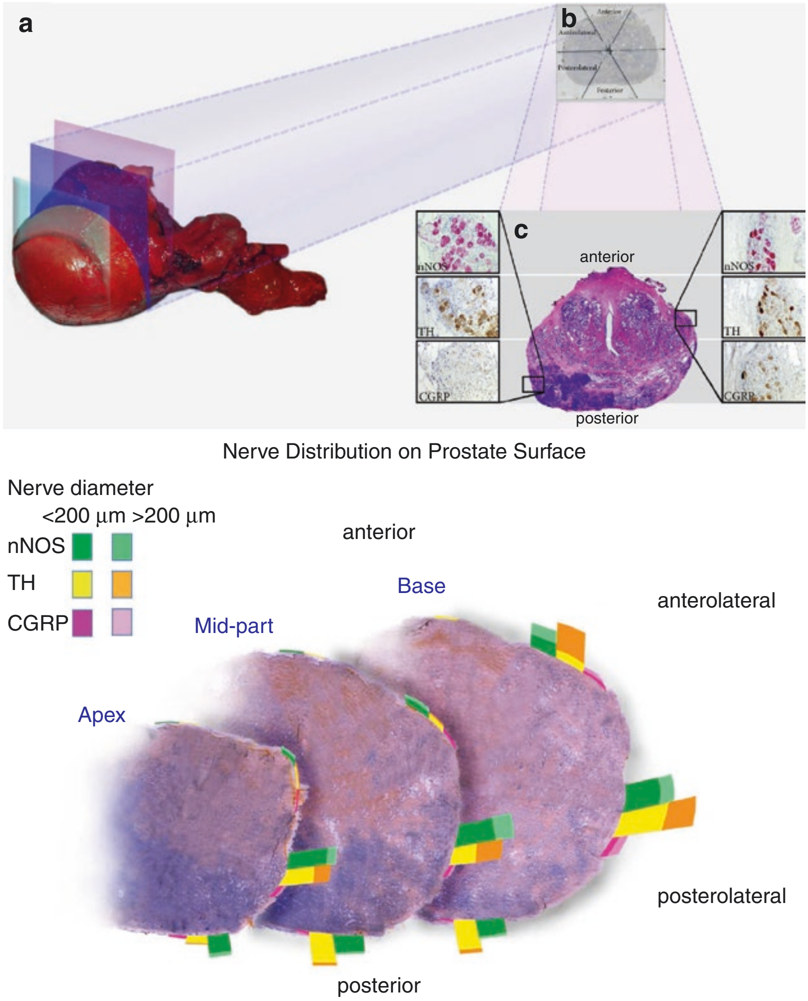

Fig. 2.13 Upper image illustrates prostate cross-sections with sectored quantification of nNOS+, TH+ and CGRP+ periprostatic nerves. Lower image illustrates the nerve distribution of the different qualities ranging from base to apex. (Reprint of Sievert et al. [49] with permission of John Wiley and Sons)

Sphincter Mechanisms

Traditional anatomy reports two muscular structures to achieve continence of the lower urinary tract: the voluntary, striated, external urethral sphincter (rhabdosphincter) located in the urogential diaphragm and the autonomous, smooth internal sphincter (lissosphincter) located in the bladder neck. However, the anatomical and functional understanding of the sphincter complex has changed over time (Fig. 2.14). In comparison to the periprostatic anatomy, various descriptions have been published. The contribution of three different components to the sphincter complex is commonly accepted: the detrusor muscle fibers of the bladder neck including the trigone, the

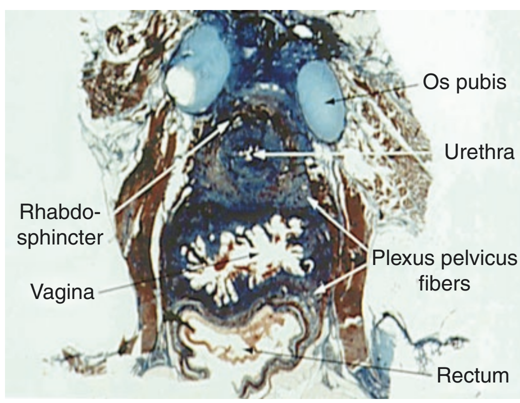

Fig. 2.14 Fetal female pelvis illustrating the omega-shaped rhabdosphincter surrounding the urethra and the topographical location of plexus pelvicus fibers. (Reprinted from Colleselli et al. [51] copyright 1998, with permission from Elsevier)

intrinsic smooth muscle fibers of the urethral wall and the external urethral sphincter. The description of the systematic anatomical circumstances and the interaction of the mentioned components vary with different authors.

The Bladder Neck Component

The presence of the circumscribable, circularly oriented smooth muscle sphincter at the outlet of the urinary bladder was denied by different authors 200 years ago. It has been demonstrated both that the detrusor muscle fibers condense especially in the direction of the trigone and that the smooth intrinsic fibers of the urethral wall arrange a complex interacting network of muscle strands at the bladder outlet. In male humans, as reported before, the detrusor fibers reach the point of the seminal colliculus. The bladder neck component is thought to be innervated by the autonomic nervous system.

The Urethral Wall Component

The smooth muscle fibers of the urethral wall do not act as a detached actor. In fact, they can be interpreted as a continuance of the muscular complex of the bladder neck. The urethral muscular layer consists of longitudinally (inner and (inconsistently described) outer layer) and circularly (middle layer) oriented muscle fibers. Reports of the exact anatomical condition vary. Also, these smooth muscle fibers receive autonomic innervations.

The External Urethral Sphincter

Many authors have shaped the anatomical understanding of the external urethral sphincter, but an overall accepted anatomical and functional definition is still lacking. Consensus of opinion exists regarding the three-dimensional profile of the external sphincter. The terms omega-shaped and horseshoe-shaped are most often used to illustrate the external sphincter in male as well as female humans (Figs. 2.15 and 2.16). Muscle fibers are located in the anterior and lateral part of the urethra—only fibrous tissue forms the dorsal interconnection between the dorsolateral "ends" of the external sphincter. In the same way, authors concur that the external sphincter is not part of an urogential diaphragm (deep transverse perineal muscle) and that the external sphincter only has a fibrous connection to the surrounding tissue (including the pelvic diaphragm).

There is extensive discussion about the vertical extend and the histological constitution of the external urethral sphincter.

The participation of striated muscle fibers in the configuration of the external sphincter has

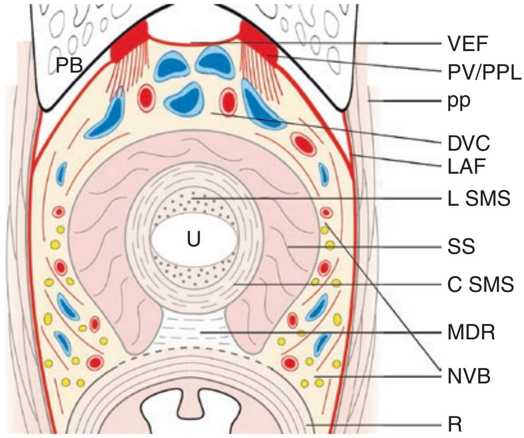

Fig. 2.15 Schematic illustration of the u-shaped rhabdosphinter (SS) (pubic bone (PB), visceral endopelvic fascia (VEF), puboprostatic ligament (PPL), puboperinealis muscle (PP), dorsal vein complex (DVC), levator ani fascia (LAF), longitudinal lissosphincter (L SMS), circular lissosphincter (C SMS), median dorsal raphe (MDR), neurovascular bundle (NVB) and rectum (R)). (Reprint of of Walz et al. [16] with permission of Elsevier)

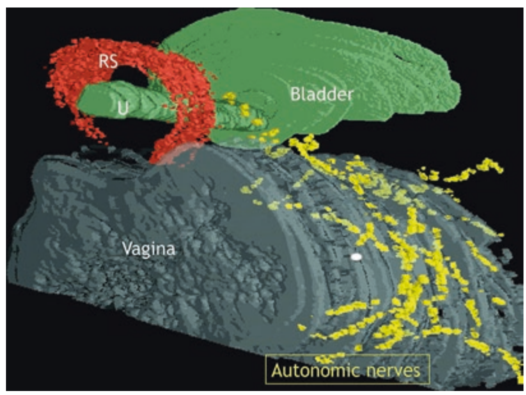

Fig. 2.16 3D reconstruction of the rhabdosphincter (RS) and the autonomic nerve supply based on female fetal pelvic studies. *U* urethra. (Reprinted from Colleselli et al. [51] copyright 1998, with permission from Elsevier)

long been well known. Essentially the external sphincter has to secure continence continuously as well as during rapid abdominal pressure. Whereas some authors favor the existence of two different striated muscle fibers ("slow twitch fibers" for basic pressure of the external sphincter and "fast twitch fibers" for rapid pressure increases), others report the existence of a smooth muscle component located inside the coat of the striated external sphincter. Therefore, the description internal urethral sphincter (in contrast to the internal vesical sphincter) is used. It is accepted that the pudendal nerve (somatic nervous system) is responsible for the innervations of the voluntary striated external sphincter. Whether autonomous fibers resulting from the inferior hypogastric plexus or lately described somatic fibers (routed through the periprostatic plexus) with potential impact after nerve sparing radical prostatectomy are involved in the sphincter innervations is still under investigation.

In male humans it is assumed that the striated muscle fibers of the pronounced anterior part of the sphincter disperse below the puboprostatic ligaments (Fig. 2.15). It is still unclear if striated muscle fibers communicate with the structures of the bladder neck. In females it could be demonstrated that parts of the striated external sphincter could only be found in the two distal thirds of the urethra. In addition, striated muscle fibers also surrounding the lateral aspect of the vagina have been recently reported [2, 4, 10, 17, 19, 20, 22, 23, 25, 51–54].

Summary

Knowledge of the anatomy of the lower urinary tract was substantiated by comprehensive investigations long ago. Over time, many consolidated findings have been refuted and then recognized again. Current urological treatments are based on these anatomical conclusions. It has been shown that while some irrevocable facts have been substantiated in several fields of urological anatomy, extensive exploration is still taking place. Especially the complex sphincter mechanism in both females and males as well as the pelvic neuroanatomy are examples of these interesting research subjects. Only functional studies will validate whether these upcoming new aspects of anatomy will also lead to better treatment outcomes for our patients.

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