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A Critical Analysis of the Current Knowledge of Surgical Anatomy Related to Optimization of Cancer Control and Preservation of Continence and Erection in Candidates for Radical Prostatectomy

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Abstract

Context: Detailed knowledge of the anatomy of the prostate and adjacent tissues is mandatory during radical prostatectomy to ensure reliable oncologic and functional outcomes.

Objective: To review critically and to summarize the available literature on surgical anatomy of the prostate and adjacent structures involved in cancer control, erectile function, and urinary continence.

Evidence acquisition: A search of the PubMed database was performed using the keywords *radical prostatectomy, anatomy, neurovascular bundle, fascia, pelvis,* and *sphincter*. Relevant articles and textbook chapters were reviewed, analyzed, and summarized.

Evidence synthesis: Anatomy of the prostate and the adjacent tissues varies substantially. The fascia surrounding the prostate is multilayered, sometimes either fused with the prostate capsule or clearly separated from the capsule as a reflection of interindividual variations. The neurovascular bundle (NVB) is situated between the fascial layers covering the prostate. The NVB is composed of numerous nerve fibers superimposed on a scaffold of veins, arteries, and variable amounts of adipose tissue surrounding almost the entire lateral and posterior surfaces of the prostate. The NVB is also in close, cage-like contact to the seminal vesicles. The external urethral sphincter is a complex structure in close anatomic

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and functional relationship to the pelvic floor, and its fragile innervation is in close association to the prostate apex. Finally, the shape and size of the prostate can significantly modify the anatomy of the NVB, the urethral sphincter, the dorsal vascular complex, and the pubovesical/puboprostatic ligaments.

Conclusions: The surgical anatomy of the prostate and adjacent tissues involved in radical prostatectomy is complex. Precise knowledge of all relevant anatomic structures facilitates surgical orientation and dissection during radical prostatectomy and ideally translates into both superior rates of cancer control and improved functional outcomes postoperatively.

1. Introduction

During the last three decades, the surgical treatment of prostate cancer has changed remarkably because of both better knowledge of prostate anatomy and advances in surgical techniques, which have improved cancer control and functional results [1–4]. These results are closely related to the identification of a multilayered periprostatic fascia (PPF), which permits definition of dissection planes for complete oncologic excision of the prostate and preservation of both the external urinary sphincter responsible for urinary continence and the autonomic nerves responsible for erectile function and urinary control [4–7]. Lack of identification of these structures during radical prostatectomy may potentially result in inferior oncologic results as well as in a higher risk of incontinence or erectile dysfunction. The aim of this paper is to summarize critically the available literature and to provide a detailed and illustrated overview of prostate anatomy with the goal of helping urologists in performing an anatomic radical prostatectomy.

2. Evidence acquisition

A search of the PubMed database was performed to identify original and review articles in English that address the anatomy of the prostate and relevant structures adjacent to the prostate, without any limit to publication date. The keywords used were *radical prostatectomy*, *anatomy*, *neurovascular bundle*, *fascia*, *pelvis,* and *sphincter*. Relevant articles and textbook chapters were reviewed, analyzed, and summarized with the consensus of the authors of this paper.

3. Evidence synthesis

3.1. *Pubovesical/puboprostatic ligaments*

Ventrally, the proximal prostate is covered by muscle fibers originating from the outer longitudinal bladder muscle and extending over the gland. These fibers constitute a detrusor apron (Figs. 1 and 2) [8–10]. The pubovesical/puboprostatic ligaments (PV/PPLs) are paired fibrous bands originating from visceral endopelvic fascia. They insert on the distal third of the posterior surface of the pubic bone adjacent and anterior to the urethral sphincter (Fig. 3) [10,11]. Because of their underlying attachment to the ventral prostate, they are known officially as the *puboprostatic ligaments* [10,12–14]. The close relationship and attachment of the PV/PPLs to the anterior bladder is easily appreciated in patients with small or normal-sized prostates, but it is more difficult to identify in the presence of ventrally expanding benign prostatic hyperplasia [12]. The PV/PPLs stabilize the prostate, urethra, and bladder to the pubic bone and are considered an important part of the "suspensory system" of the continence mechanism [15–19]. Some authors have suggested that preservation of these ligaments during radical prostatectomy may improve early recovery of urinary continence, but no definitive evidence has been established [17,18]. Preservation of the PV/PPLs is facilitated using the perineal and laparoscopic approach, whereas during open retropubic prostatectomy the PV/PPLs are more difficult to preserve [5,20–22].

3.2. *Dorsal vascular complex*

The prostate and the urethral sphincter are covered ventrally by the popularly termed *dorsal vein complex* or *Santorini's plexus*, which drains blood of penile veins together with urethral and lateral pelvic veins [11]. It often contains small arteries, which originate from the inferior vesical artery [23]. Therefore, the dorsal vein complex is in essence a dorsal vascular complex (DVC; Figs. 1–3) [10]. Distal to the prostate apex, the DVC is separated from the urethral sphincter by the sphincter's fascia [5,24]. At the apex, the DVC may be split by the PV/PPLs into medial and lateral components [13,25]. The DVC then courses cephalad on the ventral aspect of the prostate to the bladder with variable anastomoses to bladder and lateral prostate veins. Ventrally, the DVC is covered by extensions of the visceral endopelvic fascia and the detrusor apron. At the prostatourethral junction, an avascular plane is present between the prostate and the DVC, forming a landmark for DVC control [10]. When approaching the prostatourethral junction, one may find inconstant, supporting fibrous bands (Müller's ischioprostatic ligaments, Walsh's pillars) flanking the striated sphincter and into which an anterior layer of the striated sphincter inserts [26].

3.3. *Accessory pudendal arteries*

Accessory or aberrant pudendal arteries are arteries superior to the pelvic diaphragm passing posterior to the

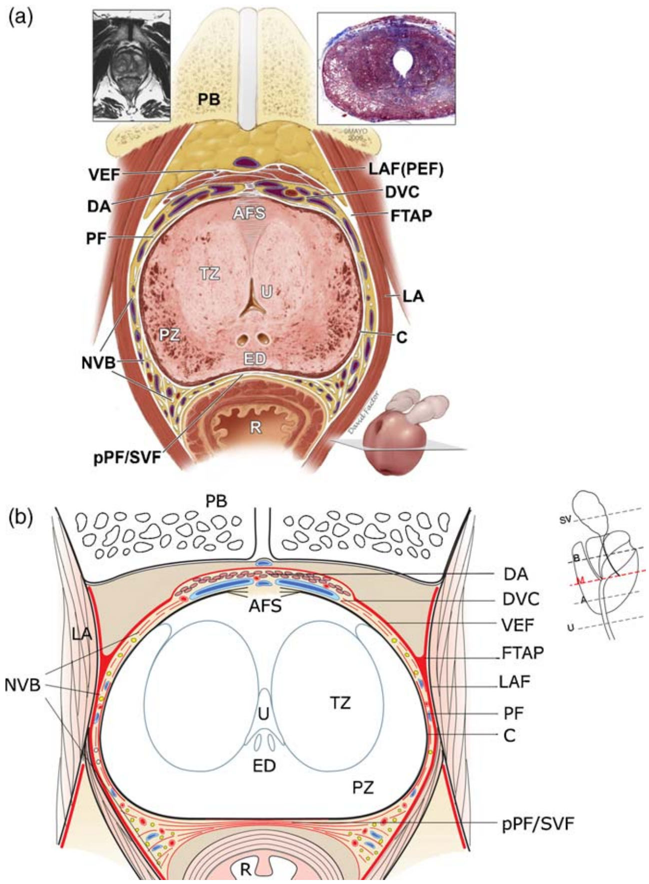

Fig. 1 – Axial section of prostate and periprostatic fascias at midprostate: (a) anatomic (reproduced with permission from the Mayo Clinic); (b) schematic.
AFS = anterior fibromuscular stroma; C = capsule of prostate; DA = detrusor apron; DVC = dorsal vascular complex; ED = ejaculatory ducts; FTAP = fascial tendinous arch of pelvis; LA = levator ani muscle; LAF = levator ani fascia; NVB = neurovascular bundle; PB = pubic bone; PEF = parietal endopelvic fascia; PF = prostatic fascia; pPF/SVF = posterior prostatic fascia/seminal vesicles fascia (Denonvilliers' fascia); PZ = peripheral zone; R = rectum; TZ = transition zone; U = urethra; VEF = visceral endopelvic fascia.

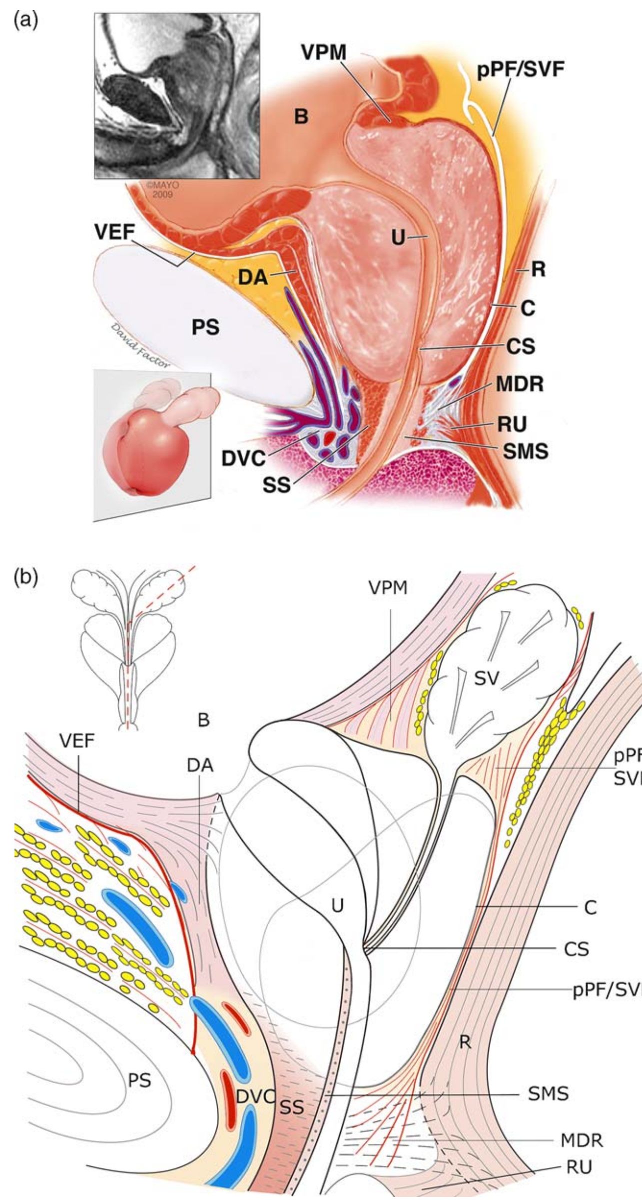

Fig. 2 – Midline sagittal section of prostate, bladder, urethra, and striated sphincter: (a) anatomic (reproduced with permission from the Mayo Clinic); (b) schematic.
B = bladder; C = capsule of prostate; CS = colliculus seminalis (verumontanum); DA = detrusor apron; DVC = dorsal vascular complex; MDR = medial dorsal raphe; PS = pubic symphysis; pPF/SVF = posterior prostatic fascia/seminal vesicle fascia (Denonvilliers' fascia); R = rectum; RU = rectourethralis muscle; SMS = smooth muscle sphincter (lissosphincter); SS = striated sphincter (rhabdosphincter); U = urethra; VEF = visceral endopelvic fascia; VPM = vesicoprostatic muscle.

pubic bone to finally enter the penile hilum. They may originate from the internal or external iliac or obturator arteries as opposed to the small arteries present within the DVC as previously mentioned. Accessory or aberrant pudendal arteries are present in 4–75% of all men and provide unilaterally or bilaterally arterial blood to the corpora cavernosa [27,28]. They may be solely responsible for arterial blood supply to the corpora cavernosa; if so, preservation of these arteries during prostatectomy would be mandatory to avoid erectile dysfunction caused by penile arterial insufficiency [29–32]. Two different types of accessory or aberrant pudendal arteries are categorizable (Fig. 4) [31,33].

Lateral accessory or aberrant pudendal arteries run along the fascial tendinous arch of the pelvis in the groove between the bladder, prostate, and pelvic sidewall (Fig. 4). Another variation enters laterally below the pubic bone. All run either above or below the endopelvic fascia. Those running above the endopelvic fascia usually branch off from either the inferior vesical or internal iliac artery, whereas those running below usually emanate from an obturator artery or external iliac artery [31,33,34].

Apical accessory pudendal arteries are found inferior and lateral to the PV/PPLs, in proximity to the anterolateral aspect of the prostate apex (Fig. 4). They characteristically emerge laterally, having passed through the adjacent levator ani muscle. They then approach the apex tangentially and may often extend to the apex before running parallel into the DVC and toward the penis [31,33].

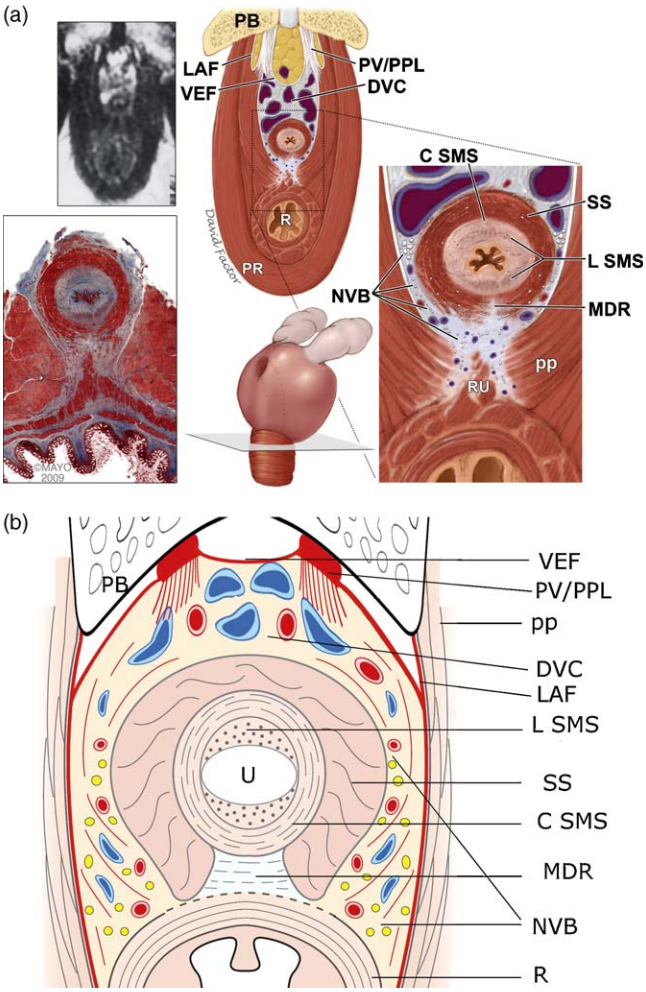

Fig. 3 – Axial section of sphincteric urethra: (a) anatomic (reproduced with permission from the Mayo Clinic); (b) schematic.
DVC = dorsal vascular complex; LAF = levator ani fascia; MDR = median dorsal raphe; NVB = neurovascular bundle; PB = pubic bone; PV/PPL = pubovesical/puboprostatic ligament; pp = puboperinealis muscle; PR = puborectalis muscle; R = rectum; RU = rectourethralis muscle; SS = striated sphincter (rhabdosphincter); C SMS = circular smooth muscle sphincter (lissosphincter); L SMS = longitudinal smooth muscle sphincter (lissosphincter); U = urethra; VEF = visceral endopelvic fascia.

Presumably, they branch off from an obturator artery or infralevator pudendal artery. Large apical accessory pudendal arteries may represent aberrant pudendal arteries, whereas smaller ones often provide only minor arterial supply to the corpora cavernosa [33].

3.4. *Fascias of the prostate*

3.4.1. *Endopelvic fascia*

The pelvic organs are covered by fascias [13,24,35]. According to the *Terminologia Anatomica*, the pelvic fascias are either parietal or visceral [36]. The parietal component denotes the fascia covering the medial aspects of the levator ani muscle, and some authors refer to it as *endopelvic fascia* [9,25]. Others consider the entire parietal and visceral pelvic fascia as endopelvic fascia [22,24,37]. In this paper, we distinguish a parietal endopelvic fascia and a visceral endopelvic fascia. The visceral component of the endopelvic fascia covers the pelvic organs including prostate, bladder, and rectum, and it is fused with the anterior fibromuscular stroma of the prostate at the upper ventral aspect of the gland (Figs. 1–3) [24,38–40].

Along the pelvic sidewall at the lateral aspect of the prostate and bladder, the parietal and the visceral components of the endopelvic fascia are fused. As a fascial condensation, this fusion is often recognizable as a whitish line and named the *fascial tendinous arch of the pelvis*. It stretches from the PV/PPLs to the ischial spine. During surgery, access to the lateral prostate may be gained by incision of the endopelvic fascia either medial or lateral to this fusion [8,13,25]. Some authors have suggested that avoiding incision of the endopelvic fascia during radical prostatectomy, often combined with an intrafascial nerve-sparing procedure, might improve early recovery of urinary continence as well as improve postoperative erectile function, but definitive evidence has yet to be established [24,37,41].

The parietal endopelvic fascia includes fascia of the levator ani muscle (Fig. 1). The incision of this fascia immediately lateral to the fascial tendinous arch incises the levator ani fascia (LAF) and leaves the muscle fibers of the levator ani bare and the LAF adherent to the prostate

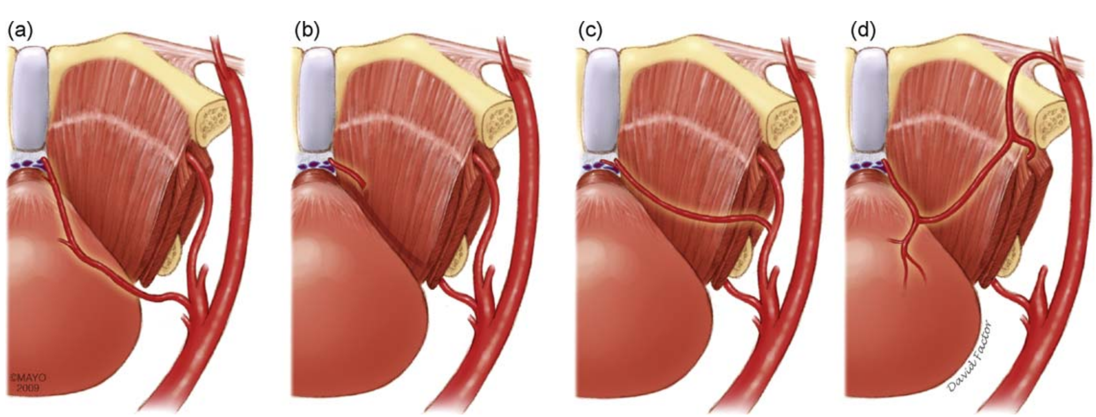

Fig. 4 – Aberrant and accessory pudendal arteries: (a) aberrant lateral supralevator pudendal artery branching from internal iliac artery; (b) accessory apical pudendal artery branching from infralevator pudendal artery; (c) accessory lateral pudendal artery branching from obturator artery; (d) accessory pudendal artery branching from external iliac artery with aberrant obturator and infravesical branches. Reproduced with permission from the Mayo Clinic.

[8,13,19,42]. An incision of the visceral endopelvic fascia medial to the fascial tendinous arch results in a dissection plane that leaves the levator ani muscle covered with its fascia without exposure of its fibers [24,37,43]. The result is a prostate covered only by prostatic fascia (PF), when present, and not by a layer of LAF [24,38].

3.4.2. Periprostatic fascias

The fascia on the outer surface of the prostate has been referred to as lateral pelvic fascia by Costello et al [42], Takenaka et al [24], and in the past by Walsh and Partin [13]. Myers and Villers [25], Stolzenburg et al [14], and Tewari et al [44] called the fascia next to the prostate the periprostatic fascia; Graefen et al [5] and Budäus et al [20], the parapelvic fascia; and Menon et al [45], Secin et al [46], and, more recently, Nielsen et al [47], the prostatic fascia. This fascia is not a discrete single-layered structure stretching over the lateral surface of the prostate. Often it is ordered in several layers over the prostate and consists of both collagenous and adipose tissue elements [38,39]. Consequently, for practical purposes in this review, we use PPF to signify all fascias on the prostate that are external to the prostate capsule. The PPF covering the prostate can now be subdivided into three basic elements according to location (Figs. 1–3 and 5).

3.4.2.1. Anterior periprostatic fascia. This element as visceral endopelvic fascia is associated with the anterior surface of the prostate from approximately the 10-o'clock to 11-o'clock positions to the 1-o'clock to 2-o'clock positions, where it covers the detrusor apron, dorsal vascular complex, and is fused in the midline with the anterior fibromuscular stroma of the prostate (Fig. 1).

3.4.2.2. Lateral periprostatic fascia. Once the endopelvic fascia is opened lateral to the fascial tendinous arch of the pelvis and the levator ani muscle is deflected laterally, the outermost fascial layer on the lateral surface of the prostate is the levator ani fascia. Moreover, there is also an inner fascia in most cases, often but not always multilayered, covering the prostate capsule, which is called the *prostatic fascia* [21,47]. Both of these layers (LAF and PF) constitute PPF for the operating surgeon. These layers of fascia, on the anterolateral prostate, extend from the anterior surface of the prostate posteriorly or dorsally to embrace or meet the neurovascular bundle (NVB) with the outer LAF passing lateral to the NVB to eventually become the pararectal fascia, which separates the rectum from the levator ani [24,42,48]. The inner PF passes medial to the NVB to cover the underlying prostate capsule. The relationship between the prostate capsule and the lateral PF may differ depending on interindividual variations (Fig. 6). Kiyoshima et al found that in 52% of all cases, the LAF, which they called "lateral pelvic fascia," does not adhere to their prostate "capsule" [39]. In the cases just cited, the apparent space consisted of loose connective and adipose tissue referred to as areolar tissue [5,39,49,50]. Furthermore, in such cases the NVB could not be identified as a distinct structure but was spread out over the lateral prostatic surface [39]. It is of note that

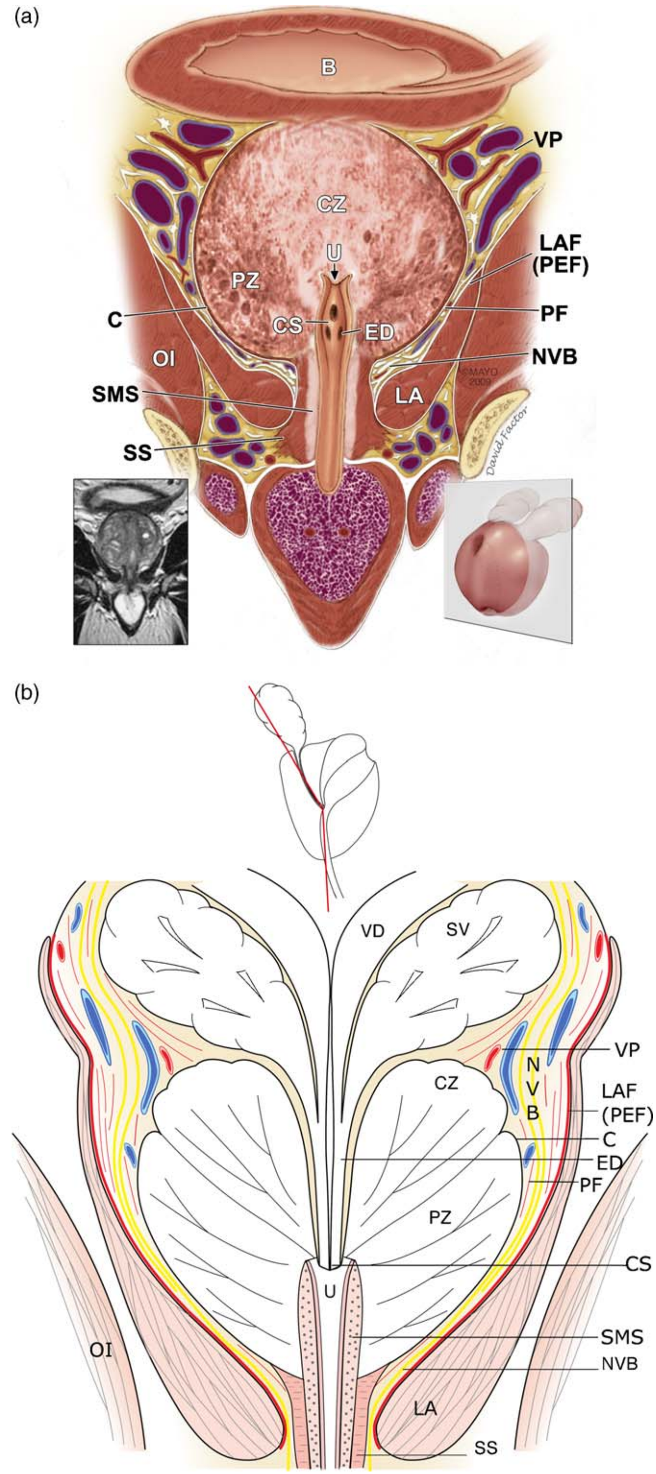

Fig. 5 – Coronal section of prostate, sphincteric urethra, periprostatic fascias, and associated musculature: (a) anatomic (reproduced with permission from the Mayo Clinic); (b) schematic.
B = bladder; C = capsule of prostate; CS = colliculus seminalis (verumontanum); CZ = central zone; ED = ejaculatory duct; LA = levator ani muscle; LAF = levator ani fascia; NVB = neurovascular bundle; OI = obturator internus muscle; PEF = parietal endopelvic fascia; PF = prostatic fascia; PZ = peripheral zone; SMS = smooth muscle sphincter (lissosphincter); SS = striated sphincter (rhabdosphincter); SV = seminal vesicle; U = urethra; VD = vas deferens; VP = vascular pedicle to prostate.

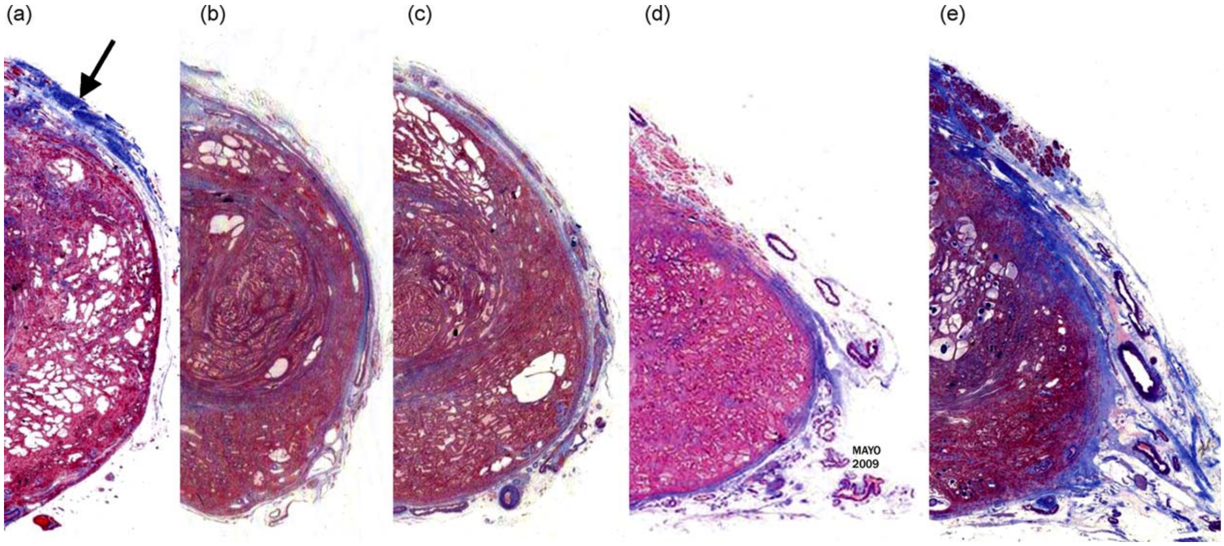

Fig. 6 – Variation of prostate capsule to prostatic fascia (PF) on the lateral surface of the prostate. Masson-trichrome staining: fascia stains bright blue; smooth muscle stains red. (a) Capsule present but no PF visible (arrow: fascial tendinous arch of pelvis); (b) PF fused to capsule; (c) capsule fused to PF; very fine levator ani fascia lateral to vessels; (d) fascia-capsular interface, variable and poorly defined; (e) relatively thick PF present but no capsule visible. Reproduced with permission from the Mayo Clinic.

the authors used hematoxylin and eosin staining only and therefore did not distinguish between the smooth muscle of the true capsule and the collagenous fibers of the PF but considered both as prostate capsule. In the remaining 48%, LAF was fused with their prostate capsule, and no areolar tissue was seen between the layers [39]. An exception to this fusion was only seen at the posterolateral angle of the prostate, and the NVB was identified there as a distinct bundle [39,40].

3.4.2.3. Posterior prostatic fascia and seminal vesicles fascia (Denonvilliers' fascia). The posterior surface of the prostate and the seminal vesicles are closely covered by a continuous layer of posterior prostatic fascia (pPF) and seminal vesicles fascia

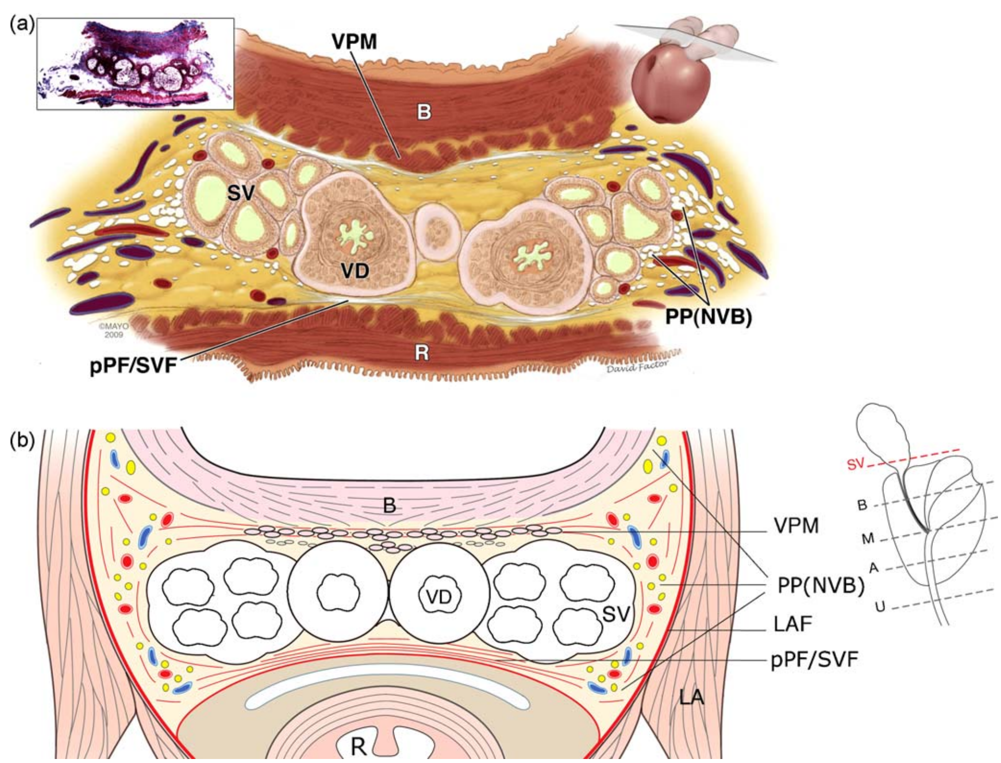

Fig. 7 – Axial section through base of seminal vesicles to show proximity of distal pelvic plexus (neurovascular bundle [NVB]): (a) anatomic (reproduced with permission from the Mayo Clinic); (b) schematic.
B = bladder; PP = pelvic plexus; pPF/SVF = posterior prostatic fascia/seminal vesicle fascia (Denonvilliers' fascia); R = rectum; SV = seminal vesicle; VD = vas deferens VPM = vesicoprostatic muscle.

(SVF), also known as *fascia rectoprostatica, septum rectovesicale, prostatoseminal vesicular fascia*, and, ubiquitously, *Denonvilliers' fascia* (Figs. 1, 2 and 7) [8,25,36]. Some authors consider the origin of the pPF/SVF as a fusion of the embryonic peritoneum of the retrovesical cul-de-sac [51–54]. Others suggest that the pPF/SVF is actually anterior to the remnant of the two fused peritoneal layers [55]. This fusion of the two peritoneal layers allows a prerectal cleavage plane between the rectal fascia propria posteriorly and the pPF/SVF anteriorly [56,57].

The cephalad origin of the pPF/SVF is found anterior to the caudal end point of the peritoneal cul-de-sac (rectovesical pouch, Fig. 2). The pPF/SVF then extends distally to the apex of the prostate to end at the prostatourethral junction in a terminal plate in continuity with the central perineal tendon [25,56]. It consists of collagenous, elastic, and numerous muscle fibers and varies from a fragile translucent layer to a dense single-layered membrane [51]. An often cited posterior layer of the pPF/SVF is actually the thin fascia propria (serosa) of the rectum, which represents a structure independent of the pPF/SVF [39,51,52,54,56,58]. The pPF/SVF is very often fused with the prostate capsule at the center of the posterior prostatic surface [39,40,56]. Toward the posterolateral aspect of the prostate, the pPF/SVF has no significant adherence to the prostatic capsule, and the space between the pPF/SVF and the capsule is once again filled by areolar tissue and the NVB [5,39,48,56].

3.4.3. Relationship between the prostatic fascias and the neurovascular bundle

The relationship between the PF and the NVB is controversial [48,51,58]. Several authors have identified the NVB as located strictly between the prostate capsule and either the LAF or the pPF/SVF. No nerve fibers were found lateral to the LAF or dorsal to the pPF/SVF [39,40,42,59,60]. Kourambas et al questioned this straightforward view and proposed that in axial section, the pPF/SVF is actually part of an H-shaped fascial structure flanking the prostate [48]. The upper limbs of the "H" are represented by the left and right lateral PPF and the lower limbs of the "H" by the pararectal fascia. The horizontal bar of the "H" corresponds to the pPF/SVF. Their main observation was that the pPF/SVF is not clearly defined at its lateral edges, where all three fascias intersect. They observed a lateral division of the pPF/SVF into several layers and especially here neural fibers were found [48]. Those fibers are not only located ventral to the pPF/SVF but also dorsal to the pPF/SVF, whereas earlier reports could not identify those nerves. The fibrous layers, not always well defined, support the notion of compartmentalization and possible functional organization of the NVB [42]. The findings just cited were corroborated by others, who described the pPF/SVF as virtually merging into the NVB or, from a practical standpoint, to split at its lateral border into anterior and posterior leaves passing around the NVB to thus bound it in a triangular fashion with the LAF (Fig. 1) [25,42,44,61].

3.4.4. Prostate capsule

The prostate itself is surrounded by a capsule-like structure that represents its outer limits. This structure is not a well-defined capsule in an anatomic sense but rather a layer of fibromuscular fascicles, primarily smooth muscle, that is an inseparable component of the prostatic stroma (Figs. 1 and 5) [39,40,62]. Multiple vessels and nerves penetrate the prostate capsule at the lateral portion of the prostate [39,40]. The prostate capsule usually cannot be identified at the anterior prostate where the anterior fibromuscular stroma including the detrusor apron is found [24,40]. Moreover, the prostate capsule cannot be identified at either the apex or the base of the prostate [40]. At its apex, the prostate stroma blends with the muscle fibers of the urinary sphincter and at the base with the smooth muscle fibers of the bladder detrusor [40,63].

It is noteworthy that despite extensive research in the field of prostate anatomy, the exact anatomy of the fascias surrounding the prostate continues to be controversial. As mentioned previously, we suggest simplification by recognizing the PPF as outer LAF and inner PF, the latter covering the prostate capsule and with the neurovascular structures found merged into or sandwiched between LAF and PF with some interindividual variation with respect to the NVB.

3.5. Neurovascular bundle

In the male, the inferior hypogastric plexus or pelvic plexus is responsible for the mechanisms of erection, ejaculation, and urinary continence [64]. It contains sympathetic fibers that derive from the hypogastric nerve originating mainly from ganglia of T11–L2 and are responsible for ejaculation [7,65]. The pelvic plexus also contains parasympathetic fibers (including nervi erigentes) that primarily derive from the pelvic and sacral splanchnic nerves and originate from the ventral rami of S2–4. In the corpora cavernosa, these nerves are mainly responsible for vasodilatation and the increase in arterial blood flow during erection [65]. The dense neural network of the pelvic plexus lies within a fibro-fatty, flat, rectangular, sagittally oriented plate between the bladder and the rectum. The branches designated for the urogenital tract are running in a caudal direction lateral to the bladder and the bladder neck [7,42,65–67]. The anterior part of the pelvic plexus gives rise to fibers designated for the bladder, prostate, seminal vesicles, and vasa deferentia, and the most inferior part gives rise to the cavernous nerves, which are responsible for erectile function [7,42,64,65].

Fibers of the pelvic plexus surround the lateral aspect of the bladder neck, the proximal prostate, and the seminal vesicles in a cage-like fashion, whereas relatively few nerve fibers are found on the purely anterior surfaces of these organs (Figs. 2, 5, 7, and 8) [65,68,69]. Many of these nerve fibers are microscopic and cannot be identified during surgery. However, surgical techniques with high optical magnification allow better identification of these structures during radical prostatectomy. Their function is most likely to innervate those organs directly, although the explicit function has not yet been clearly identified [42,65]. Costello et al noted that branches designated as cavernous nerves and destined for the urinary sphincter are mainly located posteriorly in the pelvic plexus [42]. Those nerves are

Fig. 8 – Posterior view of the neurovascular bundle (NVB) and prostate; the anterior wall of the rectum has been reflected caudally. The entire posterior surface of the prostate is covered by nerve fibers with fewer fibers at the 6-o'clock position. (Reproduced with permission from Costello et al., Anatomical studies of the neurovascular bundle and cavernosal nerves. BJU Int., Wiley-Blackwell.)

located posterolateral to the seminal vesicles and course very close to their tips [68,69]. A gentle dissection of the seminal vesicles or a seminal vesicle–sparing technique during radical prostatectomy may reduce the risk of injury to these nerves and, in consequence, may improve post-operative continence and potency rates [70–72]. The minimal distance of the latter nerves to the following anatomic landmarks has been reported as direct contact (0 mm) to the seminal vesicles and the prostate base, 4 mm to the bladder neck, and 2 mm to the levator ani [42,66,69,73]. From here, the cavernous nerves and the pelvic plexus continue in a caudal direction and were found to be only 0–7 mm lateral to the prostate pedicles [66]. The fibers often remain microscopic and are accompanied by vascular structures, which is why this complex is referred to as the NVB [7]. The bundle itself contains not only nerve fibers innervating the corpora cavernosa but also fibers innervating the prostate and the urethral sphincter [65,68,74]. From the prostate base to the apex, the vessels of the NVB provide several terminal branches to the prostate that penetrate the capsule and tether the NVB to it [8,42,75].

Lateral to the prostate the neural anatomy may vary substantially [39]. Müller's initial report described and illustrated the nerves as located at the posterolateral and the anterolateral aspect of the prostate [67]. The subsequent work of Walsh and Donker described a distinct NVB at the posterolateral aspect of the prostate [7]. More recent studies demonstrated variations of neural anatomy in this area. Takenaka et al confirmed a spray-like distribution of the nerves on the lateral and anterolateral surface of the prostate as initially described by Müller and concluded that the NVB is not a distinct structure but consists of multiple finely dispersed fibers [73]. Lunacek et al showed that the NVB develops during the embryonic phase of gestation as a distinct structure and later becomes dispersed over the lateral surface of the prostate during its development [68]. They also demonstrated that the development of benign

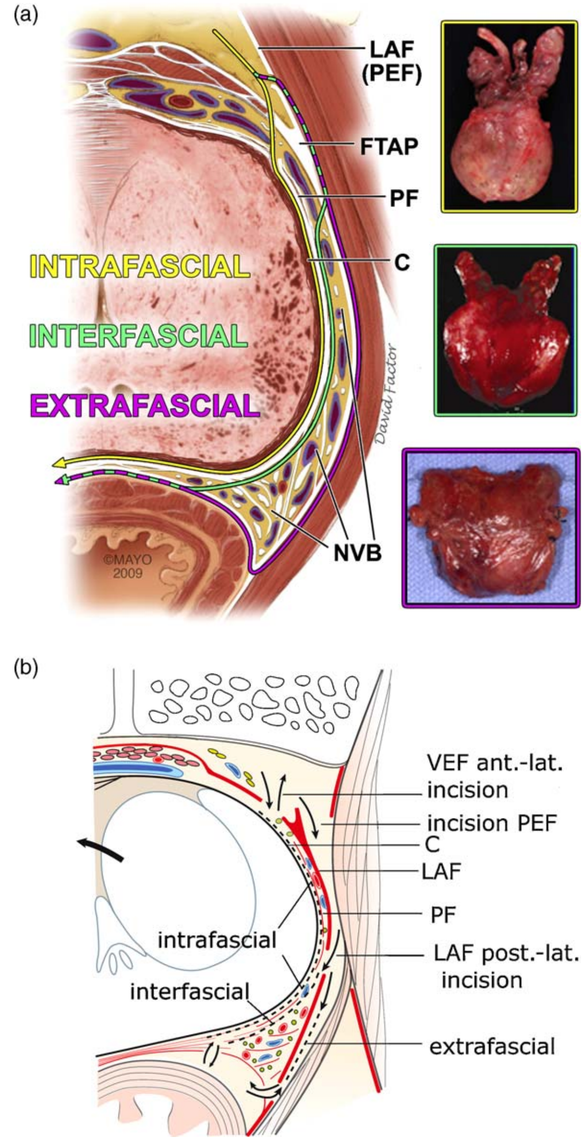

Fig. 9 – Axial section of prostate and periprostatic fascias at midprostate with three different dissection planes demonstrated (intrafascial [yellow line], interfascial [green line], and extrafascial [purple line]): (a) anatomic, showing a high anterior release of interfascial dissection (reproduced with permission from the Mayo Clinic); (b) schematic (prostate rotated counterclockwise), showing the classical posterolateral release of interfascial dissection. Insets represent pure dissections with final specimens shown, although in practice, mixtures are commonplace. C = capsule of prostate; FTAP = fascial tendinous arch of pelvis; LAF = levator ani fascia; NVB = neurovascular bundle; PEF = parietal endopelvic fascia; PF = prostatic fascia; VEF = visceral endopelvic fascia.

prostatic hyperplasia adds substantially to the dispersion of the nerves over the lateral surface of the prostate [68]. However, Ganzer et al showed that the number of nerves found on the lateral surface of the prostate is not influenced by the size of the prostate, which suggests that development of benign prostatic hyperplasia has no influence on nerve distribution [76]. Nevertheless, other groups have confirmed the dispersion of the nerves up to the 2-o'clock and 10-o'clock positions on the lateral prostate (Figs. 1, 5 and 7) [38,39,68,77–79]. They demonstrated that only two thirds of all nerves on the lateral aspect are present in the posterolateral location, and the remaining third lie on the anterolateral surface [7,42,68,78]. It is of note that even at the 6-o'clock position of the posterior surface of the prostate, nerve fibers are present but more sparse (Fig. 8) [42,56,78]. Costello et al showed that the anterior and posterior parts of the NVB are separated by about 3 cm at the base of the prostate, then converge in the midprostate only to diverge again as they approach the prostate apex [42]. Moreover, they demonstrated that the fibers running anteriorly in the NVB mainly innervate the levator ani and the prostate. The more posteromedial located fibers mainly innervate the corpora cavernosa. However, they concluded that the functional organization of the NVB is not absolute and variations are possible [42]. Kaiho et al demonstrated that every electrostimulation of the nerves found between the 1-o'clock and 5-o'clock positions on the lateral surface of the prostate results in cavernous pressure increases, suggesting that all nerves regardless of their localization on the prostatic surface participate in erectile function [80]. However, the explicit function of specific nerves lateral to the prostate remains debatable [78,81].

In the apical region, the NVB is located very close to the urethral sphincter and the prostate apex (Figs. 3 and 5) [7,68]. In this area, the NVB is less voluminous relative to the prostate base but remains dispersed [78,79]. Fibers of the NVB are found posterolaterally and laterally to the urethra up to the 2-o'clock and 10-o'clock positions (Fig. 4) [7,68,74]. The ventral aspect of the apex and the urethra, as well as the dorsal median raphe of the sphincter, are free of nerve fibers [68]. The NVB finally pierces the pelvic floor anterolateral and posterolateral to the urethra in order to innervate the corpora cavernosa [42,82].

The fascial and neural anatomy of the prostate are of special interest for radical prostatectomy, and the fascias in particular represent important surgical dissection planes. Depending on the dissection plane chosen during the procedure, several technical variations are possible (Fig. 9). The following describes the anatomic implications of the different surgical dissection planes.

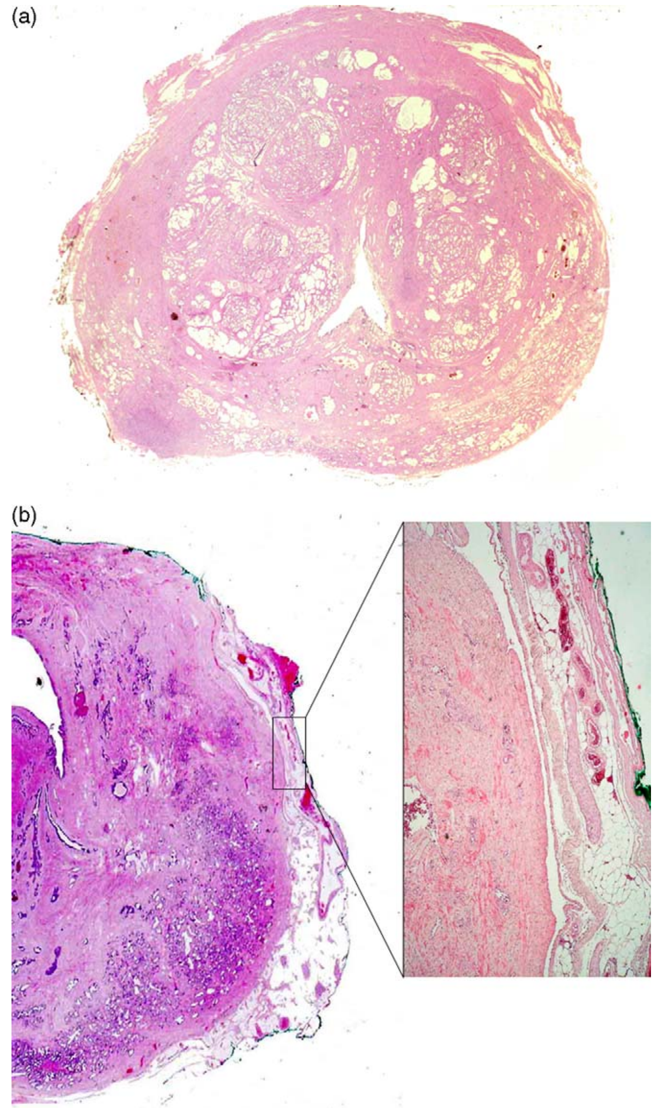

Fig. 10 – Histopathologic whole-mount section of prostate and periprostatic fascias at the level of the midprostate. (a) On left side: Prostatic fascia remains attached to the prostate after interfascial nerve–sparing procedure with peripheral zone prostate cancer covered by fascia. On right side: No prostatic fascia remains on prostate after intrafascial nerve–sparing procedure. (b) On right side: All periprostatic tissue remains attached to the prostate after extrafascial dissection.

3.5.1. *Intrafascial dissection*

Intrafascial dissection of the NVB is considered a dissection that follows a plane on the prostate capsule, remaining medial or internal to the PF at the anterolateral and posterolateral aspect of the prostate and also remaining anterior to pPF/SVF (Figs. 9 and 10) [14,45,46,83,84]. Despite this, a part of the pPF/SVF very often remains on the posterior surface of the prostate specimen where it is fused with the capsule in the midline. In an antegrade approach of intrafascial dissection starting at the 6-o'clock position, one may find an easier plane of dissection because at this level the pPF/SVF is thicker and can be more easily recognized as a single-layer structure. During a high lateral approach, this plane can be more difficult to identify due to the multilayered disposition of the fascias especially at the posterolateral border of the prostate. The intrafascial approach allows a whole-thickness preservation of the lateral PF left laterally and therefore a complete preservation of the NVB because it remains covered by and lateral to the PF. At the end of the procedure, the prostate capsule will be bare of both PF and that portion of the pPF/SVF at the posterolateral and lateral surfaces where the NVB resided (Fig. 10) [25]. Intrafascial dissection carries with it the greatest risk of inadvertent iatrogenic capsular penetrations [38].

3.5.2. *Interfacial dissection*

Interfascial dissection of the NVB is considered a dissection outside or lateral to the PF at the anterolateral and posterolateral aspects of the prostate combined with a dissection medial to the NVB at the 5-o'clock and 7-o'clock positions or the 2-o'clock and 10-o'clock positions of the prostate in axial section. This is done by moving the intact

NVB off the prostate so that the posterolateral prostate still remains covered with fascia (Figs. 9 and 10). Depending on anatomic variations, the NVB might be more prone to partial resection with this technique because this dissection will not necessarily allow the preservation of all of the nerve fibers dispersed on the anterolateral surface of the prostate. Lateral PF stays on the prostate rather than staying attached to the NVB, and the pPF/SVF remains on the posterior surface of the prostate. This approach allows a greater tissue buffer to surround the prostate in contrast to the intrafascial dissection, presumably resulting in an oncologically safer approach [13,14,25,46,83,84].

3.5.3. Extrafascial dissection

Finally, extrafascial dissection is a dissection carried lateral to the LAF and posterior to the pPF/SVF (Fig. 9). In this case the NVB running along the posterolateral aspect of the prostate is completely resected with LAF, PF, and pPF/SVF remaining on the prostate. This approach results in the largest amount of tissue surrounding the prostate compared with the intra- and interfascial dissections. It is therefore the most oncologically safe dissection but carries with it probable complete erectile dysfunction [25,46,84].

3.6. Vesicoprostatic muscle

The tissue between the posterior bladder neck and the insertion of the seminal vesicles and the ampullae of the vasa deferentia is of importance during posterior dissection of the prostate (Figs. 2 and 7) [85]. This tissue layer was believed to contain an anterior layer of the pPF/SVF [86]. One study revealed that this tissue contains two distinct tissue types [85]. The inner tissue lies directly under the bladder mucosa and consists of smooth muscle fibers originating from the outer longitudinal detrusor muscle. These fibers are longitudinally oriented and insert into the prostate base [85]. This layer might be considered the posterior counterpart of the ventral detrusor apron and is termed the *musculus vesicoprostaticus* [36,85,87]. The more posterior second layer of tissue is found in close contact with the inner layer and composed of fibroadipose tissue in continuity with the bladder adventitia [85].

3.7. Pelvic floor musculature

The innermost muscle of the anterior pelvis is the levator ani muscle. Close to the urethral sphincter, it has been called the *levator urethrae*, the *levator prostatae*, or the *pubourethral muscle* and represents the anteromedial component of the levator ani (Figs. 1, 3 and 5) [5,11,88,89]. Two reports established the term *puboperinealis* for this muscle [90,91]. They took into account that the puboperinealis, as thickenings of the levator ani, are composed of two strap-like muscles that originate from the pubis, flank the prostatourethral junction on each side, and attach to the perineal body dorsal to the urethra and anterior to the anorectal junction (Fig. 3) [90]. Relative to other components of the levator ani, this part projects anteriorly from the laterally adjacent puborectalis [89,92]. Voluntary contraction of the puboperinealis and puborectalis muscle pulls the urethra forward and upward, resulting in a closure of the urethra and termination of the urinary stream. These muscles, which are at risk during apical and urethral dissection as well as during the vesicourethral anastomosis, are very likely responsible for the active fast-stop mechanism during micturition, thus playing an important role in actively maintaining continence [19,90,93].

A muscular structure, often referred to as the *rectourethralis muscle*, between the anorectal junction and the perineal body, is found distally (>1 cm) to the urethral sphincter complex (Figs. 2 and 3) [92,94–96]. This muscle structure is relevant for the radical perineal prostatectomy technique because it needs to be divided to access the prostate apex. However, several studies have demonstrated no contact of this muscle with the urethra itself, suggesting that the term *rectourethralis muscle* is a misnomer [92,94,95].

3.8. External urethral sphincter

The external urethral sphincter complex is found primarily distal to the prostate apex. It is in close relationship but independent from the puboperinealis muscle and therefore independent of the pelvic floor (Figs. 2, 3 and 5) [13,14,25,97]. It is innervated by autonomic branches of the pelvic plexus, which partly run with the NVB and partly derive from branches of the pudendal nerve [98–102]. Those fibers enter the urethral sphincter posterolaterally from both sides, mainly at the 5-o'clock and 7-o'clock positions and the 3-o'clock and 9-o'clock positions [65,103]. The distance from the prostate apex to the point where the nearest pudendal neural branch enters the sphincter was measured at 3–13 mm [24,104].

The posterior aspect of the urethral sphincter and the prostate apex is close to the anterior surface of the rectum (Figs. 2 and 3). The urethral sphincter itself consists of two different muscle types (Fig. 3). The outer muscle layer consists of striated muscle fibers, has a vertical cylindrical to conical form, and has been described as horseshoe- or ω-shaped in cross section [99,105,106]. Many use the term *rhabdosphincter* for this part of the sphincter [68,91, 98,99,107]. The orientation of the muscle fibers is unclear and might be horizontal or vertical [25,87,108]. This discrepancy may have to do with the variable axis of the urethral lumen with respect to the vertical axis of the human body and how histologic sections are taken. The fibers have been found to be predominantly of the slow-twitch type, which suggests a passive function in urinary control relative to the fast-twitch puboperinealis muscle [90,109,110]. The striated sphincter inserts on the apex and the anterior surface of the prostate [100,111,112]. The thickness of the muscle is greater at the ventral and ventrolateral aspect and becomes thinner at the posterolateral aspect of the sphincter. Its posterior circumference is interrupted by the tendinous median dorsal raphe, which at the caudal part of the sphincter is continuous with the central perineal tendon and at the cephalad part with the pPF/SVF [19,68,112]. Some authors consider this median dorsal raphe and the adjacent tissue as a fulcrum for the contraction of the

Fig. 11 – Variations in apical shapes of prostates. Started from left, the apex can overlap the urethral sphincter anteriorly, circumferentially, symmetrically bilaterally, asymmetrically unilaterally, or posteriorly with anterior apical notch and posterior lip. Reprinted with permission from the Mayo Clinic.

sphincter, which allows movement of the urethra in the dorsal and caudal direction [19,90,107,112]. This contraction combined with the contraction of the puboperinealis muscle results in a double-sling mechanism for closure of the urethra [90,107]. The reconstruction of this posterior fulcrum during radical prostatectomy may improve early recovery of urinary continence [112–114]. However, no definitive evidence has been reported [115,116].

The inner muscle layer of the urethral sphincter surrounds the urethra completely and consists of smooth muscle fibers and elastic tissue [19]. However, an omega-shaped form of this muscle similar to the striated sphincter was suggested [87]. The smooth muscle layer can be subdivided into an outer, more circumferential-oriented layer and an inner, longitudinal-oriented layer [19,79,105]. The inner longitudinal muscle layer is found mostly at the anterior and posterior aspects of the urethra [79,105]. However, all muscle layers are intermingling, which suggests that sphincteric activity is a result of combined activity of all layers [19].

3.9. Apical prostate shape

The shape of the prostate at the apex may vary substantially, directly influencing the length of the urethra after emerging from the apex [25]. The apex may overlap the urethral sphincter circumferentially, symmetrically bilaterally, asymmetrically unilaterally, anteriorly only, posteriorly only, or can bluntly end above the sphincter (Fig. 11) [8,117]. Lee et al stated that circumferential overlap is observed in 38% of all cases, anterior overlap in 25%, posterior overlap in 22%, and no overlap in 15% [118]. Significant overlap makes the preservation of both long and short urethral sphincters difficult and should be considered during dissection and appropriate transection of the urethra at the apex.

4. Conclusions

To assist urologists in understanding the diverse structures encountered during radical prostatectomy and applying the current nomenclature for these structures correctly, we have provided a timely overview of the complex anatomy of the prostate and its surrounding structures. Knowing this anatomy and respecting it during radical prostatectomy should result in improved cancer control, as well as better postoperative functional outcomes.

Author contributions: Jochen Walz had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: Walz, Burnett, Costello, Eastham, Graefen, Guillonneau, Menon, Montorsi, Myers, Rocco, Villers.
Acquisition of data: Walz, Burnett, Costello, Eastham, Graefen, Guillonneau, Menon, Montorsi, Myers, Rocco, Villers.
Analysis and interpretation of data: Walz, Burnett, Costello, Eastham, Graefen, Guillonneau, Menon, Montorsi, Myers, Rocco, Villers.
Drafting of the manuscript: Walz, Burnett, Costello, Eastham, Graefen, Guillonneau, Menon, Montorsi, Myers, Rocco, Villers.
Critical revision of the manuscript for important intellectual content: Walz, Burnett, Costello, Eastham, Graefen, Guillonneau, Menon, Montorsi, Myers, Rocco, Villers.
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