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Neuro- and Fascial Anatomy in the Male Pelvis for Robotic Radical Prostatectomy

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1. Introduction

Prostate cancer is the most commonly diagnosed cancer and the second leading cause of cancer-related deaths in men in the US [Parker et al., 1997]. In the Prostate Specific Antigen (PSA) era, minimally invasive and nerve-sparing radical surgery for prostate cancer, e.g., conventional and robot-associated laparoscopic prostatectomy, is widely performed throughout the country.

Robotic prostatectomy started in 2000 [Menon et al., 2004], and it is estimated that 33,500 cases were performed during 2006. Robotic prostatectomy is increasing rapidly, and is becoming an important option for the management of localized prostate cancer. The da Vinci Robot® (Intuitive Surgical, Sunnyvale California) with its magnified 3-D vision and multi-jointed instruments facilitated the performance of radical prostatectomy with consideration of the pelvic anatomy (Figure 1). It is possible to view almost all pelvic anatomic structures during robotic prostatectomy. This enables the surgeon, in theory, to perform the operation with respect to anatomic findings using the multi-jointed instruments, compared with conventional for laparoscopic radical prostatectomy.



Figure 1. da Vinci system®. It consists of a surgeon's console, a patient-side cart with three or four interactive robotic arms, a high-performance *InSite*® Vision System and proprietary *EndoWrist*® Instruments

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Although mapping for nerve-sparing during radical retropubic prostatectomy was laid down by the pioneering contributions [Walsh et al., 1982], there is some need to reemphasize these anatomic principles in the robotic prostatectomy era.

Therefore, we felt the need to revisit these anatomic foundations in order to understand the macroscopic and microscopic findings and tailor them to the robotic approach. In the present paper, we review the pelvic neuro- and fascial anatomy with respect to robotic prostatectomy and demonstrate the procedures and critical points of nerve-sparing robotic radical prostatectomy based on novel anatomic concepts.

2. Materials and Methods

Anatomy of the autonomic nerves, ganglion cells and fasciae around the prostate, e.g., endopelvic fascia, Denonvilliers' fascia, was elucidated using 40 donated fresh cadavers and 60 donated fixed cadavers. The former were frozen at less than 12 to 36 hours after death and stored at -20°C until dissection mainly for macroanatomic study. The latter were used for histologic study. The age at death was over 60 years for all cadavers. Robotic prostatectomy video tapes from 205 patients treated by one of the authors (A. K. T.) between January 2005 and December 2005 were reviewed step by step to understand the procedures anatomically. We used the Cornell Institute technique described previously [Tewari et al., 2005].

3. Neuroanatomy

3.1 Tri-zonal concept

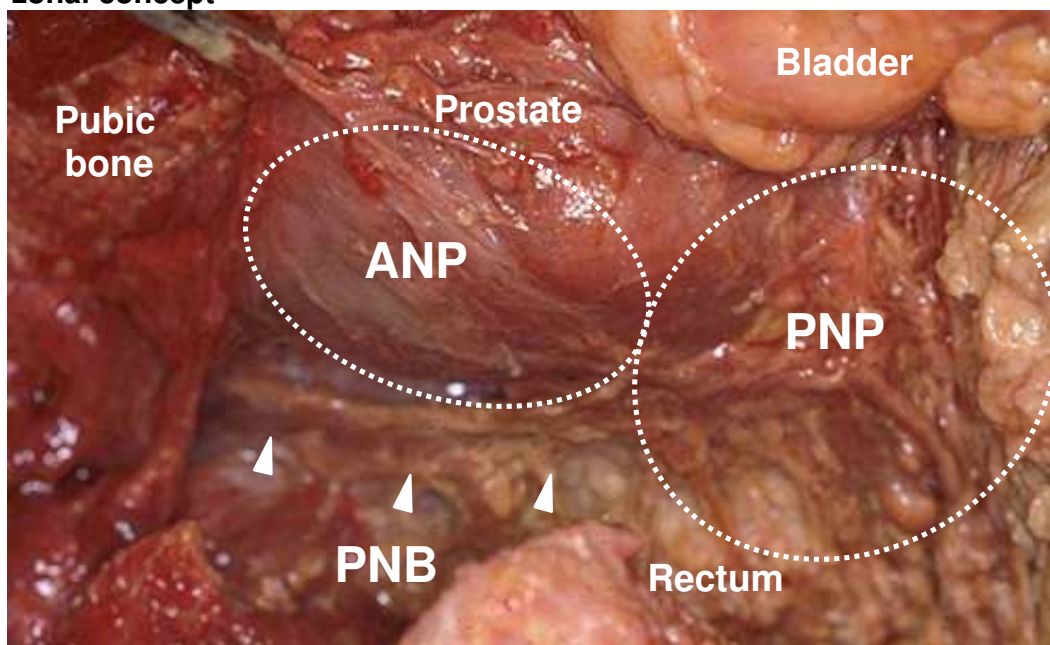


Figure 2. Tri-zonal concept of autonomic neural architecture around the prostate, proximal neurovascular plate (PNP), predominant neurovascular bundles (PNB, arrowhead), and accessory neural pathways (ANP)

In the classical concept, the neuroanatomy for nerve-sparing radical prostatectomy has been described in a limited area, i.e., only the posterolateral aspect of the prostate and the seminal vesicle [Lepor et al., 1985]. Many urologists have conceived of the preserved neural

3.1.1 Proximal neurovascular plate (PNP, Figure 3)

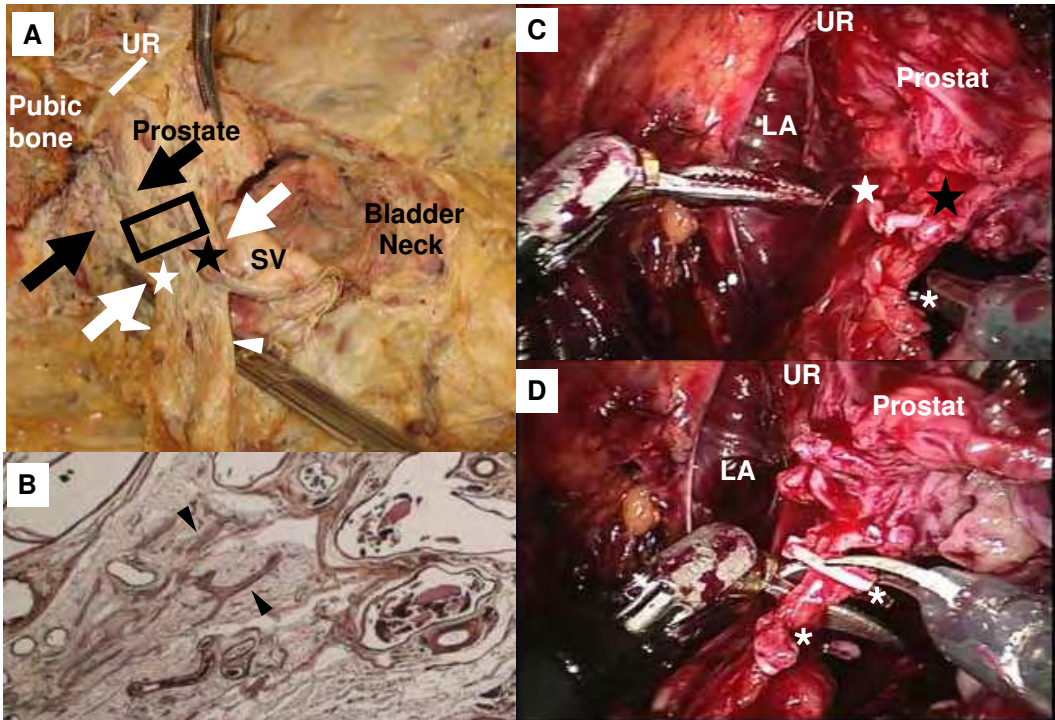


Figure 3. Control of vascular pedicle. Panel A is cadaveric dissection showing the relationship between seminal vesicle (SV) and proximal neurovascular plate (PNP, white arrowhead) according to the procedure of robotic prostatectomy. Bladder neck transaction is performed, and the prostate is lifted up by the forceps. PNP is intermingled with vascular pedicle (black star) of the prostate. Black arrow, PNP; white arrow, intermingled structure of vascular and neural (white star) component. Panel B is histologic study stained by hematoxylin and eosin in small square in Panel A. Black arrowhead, ganglion cells. Panel C and D are the surgical procedure. Viewing these structure laterally, we should estimate where is the approximate border between neural (white star) and vessel component (black star), although they are actually intermingled. We have already cut a part of the vessels using a clip (asterisk). Panel D shows we insert the tip of the left hand instrument into the border, ligate the residual vessels using clip, and are cutting sharply. UR, urethra; LA, levator ani

The PNP is an integrating center for the processing and relay of neural signals. This plate is located lateral to the bladder neck, the seminal vesicles and branches of the inferior vesical vessels and is thick in the center near the seminal vesicles. Specifically, depending on variations in anatomy and prostate size, the PNP is located 5-10 mm (average 5 mm) lateral to the seminal vesicles, and within 4-15 mm (average 6 mm) of the bladder neck, within 2-7 mm (average 5 mm) of the endopelvic fascia.

The PNP extends posterolaterally to the base of the prostate, and distally continues as the classical neurovascular bundle while a few branches travel through the fascial and capsular tissue of the prostate as accessory pathways.

3.1.2 Predominant neurovascular bundles (PNB, Figure 4)

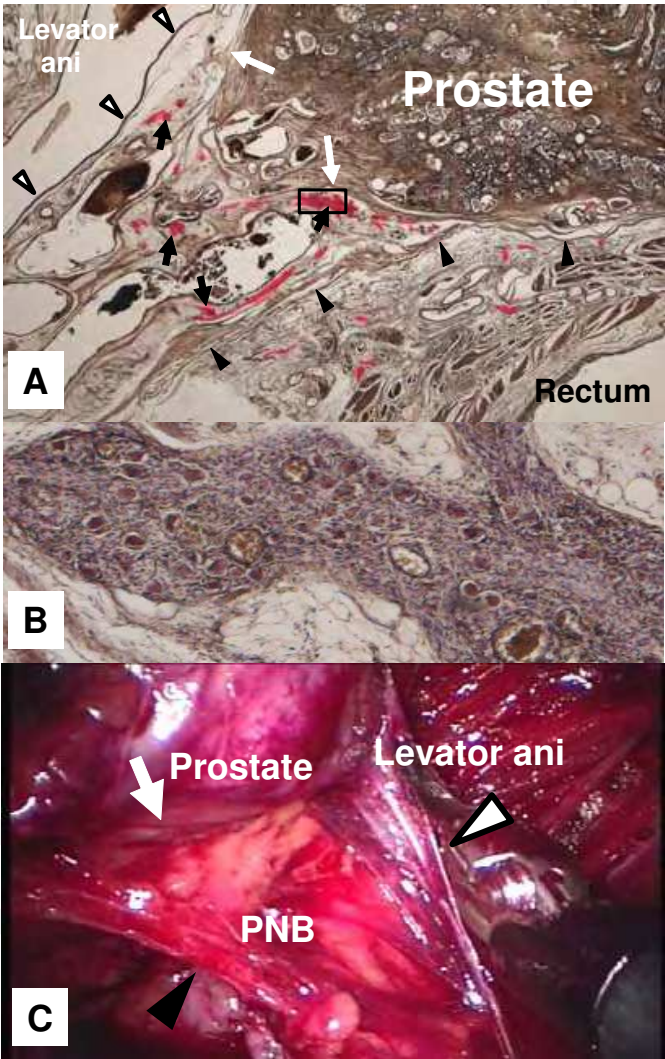


Figure 4. Release of predominant neurovascular bundles (PNB). Panel A is horizontal section of the posterolateral prostate. Ganglion cells (black arrow) in PNB are along or attaching to the posterolateral aspect of the prostate capsule (white arrow). Ganglion cells exist in the triangle of the prostate capsule, lateral pelvic fascia (white arrowhead), and Denonvillier's fascia (black arrowhead). Red, neural component. Panel B is a magnification of small square in Panel A. Hematoxylin and eosin stain. Panel C is the surgical procedure. We should imagine PNB as a triangle, which is seen in Panel A.

This corresponds to the classical bundle, however, it carries the neural impulses not only to the cavernous tissue, but also urethral sphincter and to the end of the levator ani muscle. The PNB is enclosed within the layers of levator fascia and / or lateral pelvic fascia and is located at the posterolateral aspect of the prostate. The course varies from the base to the prostatic apex.

The PNB occupies a groove between the prostate and rectum, is thickest at the base and has a highly variable course and architecture near the apex. Our anatomic study [Takenaka et al., 2004] showed the cavernous nerve candidate continued to the PNB through the distal part of the PNP. The fibers from HGN are more ventral and from PSN are more dorsal at the base of the prostate.

3.1.3 Accessory distal neural pathways (ANP, Figure 5)

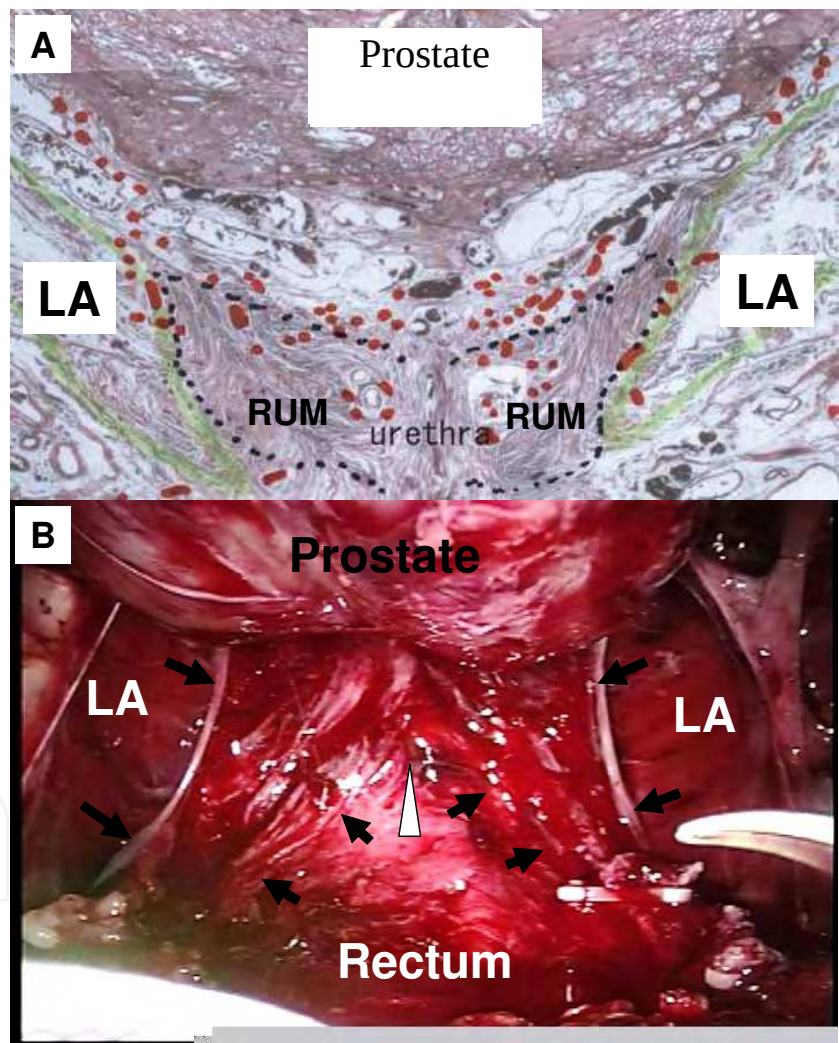


Figure 5. Apical transaction. Panel A is a frontal section through the apex of the prostate. Many nerve fibers exist behind the apex of the prostate between bilateral levator ani (LA). Some of them penetrate the rectourethral muscle (RUM) encircled by dots. Hematoxylin and eosin staining. Panel B is the surgical procedure. We can see the many nerve fibers behind the apex of the prostate during robotic prostatectomy. Bilateral PNB (black arrow) overlapped behind the apex, and formed posterior plexus (white arrowhead)

There have been discussions about putative accessory pathways besides PNB around the prostate [Lunacek et al, 2005, Menon et al, 2005]. These are usually described within the layers of the levator fascia and / or lateral pelvic fascia, on the anterolateral and posterior aspect of the prostate, which may serve as additional conduits for neural impulses. Additional accessory branches occasionally formed an apical plexus on the posterolateral aspect of the prostatic apex and urethra incorporating fibers from both the PNB. This distal plexus was observed in 35% of cases, penetrating the recto-urethral muscle. This could potentially act as a neural pathway for not only cavernous tissue but also the urethral sphincter. It could also serve as a safety mechanism to provide backup neural crosstalk between the two sides.

3.2 Distribution of autonomic ganglion cells

To our knowledge, we were the first to report the distribution of autonomic ganglion cells (GCs) in the male pelvis [Takenaka et al, 2005a]. Pelvic autonomic GCs exist not only in macroanatomic nerve components but also along the viscera. In nerve-sparing prostatectomy, major components for preservation include sparing the nerve bundles only. GCs have received little consideration in this strategy. Since GCs cannot repair themselves, special consideration should be given to these structures during nerve-sparing surgery. We examined the distribution of ganglion cells in detail, according to the robotic procedure (Table 1).

Specimen	M1	M2	M3	M4	M5	M6	M7	average
PNP	1113	332	250	-	534	411	575	535.8±307.7
PNB	698	230	448	66	908	96	500	420.9±313.3
ANP								
• Bladder, posterior	172	48	44	0	10	162	567	143.3±199.1
• B / P junction	78	280	135	53	50	232	211	148.4±93.2
• SV, posterior	163	25	78	-	212	45	273	132.7±99.2
• Prostate, posterior	155	101	0	65	230	15	535	157.3±184.7
• Prostate, anterior	0	0	10	-	3	0	0	2.2±4.0
• Prostate, apex	15	0	10	109	177	104	387	114.6±136.8
Other site								
• HGN	604	945	276	-	248	-	825	579.6±314.8
• PSN	1262	396	223	84	853	285	765	552.6±420.9
• Sacral ganglion	1566	687	-	249	1092	849	1884	1054.5±596.2
• levator ani	0	0	-	16	0	3	0	3.2±6.4

Table 1. Pelvic ganglion cell numbers and distribution in male hemipelvis using semiserial sections at 1-mm intervals

At 1-mm interval sections, we could detect many GCs in the PNP (250 to 1113 cells) and the PNB (66 to 908 cells). In the PNP, we recognized an intermingled structure comprised of GCs and a vascular component (Figure 3B). GCs were distributed widely throughout the PNB, especially laterally or posteriorly (Figure 4A, 4B). In particular, these ganglion cells were attached to the prostatic capsule or even embedded within the capsule. In the ANP, some ganglion cells existed in the bladder/prostate junction, the posterior aspect of the

seminal vesicle, and posterior aspect of the prostate, however they didn't touch the plane by our nerve-sparing robotic technique. However, almost all nerve fibers and GCs converged at the apex. Some cavernous nerve candidates penetrated the recto-urethral muscle, which filled the space between the bilateral levator ani muscle behind the urethra.

As shown above, intersubject differences were evident at all sites. Significant variations were noted in the posterior aspect and near the apex of the prostate. There were almost no ganglion cells in the anterior aspect of the prostate and levator ani muscle.

3.3 Robotic Technique based on the neuroanatomy

With respect to the distribution of GCs along the prostate, we reevaluated each step of the nerve-sparing robotic technique at our institution. Although all steps of surgery should be performed skillfully, we note the most critical procedures neuroanatomically, control of the pedicle, release of the PNB and the apical transaction. These are extremely important steps in the preservation of the GCs, because there are several GCs along the plane of dissection.

3.3.1 Control of the vascular pedicle

This is one of the most critical procedures, because neural fibers and GCs were intermingled with the vascular component in the distal end of the PNP. Furthermore, the issue becomes even more complex when we must preserve the ANP, which is present in the anterolateral aspect of the prostate. We avoided electrocautery and bulldog clamp during this phase of surgery. First, the assistant lifted the prostate ventrally and laterally in the direction contralateral to treatment. Viewing the PNP from the proximal and lateral side, we dissected the vessels in smaller packets using the EndoWrist forceps (Intuitive Surgical, CA, USA), to identify vessels entering the prostate and control these athermally using small clips (Figure 3C, 3D). The key was to stay close to the prostate, where the vessels and neural components gradually separated. This meticulous separation is necessary, because there is no clear border between the vessels and neural component. Dissection becomes further complicated due to the competing goal of avoiding the cancer containing prostatic capsule. It is crucial to remain right on the surface of prostatic fascia to avoid inadvertent entry to a deeper plane, which might compromise cancer control, especially if there is pathological capsular penetration.

3.3.2 Release of PNB

Once the prostate is freed from the vascular pedicle, it becomes more mobile with the support of the assistant. The prostate can be rotated to expose a potentially avascular triangle that is bounded posteriorly by the Denonvilliers' fascia, laterally by the levator fascia / lateral pelvic fascia, and medially by the prostatic capsule. Once this triangle leaves the prostate, the dissection appears very elegant and usually can be performed by gently pushing the prostate. We must avoid traction injury of the PNB by excessive pulling and blunt dissection (Figure 4C).

If patients have a small (5%) focus of less than Gleason 7 prostate cancer, we may choose to preserve the anterior ANP, i.e., using the Veil technique by Menon's group. To the contrary, we developed dissection planes within the fatty tissue of the PNB (incremental nerve sparing) and therefore stayed away from the capsule in cases where there was high risk of extra capsular extension.

3.3.3 Apical transaction

This is also one of the most critical steps, because almost all nerve fibers and GCs converge to the apex circumferentially. The assistant pulls the prostate ventrally again, and we push down the rectal wall gently using the left instrument. We performed sharp meticulous dissection not only at the PNB but also at the posterior aspect of the apex. It was very important to dissect the neural component together with the recto-urethral muscle (Figure 5C).

After complete apical separation from the PNB and posterior plexus, we stitched the dorsal vein complex at the apex with a small needle. After viewing the apex from various aspects and determining the shape of the apex, we cut the dorsal vein complex and anterior wall of the urethra. Finally, the posterior wall of the urethra is sharply cut, while avoiding the PNB and posterior plexus injury.

Of patients who were pre-operatively potent (SHIM score > 22) and who had nerve sparing surgery, 80% were able to have an erection firm enough to have an intercourse, or were actively having sexual intercourse, at 1 year of follow-up [Tewari et al., in press].

4. Fascial anatomy

Although the fascia or the membrane covering a structure is a very important landmark for separation of a structure, it might sometimes be anatomically tiny or thin. Therefore, there are some discrepancies between the actual anatomic construction and the pre-operative surgical planning. Because it is sometimes very difficult to demonstrate the fascial structure on micro- and macroanatomic study, the fascial anatomy occasionally might differ and might be understood arbitrarily or practically. In this section, we describe the anatomy of the endopelvic fascia (EPF) and Denonvilliers' fascia (DVF) which are extremely useful structures for improving the oncological and functional outcomes in robotic prostatectomy.

4.1 Endopelvic fascia

EPF is thought to refer to the fascia in the transitional area between the pelvic wall and pelvic viscera. However, the fascial anatomy near the prostate is not accepted anatomically, i.e., the existence and implications of the fascia of the levator ani (FLA) are not considered. The FLA is folded back at the anterior or lateral aspect of the prostate behind the EPF. The overlap of the EPF and the foldback resemble a condensed white collar, i.e., the fascial tendinous arch of the pelvis [Takenaka et al, 2005b]. In other words, the fascial tendinous arch of the pelvis is not the anatomic ligament structure. The lowest part connected to the pubo-prostatic ligament (Figure 6). When the prostate was small, the fascial tendinous arch connected to the anterior aspect of the prostate and the pubo-prostatic ligament is clearly seen to be connected to the bladder. We identify this as the pubo-vesical ligament. In large prostate cases, the location of the fascial tendinous arch is sometimes lateral, and pubo-vesical ligament was unclear. When the thin EPF was incised within the fascial tendinous arch of the pelvis, the collar and the levator ani could be separated laterally. This collar distally attached to the under surface of pubic symphysis to form pubo-prostatic ligaments. The EPF, FLA, and pubo-prostatic ligaments formed a sheet covering the pelvic floor. The shape of the collar was variable, depending on the prostate shape, volume, and pelvic shape. Pubo-prostatic ligaments were very close to the dorsal vein complex, however, we could separate this structure in fresh cadavers.

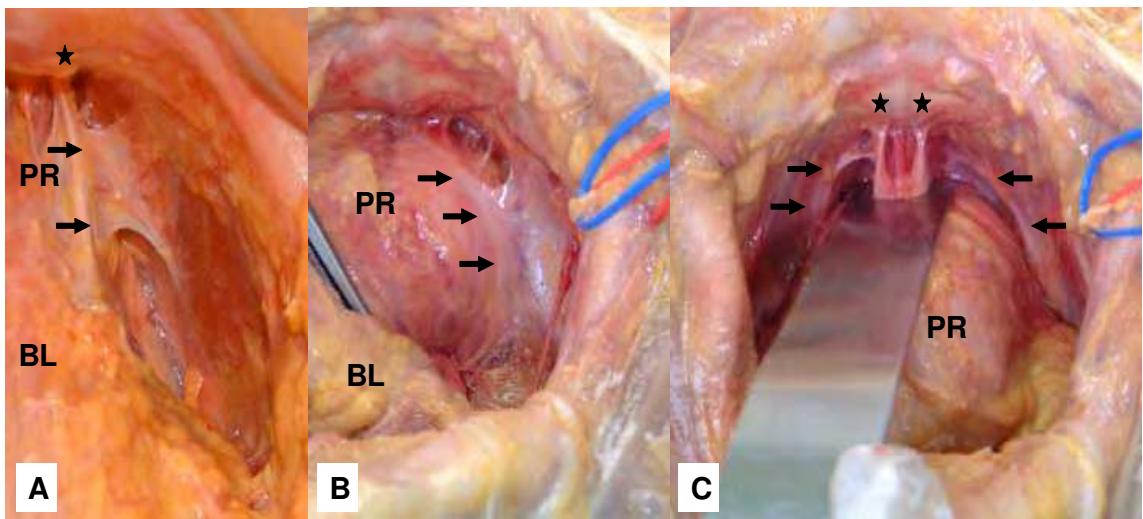


Figure 6. The various shape of the endopelvic fascia and the pubo-prostatic ligaments (star) in the fresh cadavers. The prostate in Panel A is very small. We can easily understand the fascial tendinous arch of the pelvis (arrow) connects to the pubic symphysis to form the pubo-prostatic (-vesical, in this case) ligament. In Panel B, large prostate case, the endopelvic fascia is incised along the arrows, the condensed collar, i.e., the fascial tendinous arch of the pelvis (arrow) and the levator ani could be separated laterally (Panel C). PR, prostate; BL, bladder

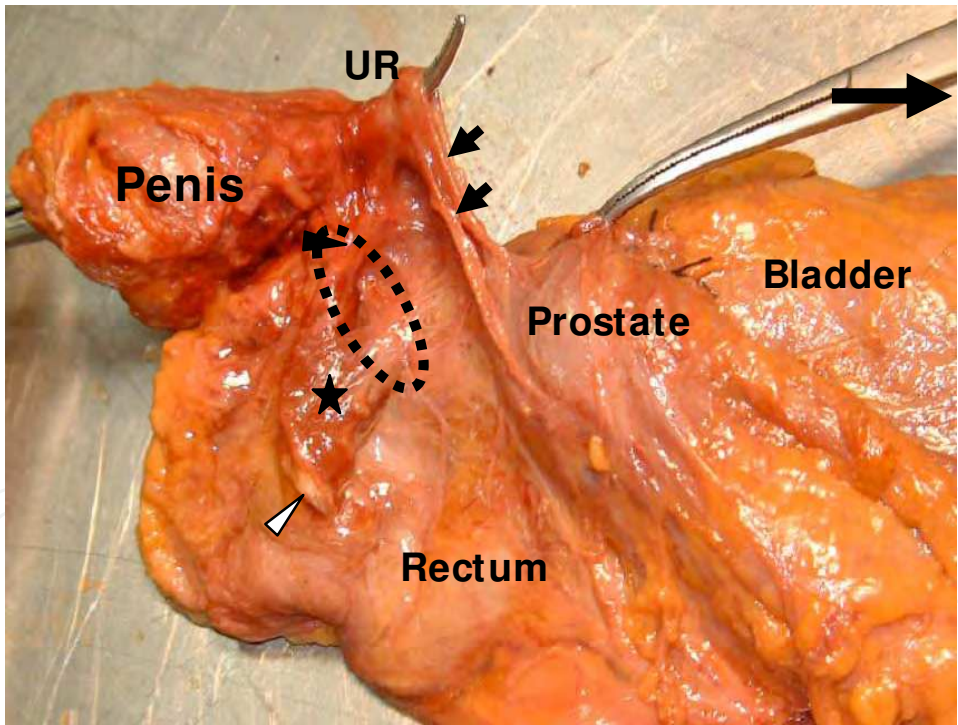


Figure 7. The rhabdosphincter, the urethra, and the pupo-perinealis muscle in the fresh cadaver. The urethra is cut at the apex of the prostate, and the forceps is inserted into the urethra retrogradely. The pubo-perinealis muscle (star) and pubo-prostatic ligaments (white arrowhead) are separated from the pubic symphysis and droop over the rectum. The rhabdosphincter is Ω shape, and the dorsal fibers coursed to the pubo-perinealis muscle and the apex of the prostate (black arrowhead and black arrow, respectively). The puboperinealis muscle terminated at the perineal body (encircled by dots). UR, urethra

The pubo-perinealis muscle was attached behind the insertion of the pubo-prostatic ligament (Figure 7). It was anteromedial to the levator ani [Myers et al., 2000] and formed a hammock around the urethra. That is to say, the pubo-prostatic ligament and the fascial tendinous arch together formed a pubo-prostatic collar on the pelvic floor. The pubo-perinealis muscle, which formed the inner layer of the levator ani muscle and connected to the urethral sphincter, attached to the back of the pubo-prostatic ligament. These three structures surrounded and supported the periurethral area, horizontally, sagittally, and frontally, as a complex.

4.2 Robotic approach to the EPF

4.2.1 Preservation of pubo-prostatic collar

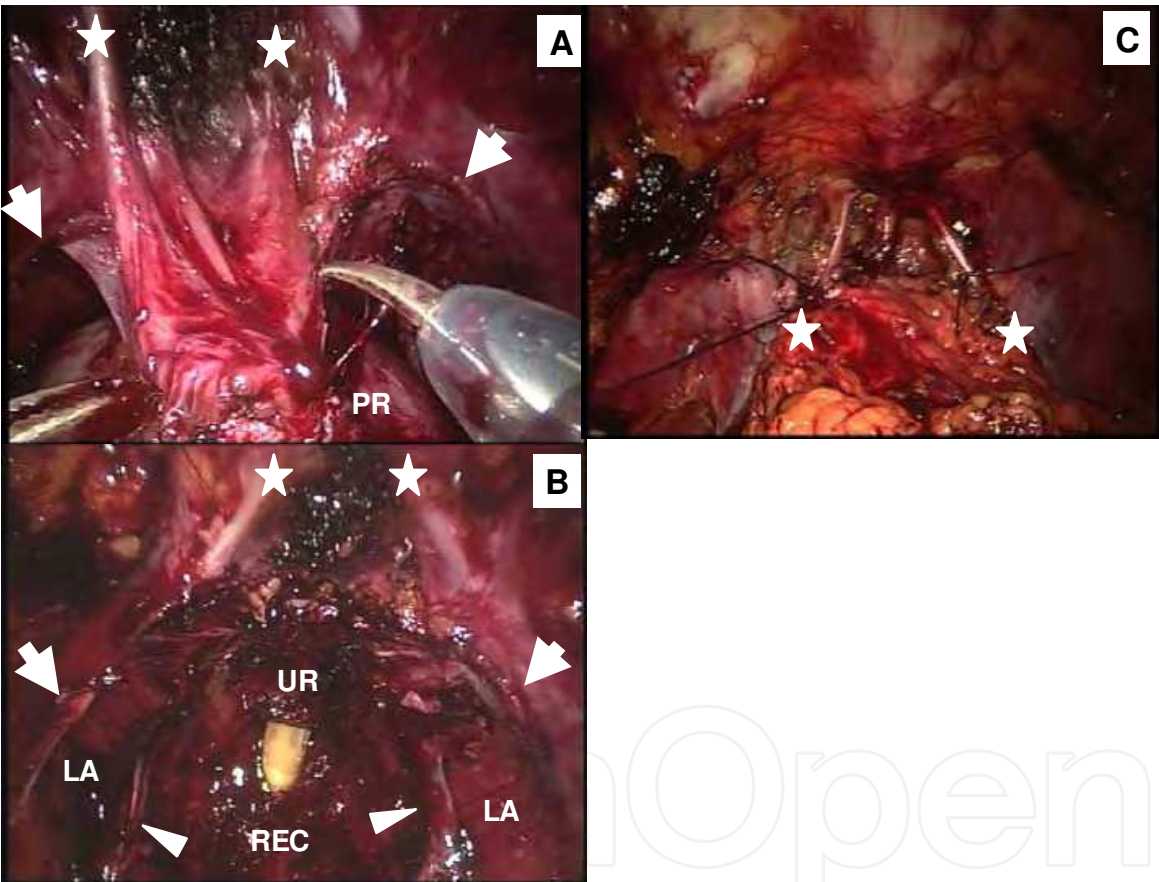


Figure 8. Panel A: After the separation of the fascial tendinous arch of the pelvis, the dorsal vein complex is cut proximal to the pubo-prostatic ligaments (closed star). Arrow, the fascial tendinous arch of the pelvis; PR, prostate; Panel B: The preserved fascial tendinous arch of the pelvis (arrow) and the pubo-prostatic ligaments (closed star) form a plate of the pubo-prostatic collar. LA, levator ani; REC, rectum; UR, urethra; white arrowhead, preserved nerve plate; Panel C: The accomplishment of the pubp-perineoplasty. The open star shows the position of the most proximal tie

The EPF was incised just medial to the fascial tendinous arch. However, at this time we stopped the incision short of the pubo-prostatic ligament in order to avoid excessive

separation around the apex [Takenaka et al, 2007a]. Because the antegrade approach is performed in robotic prostatectomy, dissection of the dorsal vein complex and apex should be the final step. After the dorsal vein stitch at the middle of the prostate, bladder neck transaction, seminal vesicle dissection, separation of the prostate and rectum, control of the vascular pedicle, and release of the predominant neurovascular bundles were performed. We separated the apex carefully from the pubo-prostatic collar complex. First, we cut the dorsal vein complex proximal to the pubo-prostatic ligaments (Figure 8A). Cautery is used at the ventral part of the dorsal vein complex, but is not used at the dorsal part in any case. Second, after viewing the apex from various aspects and determining the shape of the apex, it was completely but minimally separated from the rhabdosphincter and pubo-perinealis muscle. Finally, the urethra is sharply cut. Pubo-prostatic ligaments and the fascial tendinous arch were preserved in all cases (Figure 8B).

4.2.2 Pubo-perineoplasty

A running vesico-urethral suture is made using a tied suture of 9-inch dyed and 9-inch undyed 3-0 Biosin with a small needle (CV-23) as described previously [Menon et al., 2004]. After finishing the anastomosis, it was suspended to the collar of residual tissues using three 3-0 sutures on each side (Figure 8C). The technique is easy and requires only 5 minutes to complete. This modification helped in the early return of continence. The continence rate was 29% in the first week, 62% at 6 weeks, 88% at 12 weeks, and 95% in 16 weeks after catheter removal [Tewari et al., 2007].

4.3 Denonvilliers' fascia

In 1863, Charles Denonvilliers first described a thin layer structure separating the rectum from the bladder, seminal vesicles, and prostate. This structure has become important for urologic and colorectal surgeons, because it is an important landmark indicating a pathway between urogenital and digestive organs [Ophoven et al, 1997].

However, there is no consensus on usage of the term "Denonvilliers' fascia" during urologic and colorectal surgeries. The first reason for the confusion is that we were not able to obtain a panoramic view of the rectogenital septum. The second reason is that the clinical anatomy is quite different from histology. Consequently, surgeons might use the term "Denonvilliers' fascia" conceptually.

During robotic prostatectomy, we can directly and antegradely observe a magnified view behind the prostate. The aim of the present study is to elucidate the clinical anatomy of the Denonvilliers' fascia.

In all cases of robotic prostatectomy, we identified a membranous structure attached to the posterior aspect of the prostate near the base of the seminal vesicle or slightly distal of the base. After cutting this membrane, we encountered a mesh-like structure behind the posterior aspect of the prostate. Histologically, there existed the disorderly loose connective tissue between Douglas' cul-de-sac and the rectourethral muscle, which could correspond to the mesh-like structure in Robotics. In addition, there was the tight and thick membrane including smooth muscle fibers between cul-de-sac and posterior aspect of the prostate near the base of the seminal vesicle (Figure 9). There isn't two-layer structure in histology, either [Takenaka et al, 2007b].

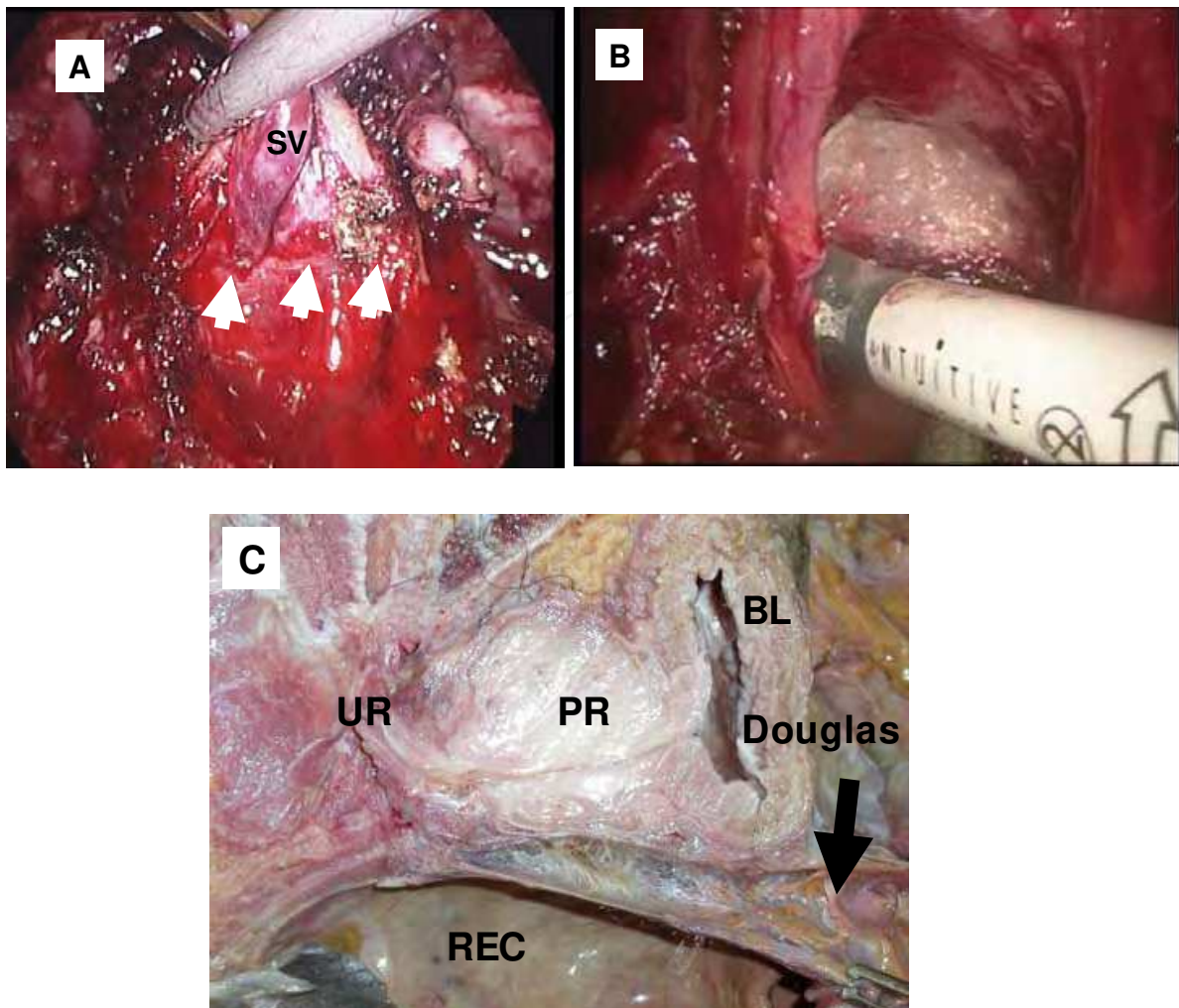


Figure 9. Panel A, After the seminal vesicle (SV) was lifted up, the arrows indicated the line where the thick membrane from the the cul-de-sac attaches. Panel B, After cutting the thick membrane, we can see the mesh-like connective tissue and the anterior surface of the rectum. Panel C, Mid-sagittal section of fresh cadaver illustrates the mesh-like connective tissue between the prostate (PR) and the rectum (REC). UR; urethra, BL; bladder, Douglas; Douglas pouch

4.4 Surgical approach to the DVF

As described above, after cutting the thick membrane between the cul-de-sac and posterior aspect of the prostate near the base of the seminal vesicle, we can easily find the flexible way to the apex, because there is a mesh-like structure, which is not a two-layered structure. Due to the angle of the anterior rectal wall and Endowrist™, we easily reach the rectal wall. To avoid rectal injury, and to preserve the neural components around the apex of the prostate, we must turn the tip of the Endowrist™ to the ventral side. If there is an advanced cancer at the border of the posterior aspect of the prostate, we can keep the dissection plane adjacent to the rectal wall.

5. Conclusion

These tri-zonal and ganglion cell concepts may be beneficial to new surgeons undertaking nerve-sparing robotic radical prostatectomy. An anatomic approach to the EPF might lead to improvement of the functional outcomes. Anatomically, there was no two-layer structure of the Denonvilliers' fascia. It is important to delineate the difference between embryologic concept, surgical anatomy, and histologic findings in order to avoid misunderstanding of the term "Denonvilliers' fascia."

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The first generation of surgical robots are already being installed in a number of operating rooms around the world. Robotics is being introduced to medicine because it allows for unprecedented control and precision of surgical instruments in minimally invasive procedures. So far, robots have been used to position an endoscope, perform gallbladder surgery and correct gastroesophageal reflux and heartburn. The ultimate goal of the robotic surgery field is to design a robot that can be used to perform closed-chest, beating-heart surgery. The use of robotics in surgery will expand over the next decades without any doubt. Minimally Invasive Surgery (MIS) is a revolutionary approach in surgery. In MIS, the operation is performed with instruments and viewing equipment inserted into the body through small incisions created by the surgeon, in contrast to open surgery with large incisions. This minimizes surgical trauma and damage to healthy tissue, resulting in shorter patient recovery time. The aim of this book is to provide an overview of the state-of-art, to present new ideas, original results and practical experiences in this expanding area. Nevertheless, many chapters in the book concern advanced research on this growing area. The book provides critical analysis of clinical trials, assessment of the benefits and risks of the application of these technologies. This book is certainly a small sample of the research activity on Medical Robotics going on around the globe as you read it, but it surely covers a good deal of what has been done in the field recently, and as such it works as a valuable source for researchers interested in the involved subjects, whether they are currently “medical roboticists” or not.

How to reference

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