The Anatomy of the Male Inferior Hypogastric Plexus: What Should We Know for Nerve Sparing Surgery

Raphael Röthlisberger[2], Valerie Aurore[1], Susanne Boemke[1], Hannes Bangerter[1], Mathias Bergmann[1], George N. Thalmann[2], Valentin Djonov[1]

[1] Institute of Anatomy, University of Bern, Switzerland
[2] Department of Urology, Inselspital Bern, University of Bern, Switzerland

Please address correspondence to:
Valentin Djonov, MD
Institute of Anatomy
University of Bern
Baltzerstrasse 2
CH-3000 Berne 9
Switzerland
Phone: +41 31 631 8432 / 8431
Fax: +41 31 631 3807
e-mail: djonov@ana.unibe.ch

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Abstract

Introduction: The aim of this study was to investigate the nerve supply to the structures in the male lesser pelvis and review its clinical relevance, especially during nerve sparing surgery.

Material and Methods: Three formalin-embalmed and 16 Thiel-embalmed male hemipelves were used. They were microdissected after repeated treatments with nitric acid diluted 1:10 with milliQ-water.

Results: The inferior hypogastric plexus is a fan-ike structure lateral from the rectum on the fascia of the levator ani. Nerves emerging from the proximal, solid part of the plexus follow the internal iliacal vessels and reach the prostate from dorsolateral. The innervation of the urethra and the corpora cavernosa derives from two origins: one follows the ejaculatory duct and the seminal vesicle, reaching the proximal urethra and the prostate from dorsal; the other follows the inferior vesical artery to reach the prostate from lateral, and then forms the neurovascular bundle on both sides of the prostatic fascia, spreading to the pelvic floor muscles and the corpora cavernosa along with the distal urethra. A connection between the two parts was demonstrated in approximately one third of the samples investigated.

Conclusion: The nerve supply to the urinary bladder, the urethra, and the corpora cavernosa emerges mainly from the inferior hypogastric plexus. The innervation of the proximal urethra and its autonomic muscular structures has a dorsal (ejaculatory duct) and

lateral (inferior vesical artery) origin. To maintain good erectile and continence function it is important to save both the dorsal and lateral neurovascular roots.

KEYWORDS

hypogastric plexus, microdissection, nerve sparing, prostate, seminal vesicles, urinary bladder, lesser pelvis, male urethra, pelvic floor

INTRODUCTION

It is common knowledge that the viscera inside the pelvis are innervated from the inferior hypogastric plexus, which contains nerves from the sacral plexus and the superior hypogastric plexus. The superior hypogastric plexus is a network of sympathetic nerves taking its origin in the thoracic and lumbar segments of the spinal cord. Out of this preaortic plexus rises the hypogastric nerve, carrying sympathetic fibers towards the lesser pelvis, where they join the parasympathetic splanchnic nerves coming from the sacral plexus and building a fan-like meshwork. The latter is called the inferior hypogastric plexus (IHP) or pelvic plexus. It provides nerves for all organs in the lesser pelvis, in particular the rectum, the urinary bladder, the seminal vesicles, the prostate, the urethra and the penis in males.

There is a large body of evidence that the autonomic nerves are responsible for erectile function and also partly for continence. The sympathetic nerves have their origin within spinal cord segments T12-L2 and the parasympathetic nerves come from S2-4. The splanchnic nerves and their parasympathetic fibers course towards the pelvic organs enabling the detrusor, the urinary bladder sphincter muscles and the anal sphincter. Although this autonomic plexus and its origin are well known, the exact route of the fibers through the lesser pelvis to reach their target organs remains unclear. There is also some uncertainty about exactly how the organs, especially the so-called continence organ, are innervated.

To effect the 'continence organ', different structures are involved. Mainly this term stands for the pelvic floor muscle and the sphincter muscle around the urethra and rectum. The pelvic floor muscles are represented by the levator ani, and in the older literature the urogenital diaphragm is also represented by the transverus perinei muscle, which was believed to form the external sphincter of the urethra. Strasser et al. (1996) showed that the urogenital diaphragm is not a horizontal muscle under the levator ani, not is the sphincter muscle along the male urethra a circular structure within the urogenital diaphragm. It is a much more longitudinal muscle starting from the base of the urinary bladder and extending up to the bulb of the penis. This structure is commonly called the rhabdosphincter and seems to be *omega*-shaped and to surround the urethra. It covers the urethra from ventral and lateral but not from dorsal. Different authors describe it as either a muscular structure comprising two different tissue types, an inner smooth muscle cell area and a striated muscle fiber part; or according to a recent concept of two different muscles it comprises the inner sphincter, the so-called lissosphincter, composed of smooth muscle fibers, and an outer coat-like sphincter, the rhabdosphincter, composed of striated muscular tissue.

As there are two different muscle types, it was hypothesized that two different neurological structures are responsible for the innervation: a somatic part via the pudendal nerve on one side, and an autonomic part via nerves coming from the inferior hypogastric plexus on the other. Hollabaugh et al. (1997) demonstrated a branch from the pudendal nerve innervating the striated muscle around the urethra. This so-called continence nerve reaches the muscle after the pudendal nerve is already in the ischio-anal fossa inside the pudendal canal.

The innervation via the inferior hypogastric plexus seems to pass through the lesser pelvis following the internal iliac vessels.

The aim of this study was to determine the exact anatomical branching of the inferior hypogastric plexus and improve knowledge about the autonomic innervation of the male urogenital organs.

MATERIALS AND METHODS

Collecting process

All male pelves were collected from body donors and provided by the Institute of Anatomy of the University of Bern. Human material was used in accordance with the Guidelines of the Swiss Academy of Medical Sciences adapted 2014 and to the Federal Act on Research involving Human Beings (Human Research Act, HRA) of January 1, 2014. In total, 16 Thiel-embalmed and three formalin-embalmed hemipelves were prepared. Exclusion criteria were:

- The institute of Anatomy was not notified within 24 hours after the body donor's death;
- Infectious diseases (e.g. tuberculosis, HIV);
- Morbid obesity;
- Open or unhealed wounds (e.g. after surgery);
- Amputation of body parts or organs (e.g. after different research performed on the material);
- Surgical removal of organs for organ donation programs prior to death;
- Female gender of the donor

There was no upper age limit.

Dissection

To obtain a brief overview of the anatomy of the inferior hypogastric plexus and its location in the male pelvis, three formalin-fixed hemipelves were grossly dissected. The formalin-embalmed material was not studied further as it was only used for orientation, so the Thiel-embalmed material could be dissected exactly.

For microdissection, Thiel-fixed specimens were used according to the following protocol: Prior to microdissection, the vessels were injected with polyurethane (PU4ii, VasQec®, Switzerland), blue colored PU4ii into veins and red PU4ii into arteries. Pressure was applied during the injection, so the capillary system was also filled. A macroscopic gross dissection was then performed, removing most of the connective tissue and fat, to gain access to the tissue of interest. To obtain better insight into the pelvis, the pelves were cut in half or one ilium was removed. The inferior hypogastric plexus was more clearly imaged in the halved pelvis because the organs could be pulled apart and away from the nervous structures. With only the ilium removed, the organs remained intact, and making it possible to reveal the exact routes of the nerves and the relationship between the left and right inferior hypogastric plexus and all the nerves prior to reaching their target organs.

In order that very small nerves could also be identified, the tissue was macerated according to Bangerter et al. (2017). Briefly: the pelves were embedded in nitric acid diluted 1:10 in miliQ water for 6-8 hours, then rinsed under tap water for 15-30 minutes and embedded in tap water for one hour. The acid solution removed fat tissue and colored the nerves more whitish. The tap water caused swelling of the small nerves, which made their preparation easier. This procedure was performed at any time during the dissection process, whenever it was no longer possible to distinguish small nerves from connective tissue.

In addition to maceration, to obtain an even more specific view in the end, microdissection was performed using a surgical microscope (OPMI® Pico, Carl Zeiss Surgical GmbH, Germany).

Imaging

During the dissection, images were taken with a Canon EOS 5D and processed with Adobe Photoshop CC 2015.1.2.

For histology samples, tissue was taken from the urinary bladder, the prostate and the seminal vesicles in the same pelvis. The material was embedded in 4% paraformaldehyde and fixed in paraffin. Afterwards it was cut in 5µm slices and stained using Hematoxylin-eosin. The histology samples were examined with a Zeiss Axio Imager M2 microscope.

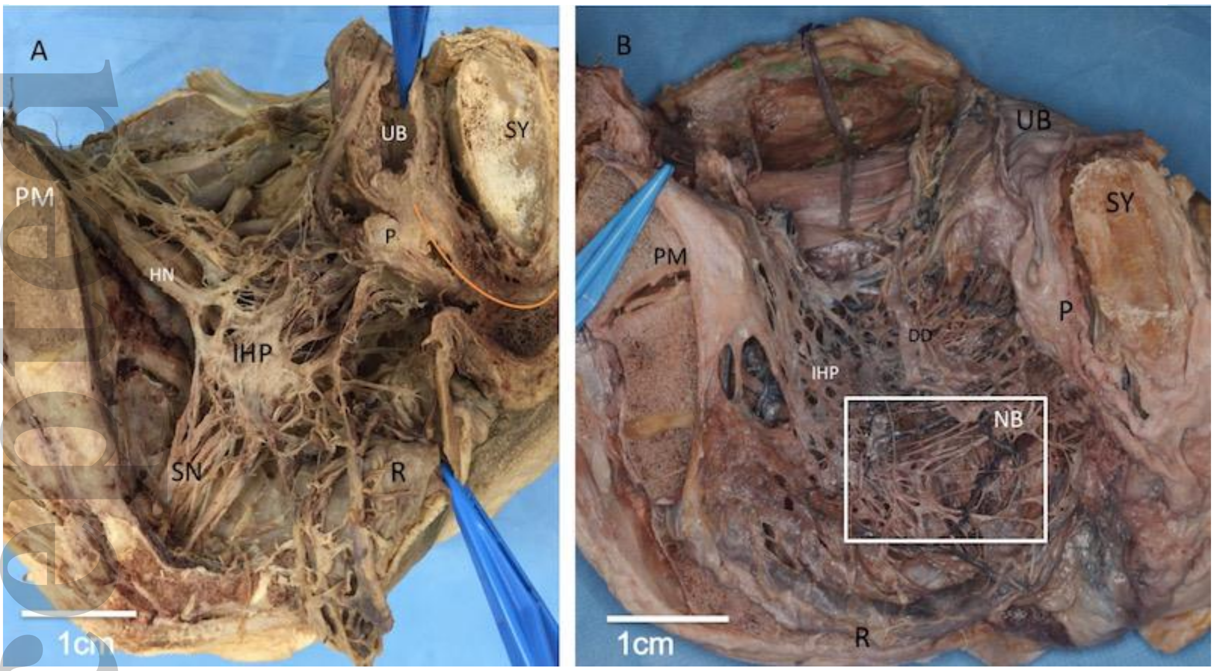
RESULTS

Overview of nerve supply in the male pelvis

Formalin embalming resulted in robust tissue preservation but the connective tissue surrounding the nerves and blood vessels had a stiff and firm consistency. This made precise microdissection of tiny delicate nerves nearly impossible, and often they could not be distinguished from connective tissue strands. Therefore, formalin-embalmed samples were used to obtain an overview of the gross anatomy of the autonomic nerves in the lesser pelvis (Fig. 1 A), and this was used as a guide to gain knowledge of the anatomy of the inferior hypogastric plexus (IHP) and its location and connections.

Gross dissection of formalin-embalmed material showed the nervous structure forming a main part of the IHP medial from the levator ani between the rectum and the urinary bladder. In the cranial region there was always a connection to the superior hypogastric plexus via the hypogastric nerve. Starting from this point, the IHP spread in a triangular, fan-like form. Towards the dorsal part the IHP connected to the roots of the sacral plexus via the splanchnic nerves carrying the parasympathetic fibers. The branches from the IHP towards the rectum were visible towards the dorsomedial region, and the nerves for the urinary bladder, the seminal vesicles, the prostate and the urethra were present towards the anterior. After this gross overview of the structures in the male lesser pelvis had been obtained, even the smallest branches entering the organ wall could be dissected precisely in the Thiel-embalmed material (Fig. 1 B).

Figure 1: Overview of a formalin-embalmed (A) and Thiel-embalmed (B) male hemi pelvis



Nerves to the urinary bladder

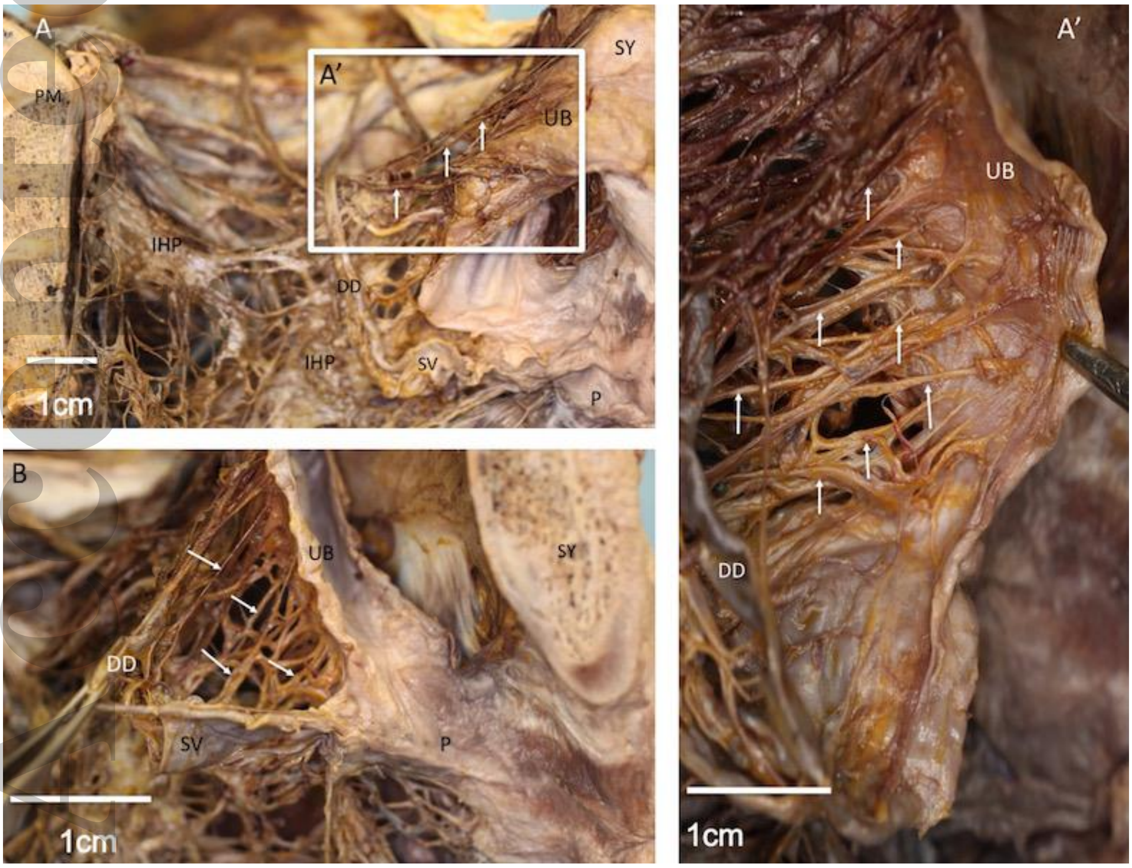
Following the hypogastric nerve, the solid part of the IHP could be displayed in all hemipelves. It was always found on top of the fascia of the levator ani, medial of the internal iliac vessels. This part seemed to be built from solid nerve fibers forming a dense network. Its consistency was variable, ranging from a solid plate to a more or less divisible nervous structure. Numerous nerve branches arose from this solid part and followed the umbilical artery towards the top of the urinary bladder. This was similar in all dissected pelves.

The nerves going ventrally were followed and the supply to the urinary bladder was investigated. Two main portions could be distinguished: nerves coming directly out of the IHP running to the dorsal, i.e. to the apex of the urinary bladder (Fig. 2A and A'), following the umbilical artery; and nerves coming out of the IHP to form a sub-plexus around the seminal vesicles. This sub-plexus provided nerves for the basal part of the urinary bladder (the so-called trigone of the bladder), the seminal vesicles and the prostate (Fig. 2B).

Up to 40 different nerves came directly out of the solid part of the plexus in all pelves. They were found directly under the peritoneum. By gently pulling the visceral peritoneum off the top of the urinary bladder, their entire pathways through the lesser pelvis were revealed. On their way to the urinary bladder they made connections to the nerves around the vas deferens and ended on the top of the urinary bladder. They seemed to innervate the detrusor.

Apparently, the nerve supplies to the base of the urinary bladder, the prostate and the prostatic part of the urethra originate from the same sub-plexus. In all individuals there was a more or less dominant sub-plexus around the seminal vesicle. It was located on the outer superior part of this glandular structure. Following the ejaculatory duct, the nerves entered the prostate and also reached the bottom of the urinary bladder (Fig. 2 B), where the lissosphincter lies.

Figure 2: Close-up of the urinary bladder's autonomic nerve supply in Thiel-embalmed material



Nerves to the prostate and the rhabdosphincter

To locate the nerves around the prostate more exactly, a separate and more detailed microdissection was performed in this area. This showed nerves following the seminal vesicles and the ejaculatory duct into the prostate and towards the prostatic urethra (Fig. 3A). These nerves showed connections to the trigone of the bladder, where the internal urethral orifice lies. They seemed to reach the urethra directly between the bottom of the urinary bladder and the base of the prostate (Fig. 3 A). To explore this area, the prostate was gently stripped away from the base of the bladder. This allowed for a preparation of the nerves following the seminal vesicles. The nerves lying on the lateral wall of the seminal vesicles turned more medially and were then found cranial of the seminal vesicles to enter between the base of the prostate and the urinary bladder, ending in the area of the lissosphincter. Some nerve fibers also followed the seminal vesicles and the vas deferens into the prostate. To reveal these structures, the prostate was also dissected. In the prostatic tissue we observed small nerves ending at the prostatic urethra.

There were also nerves from the lower part of the IHP that did not enter the plexus around the seminal vesicles but ran downwards between the rectum and the prostate and then went laterally, around the prostate, ending on the side and in front of the organ. These nerves were identified as part of the so-called neurovascular bundle (Fig. 3 B).

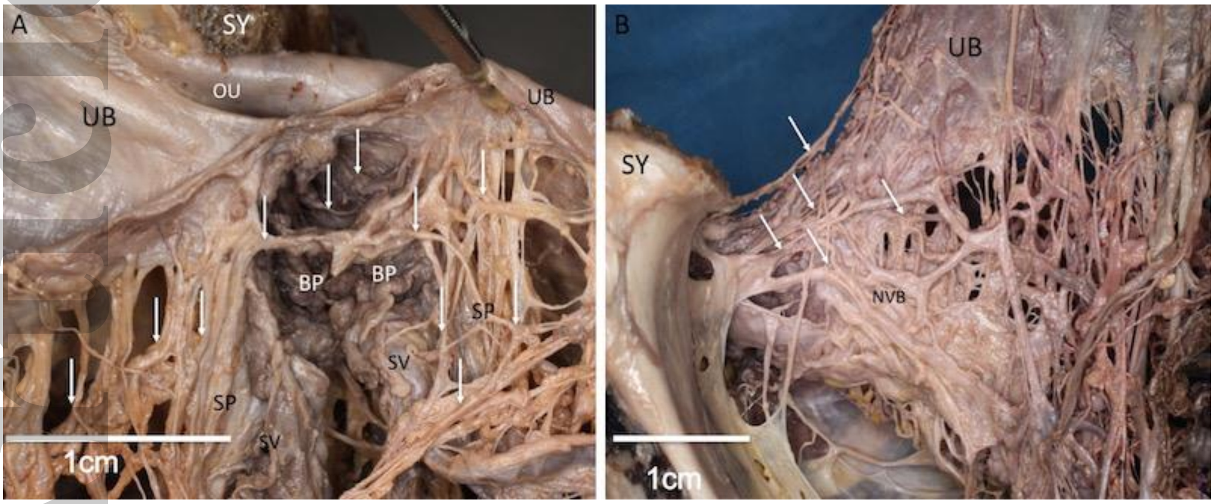


Figure 3: Insight on the autonomic innervation of the different organs in the lesser pelvis

In five of the 16 hiel-embalmed (31.25%) hemipelves there were nerve fibers running along the seminal vesicles, turning more laterally. They did not enter the prostate but ran down towards its lateral side to join the nerves coming out of the IHP, not forming a sub-plexus around the seminal vesicles.

The most lateral lying structure from the prostate was a venous plexus, followed more medially by the arteries and nerves. We identified the main artery in this area as the inferior vesical artery. On their way, several nerves left the neurovascular bundle and ended at different levels of the prostate, penetrating the gland to reach the prostatic urethra. The final nerves ended in front of the prostate, where the rhabdosphincter lies, and in the corpora cavernosa.

To provide a good view of the structures close to the prostate and the surrounding muscles, the soft tissue was disconnected from the pubic symphysis. This revealed a meshwork of nerve branches coming from posterior (from the lower part of the IHP) and traveling lateral from the prostate on the fascia of the levator ani. Some of these nerves could be seen to penetrate the prostate and end at the prostatic part of the urethra (Fig.4 A). A second set of nerves traveled to the corpora cavernosa and formed a more ventral-lying network (Fig. 4 B).

We believe these nerves are part of the neurovascular bundle. They were also found to innervate the rhabdosphincter or continue with the urethra through the pelvic floor, ending at the corpora cavernosa.

The routes of the different nerves are summarized in the scheme in Fig. 5. The IHP is marked as the red triangular structure on the rectum.

Figure 5: Microdissection of the nerves around the prostate

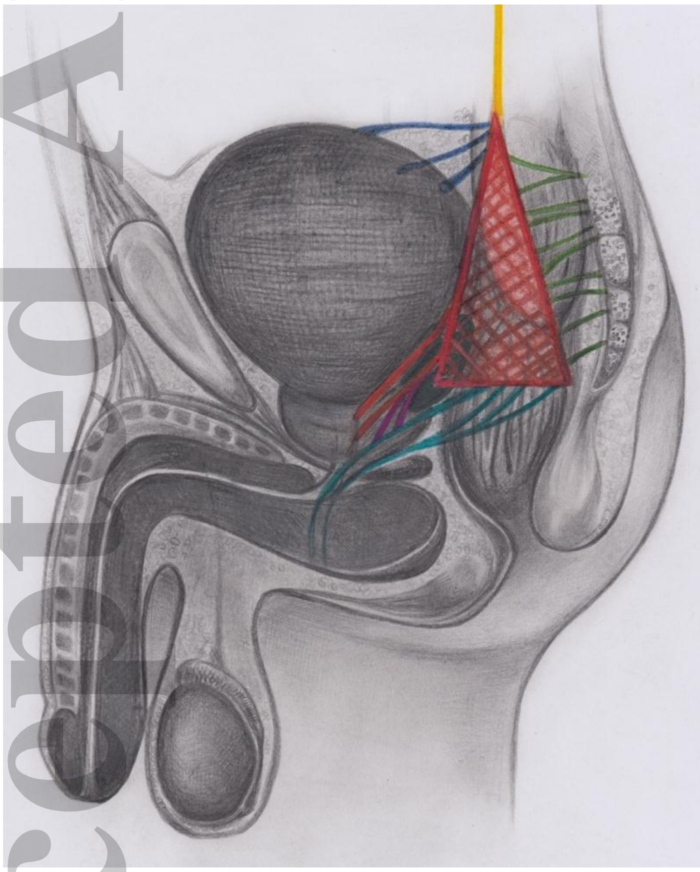
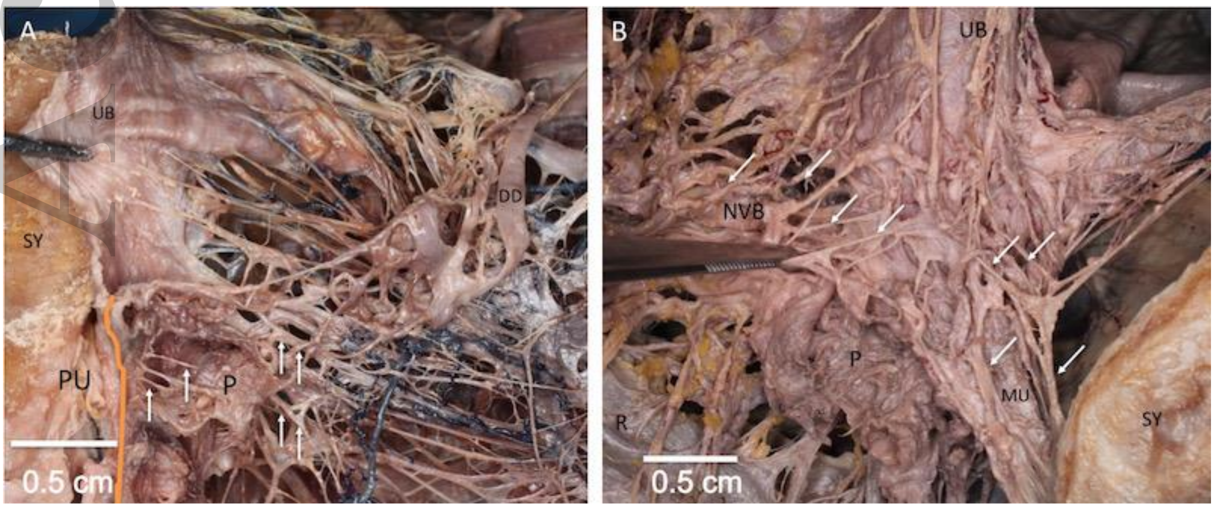


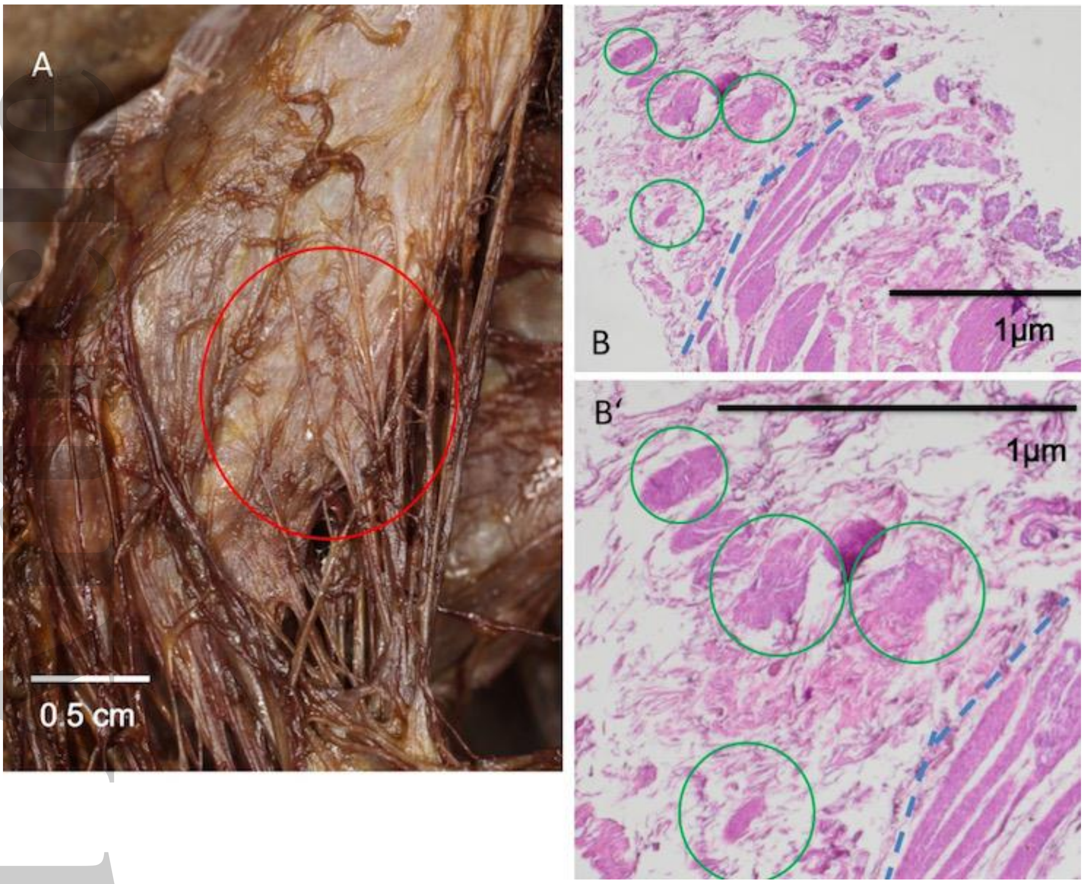
Figure 4: Scheme of innervation of the urinary bladder, the urethra and the corpora cavernosa



Histological assessment

To demonstrate the nervous tissue in the dissected area we took histological samples of the urinary bladder, where the nerves were clearly visible. This material was processed for microscopic examination. The stained material clearly revealed nerves beside the muscular structures of the urinary bladder (Fig. 6).

Figure 6: Correlative microscopy


A
0.5 cm
B
1μm
B'
1μm

DISCUSSION

The male sphincter complex was described by Koraitim (2008) as comprising an internal and an external muscular structure. The internal muscle lies directly under the urothelium of the proximal urethra and extends up to the membranous urethra. It is composed of circular and longitudinal smooth muscle fibers. This structure is also called the lissosphincter. It is predominant in the upper part of the urethra underneath the internal urethral orifice in the deep trigone. More ventral to this structure is a striated muscle fiber plate. This so-called rhabdosphincter is the external part of the male sphincter complex. Several studies have shown the rhabdosphincter not to be a horizontal muscular plate but a more vertical, coat-like structure in front of the prostate. It surrounds the prostate and the urethra from ventral in an *omega*-shape from the base of the prostate to the membranous urethra.

This dual muscular system strongly suggests that the nerve supply must also be dual. Narayan et al. (1995) demonstrated a somatic component provided by the pudendal nerve, reaching the striated muscular formation from ventrally, after the pudendal nerve has entered the pudendal canal. These nerves travel far from the prostate under the levator ani.

The autonomic nerves must be provided by the IHP (pelvic plexus), which is located medial from the fascia on the levator ani and lateral of the rectum. With its anterior border it reaches the seminal vesicles and the urinary bladder. We confirmed this location and orientation as consistent in all dissected male pelves. This solid part was found right and left of the rectum, medial to the internal iliac vessels. Lunacek et al. (2005) described the lowest part of the IHP as giving origin to the cavernosal nerve, which travels between the prostate and the rectum in a caudal direction to then goes laterally around the prostate to reach the corpora cavernosa of the penis and also provides nerves to the rhabdosphincter. It has been shown that by sparing these nerves, continence and erectile function are much better retained. We found the IHP to give origin to numerous nervous structures running down the pelvis in relation to the inferior vesical artery towards the prostate and the rhabdosphincter. We did not find these nerves to be part of one solid structure, as the term 'cavernosal nerve' implies. The numerous nerves travel between the rectum and the prostate, to turn more laterally and there form the neurovascular bundle (Fig. 4B), where they are accompanied by vessels ending at the rhabdosphincter and the corpora cavernosa. Concerning the nerve supply to the urinary bladder and urethra, we found two clearly different structures in our study: on one side the nerves coming from the inferior part of the IHP running towards the apex of the prostate and the rhabdosphincter; and a more superior part forming a sub-plexus around the seminal vesicles and innervating the more proximal prostate and the prostatic urethra with the lissosphincter. These nerves were very variable in thickness, number and location. In some specimens, they could be clearly discriminated from one another. In other pelves (five out of 16; 31.25%), several connections between the sub-plexus around the seminal vesicles and the neurovascular bundle could be identified.

In the literature, the effect of nerve sparing surgery is controversial. Burkhard et al. (2006) showed a strong association between postoperative continence and nerve sparing surgery, and a meta-analysis by Nguyen et al. (2017) led to the same conclusion. These clinical results are supported by our anatomical findings. The nerves leaving the lower part of the IHP and traveling around the prostate either ended by reaching the rhabdosphincter or followed the urethra to reach the corpora cavernosa outside the pelvic structures. By saving these nerves during radical prostatectomy, erectile function and continence of the urinary bladder should be improved.

Second, our findings suggest an important role for the nerves surrounding the seminal vesicles in maintaining continence and erectile function after surgical interventions, as the sub-plexus around the seminal vesicles seems to be responsible for innervating the prostatic urethra and not the cavernosal nerve (Figs. 3A and 4A). We think these nerves innervate the most proximal part of the lissosphincter and provide continence at rest. Also, in approximately one third of the dissected hemipelves, we found nerves connecting the neurovascular bundle and the sub-plexus around the seminal vesicles. These nerves showed no connection to the prostatic urethra but joined the neurovascular bundle on its way towards the rhabdosphincter and the corpora cavernosa. This suggests that the seminal vesicles, predominant on the lateral side, are guiding structures for important nerves worth preserving during surgery for good functional results. The landmark of the inferior vesical artery could save most of the neurovascular bundle coming from the lower part of the IHP (as we found in our study), but the clinical relevance of saving the seminal vesicle has to be investigated in further clinical trials.

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CONFLICT OF INTEREST

No author has to declare any conflict of interest.

FIGURE LEGENDS:

Figure 1: Overview of a formalin-embalmed (A) and thiel-embalmed (B) male hemi pelvis

A: Medial view of a grossly dissected hemipelvis. The promontory (**PM**) and pubic symphysis (**SY**) form the left and right borders respectively around the pelvic organs. The rectum (**R**) is pulled towards caudal and medial to reveal the inferior hypogastric plexus (**IHP**). On the tip of the IHP, the hypogastric nerve (**HN)** is visible, marking the connection with the superior hypogastric plexus. Coming from dorsal, the pelvic splanchnic nerves (**SN**) join the IHP. The urinary bladder (**UB**), prostate (**P**) and urethra (**orange line**) receive multiple nerve branches from the IHP.

B: Thiel-embalming allows the same structures to be revealed in greater detail. The blue tweezers mark the lumbar spine; the pubic symphysis (**SY**) and the promontory (**PM**) mark the ventral and dorsal borders of the lesser pelvis respectively. Again, the rectum (**R**) is pulled towards caudal and medial (lower border of the image) to reveal the nerves. In the middle of the image the solid part of the inferior hypogastric plexus (**IHP**) is visible. Also visible are the urinary bladder (**UB**), the prostate (**P**), the ductus deferens (**DD**) and nerve branches (**NB**) out of the IHP towards the viscera. The nerve branches are surrounded by the square labeled at the edge with **NB.** Also in the square, in a second plane, the dark blue colored branches of the pelvic vessels are visible behind the nerves.

Figure 2: Close-up of the urinary bladder's autonomic nerve supply in Thiel-embalmed material

A: Overview of the male hemi-pelvis: The urinary bladder (**UB**) is pulled towards anterior in the direction of the pubic symphysis (**SY**). The promontory (**PM**) marks the posterior border. In the middle of the image, the ductus deferens (**DD**) and its connection to the seminal vesicle (**SV**) and the prostate (**P**) are visible. From posterior the inferior hypogastric plexus (**IHP**) sends its autonomic nerves towards the urinary bladder. The autonomic nerves coming directly out of the IHP to reach the back and the top of the urinary bladder are marked with white arrows.

A': Zoom-in on the cranio-dorsal aspect of the urinary bladder: The forceps pulls the bladder towards ventral. The top and back of the urinary bladder are displayed to reveal the autonomic nerves in this area. Again, the nerve supply is marked with white arrows.

B: Zoom-in on the base of the urinary bladder and the plexus around the seminal vesicle: The urinary bladder (**UB**) is pulled lateroventral in the direction of the pubic symphysis (**SY**). The forceps in the left lower corner holds the ductus deferens (**DD**) with the seminal vesicle (**SV**) and the surrounding sub-plexus. Between the urinary bladder and the seminal vesicle, the nerves and vessels to the base of the urinary bladder and the prostate (**P**) are indicated with white arrows.

Figure 3 Insight into the autonomic innervation of the different organs in the lesser pelvis

A: Autonomic innervation of the base of prostate, seminal vesicle and proximal urethra: The pubic symphysis (**SY**) is located in the upper part of the image. The urinary bladder (**UB**) is cut in half to reveal the internal urethral orifice (**OU**), the sub-plexus (**SP**) around the seminal vesicle (**SV**) and the base of prostate (**BP**). The prostate is dissected to reveal nerves towards the proximal urethra. The autonomic nerves appear as yellow structures as all the fat is removed. Nerves are indicated by white arrows. These structures represent the nervous tissue towards the prostatic urethra and the base of the urinary bladder.

B: Anterior-lateral portion of the autonomic prostate innervation: The nerves (**indicated by arrows**) ending on the side and in front of the organ are identified as part of the neurovascular bundle (**NVB**). The urinary bladder (**UB**) is pulled towards medial and the pubic symphysis (**SY**) is located on the left border.

Figure 4 Microdissection of the nerves around the prostate

A: Microdissection of the nerves to the prostatic urethra: The nerves responsible for innervating the prostatic urethra originate from the dorsal i.e. lower part of the IHP. The pubic symphysis (**SY**) is located on the left side and the ductus deferens (**DD**) on the right. The urinary bladder (**UB**) is pulled towards anterior. The prostate (**P**) is dissected to make the small nerves (**arrows**) to the prostatic urethra (**PU**) visible. The route of the prostatic urethra is marked with the orange line.

B: Microdissection of the lateral nervous supply, ending in the anterior part of the prostate: Medial view of the urinary bladder, the prostate, the rectum and the neurovascular bundle. In the lower right corner, the pubic symphysis (**SY**) is visible.

The urinary bladder (**UB**) is pulled towards cranial and lateral. The prostate (**P**) is dissected. Beneath the prostate the membranous urethra (**MU**) is visible. On top of these structures lies a meshwork of nerves (**arrows**) coming from posterior (where the rectum (**R**) lies). The tweezers are holding the neurovascular bundle (**NVB**). It can clearly be seen how small nerve branches (**arrows**) leave the neurovascular bundle and reach the urethra through the prostate and also how they follow the membranous urethra (**MU**) towards the corpora cavernosa.

Figure 5: Scheme of innervation of the urinary bladder, the urethra and the corpora cavernosa

The IHP is marked as the red triangular structure on top of the rectum. From cranial, the hypogastric nerve runs down into the lesser pelvis (in **yellow**). From dorsal, the splanchnic nerves provide the parasympathetic nerve fibers (in **green**). Towards anterior, the nerve supply to the top of the urinary bladder is marked in **dark blue**. The nerves forming the sub-plexus around the seminal vesicles are displayed in **orange** and the neurovascular bundle lateral of the prostate in **light blue**. The connection between the sub-plexus around the seminal vesicle and the neurovascular bundle is illustrated in **purple**.

Figure 6: Correlative microscopy

A: Nerve supply to the cranio-dorsal part of the urinary bladder: In the upper left corner the pubic symphysis would be located. The nerves coming out of the IHP directly innervating the back of the urinary bladder are visible. The circle marks the area from which histological samples were collected.

B: Hematoxylin-Eosin stain: Histological picture of the structures marked by the circle in A. The muscular tissue of the top of the urinary bladder is visible on the right side of the image. The nervous structures are marked by circles.

B': Zoom in on the nervous tissue: Histologically, the dissected structures were proven to be peripheral nerves.