New laparoscopic approach to the pudendal nerve for
neuromodulation based on an anatomic study

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AIMS: The aim was to develop a new laparoscopic technique for placement of a pudendal lead.

METHODS: Development of a direct, feasible and reliable minimal-invasive laparoscopic approach to the pudendal nerve (PN). Thirty-one embalmed human specimens were dissected for the relevant anatomic structures of the pelvis. Step-by-step documentation and analysis of the laparoscopic approach in order to locate the PN directly in its course around the medial part of the sacrospinous ligament and test this approach for feasibility. Landmarks for intraoperative navigation towards the PN as well as the possible position of an lead were selected and demonstrated.

RESULTS: The visible medial umbilical fold, the intrapelvine part of the internal pudendal artery, the coccygeus muscle and the sacrospinous ligament are the main landmarks. The PN traverses the medial part of the sacrospinous ligament dorsally, medially to the internal pudendal artery. The medial part of the sacrospinous ligament has to be exposed in order to display the nerve. An lead can be placed ventrally on the nerve or around it, depending on the lead type or shape.

CONCLUSIONS: A precise and reliable identification of the PN by means of laparoscopy is feasible with an easy four-step approach: (1) identification of the medial umbilical fold; (2) identification of the internal iliac artery; (3) identification of the internal pudendal artery and incision of the coccygeus muscle (‘white line’, arcuated line); and (4) exposition of the medial part of the sacrospinous ligament to display the PN.

KEYWORDS
internal pudendal artery, laparoscopic approach, medial umbilical fold, neuromodulation, pudendal nerve, sacrospinous ligament
1 | INTRODUCTION

The pudendal nerve (PN) is a peripheral nerve formed of afferent sensory and efferent motor nerve fibres from the sacral roots S2–S4, sometimes gaining contributions from the roots S1 and S5. Along its course, the nerve gives rise to the inferior rectal nerve, the perineal nerve and the dorsal nerve to the penis or clitoris, respectively. It supplies the somatic anal, urethral, and penile or clitoral musculature. The bulk of the afferent fibres are contributed to S2 (60,5%) and S3 (35,5%). Moreover, the PN is a major contributor to both bladder regulation and bladder function. Due to the large percentage of afferent fibres, the PN is attractive for neuromodulation therapy, offering a therapeutic approach to patients affected by bladder dysfunctions such as overactive bladder with urinary urge incontinence (e.g. ref.3).

Neuromodulation is the electrical modulation of a nerve in order to influence the physiologic behaviour of an organ, initially described by Tanagho et al. already in 1989. They selected S3 as primary target, nevertheless the most favourable nerve has not yet been defined. In some cases, S3 might not be accessible for the standard procedure. For specific indications, there could be the need to approach more than one nerve to apply a combined stimulation.

The exact mechanism of sacral neuromodulation action is not well understood, it can be described as a somatic afferent inhibition of sensory processing in the spinal cord. It is hypothesised that the effect of sacral neuromodulation depends on the electrical stimulation of somatic afferent axons in the spinal roots, which, in turn, modulate the voiding and continence reflex pathways in the CNS. This standard sacral neuromodulation has been approved by the FDA (US Food and Drug Administration) for many years to treat non-neurogenic urge incontinence, urinary frequency and refractory and non-obstructive urinary retention.

Various approaches and surgical procedures have been used for neurostimulation or to treat the pudendal canal syndrome, which presents with pain, hypo- or hyperesthesia, anal incontinence, urinary incontinence and impotence. The transperineal, transgluteal, transischiorectal approaches were described.

Alternative sites of neuromodulation are the neuromodulation of the tibial nerve, which also contribute to sensory and motor control of the urinary bladder and pelvic floor, and anogenital neuromodulation. Percutaneous implantation of a tined lead at the PN by an either posterior or perineal approach is the method of choice for pudendal neuromodulation contributing to the sensory and motor control of the urinary bladder and pelvic floor, and anogenital neuromodulation. The percutaneous implantation of a tined lead at the PN by an either posterior or perineal approach is the method of choice for pudendal neuromodulation. Although the percutaneous implantation method is highly feasible and tested in clinical trials, a supplementary implantation technique is needed for patients in whom the percutaneous approach is ruled out or poses a problem.

Laparoscopy as a highly precise and minimal-invasive standard surgical technique provides an option to visualise the target structures in contrast to the conventional technique. It could offer advantages as for instance a lower lead migration risk, and optimised placement and, thus, improved stimulus transmission and finally a better clinical effect. Moreover, wound problems and infections appear to be low. Laparoscopic implantation of leads to various nerves in the small pelvis have been frequently performed, but never controlled or established in a model prior to operating a patient. Nevertheless, the pelvic neuro-anatomy is difficult and demanding, in particular as the laparoscopic surgeons are most likely not from the beginning experts in this field. Thus, the present study focuses on secure identification of the PN, clarifying the anatomic relations and optimising the access to the PAN by laparoscopy. This has never been performed before but is an important part of establishment of a potential new therapy, the more as most of the time there is no immediate control of success or clinical effects. We have also learned from clinical experience as well as from publications that the clear identification of the PN was not always given for sure. Thus, our study is very important as basic research to facilitate the surgeons’ goals, to further go down the road and expand neuromodulation to different nerves and techniques. Therefore, aim of our study was to develop a new, feasible, minimal-invasive, laparoscopic approach directly to the PN. Consequently, optimal anatomic landmarks were determined. We demonstrate our laparoscopic approach step-by-step. Due to topographical and nomenclature impreciseness concerning the PN in many studies we also discuss surgical pitfalls.

2 | MATERIALS AND METHODS

In the first step, in order to develop surgical landmarks for a new laparoscopic approach, we dissected the pelvic structures of 31 human specimens macroscopically (and bilaterally) in order to find constant and reliable surgical landmarks, the courses of blood vessels, nerves and ligaments. Their relations to bony structures were exposed and documented photographically. The human specimens were embalmed either by formaldehyde-phenol or alcohol-glycerine. The possibility of this solution causing preservation artefacts can be denied. The bodies were donated to the Division of Clinical and Functional Anatomy of the Medical University of Innsbruck by people who had given their informed consent for their use for scientific and educational purposes prior to death. According to Austrian National Law, scientific institutions (in general Institutes, Departments or Divisions of Medical Universities) are entitled to receive the body after
death mainly by means of a specific legacy, which is a special form of last will and testament. No bequests are accepted without the donor having registered their legacy and been given appropriate information upon which to make a decision based upon written informed consent (policy of ethics); therefore, an ethics committee approval is not necessary.

Secondly, due to these landmarks, we developed and optimised the laparoscopic access for locating the PN directly in its course around the medial part of the sacrospinous ligament in order to document and test it for feasibility. We used a laparoscopic unit for photo documentation (Karl Storz Endoskop Austria GmbH, Vienna, Austria) and a 0° optic endoscope to simulate laparoscopy in the bodies. In the anatomic setting, the dissection was performed with instruments for open surgery.

The landmarks for intraoperative neuronavigation towards the PN as well as the possible position of a lead were selected and demonstrated. The approach was demonstrated step by step.

3 | RESULTS

3.1 | Normal topographic anatomy of the PN

The PN originates from the sacral ventral spinal rami S2–S4 and exits the pelvis through the greater sciatic foramen below the inferior margin of the piriiformis muscle together with the internal pudendal artery and veins just cranial to the ischial spine. The pudendal neurovascular bundle wind around the posterior aspect of the ischial spine or the sacrotuberous ligament before they reenter the pelvis through the lesser sciatic foramen. When the PN, artery and veins passe through the lesser sciatic foramen, they enter the ischioanal fossa and dive into the Alcock canal between the coccygeus muscle and internal obturator muscle. The entrance of the Alcock canal is immediately below the level of the ischial spine, the sacrospinous ligament and the superior gemellus muscle and is formed by splitting of the internal obturator fascia. The PN has three terminal branches: (1) the inferior rectal nerve, originating near the proximal end of the Alcock canal, innervating the external anal sphincter, the mucous membrane of the lower part of the anal canal and the perianal skin; (2) the dorsal nerve of the penis/clitoris running anteriorly along the inferior pubic ramus together with the pudendal artery deep to the perineal membrane finally innervating the skin of the penis/clitoris; and (3) the perineal nerve and its deep muscular branch innervating the perineal muscles (deep and superficial transverse perineal, external urethral sphincter, bulbospongiosus and ischiocavernosus muscles). The superficial branch of the prineal nerve innervates the skin of the posterior part of the scrotum/labia majora. The pelvic floor muscles itself—levator ani and coccygeus muscles—are innervated by direct branches of the sacral plexus and by the coccygeal plexus, respectively.

3.2 | Gross anatomic findings

We dissected the pelvic structures bilaterally in order to find constant anatomic landmarks to reach the PN directly in its position around the sacrospinous ligament. Topographically, we demonstrated the lumbosacral plexus, pudendal plexus, muscles, all vessels and ligaments. Thus, we found the following constant anatomic landmarks for a reliable step-by-step exploration of the PN:

- medial umbilical fold,
- internal iliac artery,
- intrapelvine part of the internal pudendal artery,
- ischial spine,
- ‘white line’ (‘arcuated line’), coccygeus muscle,
- sacrospinous ligament.

The PN was always the most medial nerve of the sacral plexus (‘pudendal plexus’). At its ‘supra-levatorian portion’ it was invariably crossed by the internal pudendal artery from medial to lateral (Fig. 1). It was reliably always the most medial structure at the level of the sacrospinous ligament, consequently running in the fat-filled groove formed by the sacrospinous ligament ventro-medially and the sacrotuberous ligament dorso-medially (the ‘biligamentary tunnel’) (Fig. 2).

The nerve was accompanied by the vein and the artery, which now lied laterally (Fig. 3). The nerve ran through the

![FIGURE 1](image-url)  Gross section of the gluteal region, view from dorsal: the internal pudendal artery crosses the PN from medial to lateral (dark arrows), ipa, internal pudendal artery; pn, pudendal nerve; iga, inferior gluteal artery; pcfn, posterior cutaneous femoral nerve; stl, sacrotuberous ligament; pm, piriiformis muscle
3.3 | Laparoscopic procedure

3.3.1 | Step 1: (Fig. 4)—medial umbilical fold

At the beginning of the procedure, the body was laid in supine position. As a modification to the laparoscopic approach, just for anatomic purposes, the abdomen was opened with a midline incision. The optics was placed umbilical in the same position, as for a laparoscopic approach. After the correct placement of the 0° optics, the medial umbilical fold was identified and the peritoneum was incised at its lateral side. To gain access, the tissue layer between the bladder and the pelvic sidewall was opened.

3.3.2 | Step 2: (Fig. 5)—internal iliac artery

By using the medial umbilical fold, which directed towards the internal iliac artery, we could identify the internal iliac artery. The internal iliac artery divided into its branches, the first regularly being the obturator artery.

At the point where the umbilical arterial cord started, the internal iliac artery branched out. Arterial variations had to be considered.17
3.3.3 | Step 3: (Fig. 6)—internal pudendal artery, coccygeus muscle (‘white line’), sacrospinous ligament

The internal pudendal artery was identified and followed down to the pelvic floor, where it disappeared behind the coccygeus muscle (next to the beginning of the ‘white line’, arcuated line). This muscle was (partly) incised along the internal pudendal artery to identify the sacrospinous ligament. The sacrospinous ligament was hidden behind the fibres of the coccygeus muscle, which had to be cleared away. (Functional impacts concerning a—even complete—transsection of the coccygeus muscle can be denied. The muscle itself often is absent.) The identification of the sacrospinous ligament was facilitated by the palpation of the ischial spine. The internal pudendal artery left the pelvis dorsally to the sacrospinous ligament.

3.3.4 | Step 4: (Fig. 7)—medial part of sacrospinous ligament, PN

The medial part of the sacrospinous ligament had to be exposed in order to display the PN in the fat-filled groove formed by the sacrospinous ligament ventro-medially and the sacrotuberous ligament dorso-medially (the ‘biligamentary tunnel’). The nerve was the most medial structure, situated medially to both the internal pudendal artery and the vein. A lead could be placed ventrally on the nerve or around it and fixed on the sacrospinous ligament (depending on the type and shape of the lead).

Because of its typical and reliable anatomic configuration, the PN could not be confounded with any other nerve at this location.

4 | DISCUSSION

Recently it has been shown that the neuromodulation of the PN could in some cases be an alternative to the stimulation of the S3 root. The problem is, however, that this nerve is difficult to approach from the outside. Therefore, we have developed a new and reliable, laparoscopic approach, allowing for reproducible, precise and minimally invasive identification of this nerve.

Erdogru et al.18 and Possover et al.9 described two laparoscopic methods to reach the PN, which were solely based on clinical and intraoperative findings. Nevertheless, to define a standardised approach, detailed knowledge of the topographic pelvic anatomy is essential. Moreover, Possover’s approach seems problematic from an anatomic point of view.9 The sciatic nerve itself, in our point of view, is topographically situated too far lateral to serve as a guiding structure to reveal the PN at the level of the sacrospinous ligament. This could be a classical pitfall for all surgeons implanting a lead too much lateral to the ‘true’ PN. The fibre anastomoses between the sciatic nerve and PN are very variable in numbers, size and in length. Thus, the possibility to confound them with the PN itself is very high. At the level of the sacrospinous ligament the PN is always the most medial structure, situated medially to the internal pudendal artery and the veins, what makes it very prone to be confused with different structures. Thus, the most interesting part of our study was the supra-levatorian portion of the PN, which has also been investigated and discussed in other studies.19–21 Detailed knowledge of the PN’s variations and its position adjacent to the sacrospinous ligament could be clinically significant for PN syndrome. Even the different types of PNs and their topography in relation to the sacrospinous ligament are relevant, not only for PN syndrome, but also for sacrospinous colpexy, ultrasound-guided infiltrations or blocks, pudendal canal syndrome, chronic pelvic pain syndrome, nerve entrapment and other clinical scenarios. The variations in the nerve trunks of the PN (Types I–V),19 the possible diameters of the trunks and their different distances to the internal pudendal artery and ischial spine20 must be considered in order to find the nerve for the correct placement of the lead. Moreover, the average length of the PN-trunk before its terminal branching (28.5 mm)19 should also be borne in mind, which can vary by ethnicity, lifestyle or body-height, whereas there are neither side nor gender differences. Concerning the posterior and perineal...
too, one has to consider these divisions of the PN in its course caudally of the sacrospinous ligament in order to achieve optimal results.

Another anatomic study described a new laparoscopic approach to the PN for pudendal canal decompression. The authors stated that their guiding structures, after the incision of the peritoneum, were the external iliac vein, the internal iliac vein and the internal pudendal vein, resulting in the identification of the PN. Nevertheless, veins are very unreliable topographic structures with a huge variability. Therefore, they should never serve as guiding structures, the more if it belongs to a high precision technique.

Furthermore, there are confusing descriptions of the exact topography of ‘Alcock’s Canal’ in the literature, relating to the PN. This is the region which Alcock himself termed the posterior part of the third stage of the pudendal artery’s course. The PN, accompanied by the internal pudendal artery and internal pudendal vein(s), travels within the obturator internus fascia (not laterally to it), bordered by the internal obturator muscle and the ischiatic tuberosity laterally and the sacrotuberous ligament caudally (‘Alcock’s Canal’ or ‘Pudendal Canal’). In consent with Colebunders and co-workers and by definition, ‘Alcock’s Canal’ does not include the PN within the pelvis, the region between the sacrospinous ligament and sacrotuberous ligament, the region in which the rectal branch of the PN crosses the curved falciform process connecting the sacrotuberous ligament to the ischiatic tuberosity at the site of the obturator foramen and, finally, the passage of the PN along the ramus of the pubis towards the pubic symphysis.

Other authors described a so-called ‘fascia lunata’, a part of the obturator fascia which forms the outer wall of the ischio-rectal fossa, which ensheaths the PN and its accompanying vessels. Elliot Smith stated that there is ‘no splitting of the obturator fascia’ and that it consists of an investment of fibrous tissue, which has nothing to do with the sheath of the obturator internus muscle. The fascia lunata often, but not always, becomes attached to the surface of the sheath of the obturator internus fascia. Therefore, although there are a lot of descriptions in literature, we can state that the PN and the vessels lie within a distinct fascia, forming a canal (‘Pudendal Canal’), which can easily cause problems such as a PN entrapment. The accurate topographic description of the ‘Alcock’s Canal’ should always be considered, the more, when it is to be used with any clinical relationship, and especially, as it is currently used erroneously as a synonym for any form of PN-entrapment independently of its location of compression.

5 | CONCLUSION

Our new laparoscopic approach to the PN, considering the accurate topography of the nerve, described step-by-step in this paper, can be a guideline for all surgeons. Due to our results, a precise and reliable identification of the PN is possible, described with a four-step approach:

1. identification of the medial umbilical fold,
2. identification of the internal iliac artery,
3. identification of the internal pudendal artery and (partly) incision of the coccygeus muscle (‘white line’, arcuated line),
4. exposition of the medial part of the sacrospinous ligament to display the PN (the most medial structure) and placing a lead.

Due to the reliability of the described topography of the PN directly in its course around the medial part of the sacrospinous ligament, corresponding to the ‘second stage’ of the internal pudendal artery as described by Alcock, our new laparoscopic approach is possible and applicable. It could be now transferred into operative procedure by experienced laparoscopic surgeons to facilitate the approach to the PN.

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POTENTIAL CONFLICTS OF INTEREST

Nothing to disclose.

AUTHOR CONTRIBUTIONS

The authors listed below have made substantial contributions to the intellectual content of the paper in the various sections described below:

- Conception and design: MK, KHK, GJ.
- Acquisition of data: MK, EF, RZ, KHK, GJ, SB.
- Analysis and interpretation of data: MK, EF, RZ, GJ, EB, BM, ST.
- Drafting of the manuscript: MK, EB, BM, RZ.
- Critical revision of the manuscript for important intellectual content: MK, EB, BM, GJ, KDS, KHK, RZ.
- Statistical analysis: MK, KHK, EF, SB, GJ.
- Administrative, technical or material support: MK, RH, EF, RZ.
- Supervision: KHK, GJ, KDS, EB, BM.

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