The Anatomy of the Pelvis: Structures Important to the Pelvic Surgeon
Workshop 45
Tuesday 24 August 2010, 14:00 – 18:00

Time	Time	Topic	Speaker
14.00	14.15	Welcome and Introduction	Sylvia Botros
14.15	14.45	Overview - pelvic anatomy	John Delancey
14.45	15.20	Common injuries	Lynsey Hayward
15.20	15.50	Break	
15.50	18.00	Anatomy lab – 25 min rotations through 5 stations.	
		Station 1 &2 – SS ligament fixation	Dennis Miller/Roger Goldberg
		Station 3 – Uterosacral ligament fixation	Lynsey Hayward
		Station 4 – ASC and Space of Retzius	Sylvia Botros
		Station 5- TVT Injury	To be determined

Aims of course/workshop

The aims of the workshop are to familiarise participants with pelvic anatomy in relation to urogynecological procedures in order to minimise injuries. This is a hands on cadaver course to allow for visualisation of anatomic and spatial relationships.

Educational Objectives

1. Identify key anatomic landmarks important in each urogynecologic surgery listed.
2. Identify anatomical relationships that can lead to injury during urogynecologic surgery and how to potentially avoid injury.

Anatomy Workshop ICS/IUGA 2010 – The anatomy of the pelvis: Structures important to the pelvic surgeon.

We will Start with one hour of Lectures presented by Dr. John Delancy and Dr. Lynsey Hayward.

The second portion of the workshop will be in the anatomy lab rotating between 5 stations as presented below.

Station 1 & 2 (SS ligament fixation) Hemi pelvis – Dennis Miller/ Roger Goldberg A 3rd hemipelvis will be available for DR. Delancey to illustrate key anatomical structures in this region.

1. pudendal vessels and nerve
2. ischial spine
3. coccygeus muscle
4. SS ligament
5. Levator Ani
6. Piriformis

Key Learning Points:

1. which vessels and nerves pass under the sacrospinous ligament
2. pudendal nerve at risk with SS ligament fixation

Station 3 (uterosacral ligament fixation) Hemi pelvis – Lynsey Hayward

1. Uterosacral ligament and course from cervix to sacrum
2. Lumbo sacral trunk
3. Relationship of ligament to ureter and lumbosacral nerve roots
4. Int and ext Iliac vessels
5. Inferior and Superior hypogastric vessels

Key Learning points:

1. which nerves are at risk for entrapment
2. relation of uterosacral ligament to the Ischial spine and levels of support

Station 4 ASC / Burch / Paravaginal repair

1. Cooper's Ligament
2. Space of Retzius
3. ATFP/Ischial spine
4. Obturator membrane/foramen, vessels and nerve
5. Course of ureter
    a. Over pelvic brim
    b. relation to IP ligament
    c. side wall as dissecting peritoneum
    d. in relation to uterine artery
    e. entry into bladder

6. Bifurcation of the aorta
7. Anterior longitudinal ligament
8. Middle sacral artery
9. Uterus/Cervix/ uterine artery
10. Ovaries/IP ligament

Key Learning Points:
1. Understand proximity of the ureter to the cervix
2. Which nerve is at risk during the paravaginal repair?
3. Describe potential vascular injury with the ASC.

Station 5 TVT injury Full Pelvis – (to be determined)

The objective of this station is to be able to visualize the potential sites of injury with the TVT trocar.

The lumbosacral trunk, internal iliac artery and uterosacral ligament

During this station we will be exploring the anatomy of the lumbosacral plexus, its relationship to the Iliac vessels and when it may be vulnerable to damage during surgery, We will also explore the anatomy the uterosacral ligament and its relationship to the ureter and the lumbosacral plexus. We will also explore the path of the ureter as it head over the pelvic brim and its path to the bladder trying to ascertain its points of vulnerability during pelvic and vaginal surgery

Anatomy of The lumbosacral Trunk

The Lumbosacral Trunk is a Collection of nerves providing sensory motor and autonomic innervations, it is composed from L1,L2,L3,L4,L5 and S1,S2,S3 nerve roots.

The L1 to L4 nerve roots form the lumbar plexus and give rise to the following nerves

L1, The iliohypogastric and ilioinguinal nerves.

L!,2 the genitofemoral nerve

L2 lateral cutaneous nerve of the thigh

L2,4 the obturator nerve

L3,4 the femoral nerve

The sacral plexus forms from L5 to S4 and give rise to:

L4,5,S1,2,3 the sciatic nerve which branches into the:

Superior gluteal nerve

Inferior gluteal nerve

Nerve to obturator internus

Nerve to quadratus femoris.

S2,3,4 forms the pudendal nerve.

We will examine these nerves and their path during this station and examine how they may be damaged during surgical procedures.

Pelvic Neuropathies

Iliohypogastric (Lumbar plexus: usually L1, occasionally T12)	Parallels the iliac crest; divides into the lateral & anterior cutaneous branches	Lateral cutaneous branch supplies superolateral quadrant of buttock	• Rarely injured in isolation • Most common causes of injury are surgical procedures: -transverse lower abdominal incisions (as in hysterectomies) -procedures such as inguinal herniorrhaphy & appendectomies. • Sports injuries (eg. muscle tears of the lower abdominal muscles) • Pregnancy may also result in injury to the nerve	• Burning pain immediately following the operation • Tenderness in the area • Hyperesthesia or hypoesthesia may occur in the area supplied by this nerve
Lateral Cutaneous Nerve of the Thigh (Lumbar plexus: L2-L3)	Passes deep to inguinal ligament & 2-3cm medial to the anterior superior iliac spine (ASIS)	Supplies skin on anterior & lateral aspects of the thigh	• Caused by entrapment of the nerve, usually at the inguinal ligament • Entrapment may be due to: -intrapelvic causes, (pregnancy, abdominal tumours, appendicitis etc.) -extrapelvic causes (tight belts, garments, girdles or stretch from obesity) -or mechanical causes	• Anterior & lateral thigh burning, tingling &/or numbness that increases with standing, walking, or with hip extension • Hyperesthesia over the lateral thigh • Pain can be produced, medial to ASIS
Femoral (Largest branch of the lumbar plexus: L2-L4)	Emerges from the lateral border of the psoas muscle then courses inferiorly in the intermuscular groove between this muscle & the iliacus. It then passes under the inguinal ligament lateral to the femoral artery & vein (forming the femoral triangle)	Innervates the anterior thigh. It also sends articular branches to the hip & knee joints and provides several cutaneous branches to the anteromedial side of the thigh	• Major cause is diabetic amyotrophy • Can also be injured due to: -nerve entrapments -heat developed by hip arthroplasty -by foetus during birth -pelvic fractures -pelvic procedures that require the lower extremity to be positioned in an acutely flexed, abducted, and externally rotated position for long periods	• Pain in the inguinal region • Dysesthesia over the anterior thigh & antero~~medial~~ lateral leg • Difficulty with walking, & buckling of the knee • Weak hip flexion, knee extension, & impaired quadriceps tendon reflex • Sensory deficit in the anteromedial aspect of the thigh
Obturator (Lumbar plexus: anterior rami of L2-L4)	Runs in the extraperitoneal fat along the lateral wall of the pelvis to the obturator canal	Anterior & posterior branches innervate medial thigh muscles	• Rarely injured in isolation • Injury can occur with: -pelvic trauma & associated fractures -compression of the nerve between the head of the fetus & the bony structures of the pelvis -between a tumor the bony pelvis	Complications may include: • Difficulty with ambulation & complaints of an "unstable" leg. • Groin & leg pain • In severe injuries: wasting of the adductor muscles of the thigh
Genitofemoral (Lumbar plexus: L1-L2)	Descends the anterior surface of psoas major muscle; divides into genital and femoral branches	Femoral branch supplies skin over lateral femoral triangle; genital branch supplies anterior scrotum or labia majora	• Can be trapped throughout its course in the pelvis • Most common injury is due to surgical procedures: -hernia repair; appendectomy; biopsies; caesarean delivery • Injury may also occur due to intrapelvic trauma to the posterior abdominal wall, retroperitoneal hematoma, pregnancy, or trauma to the inguinal ligament	• Hyperesthesia over the anterior thigh below the inguinal ligament • Groin pain that can worsen with internal or external rotation of the hip, prolonged walking or even with light touch
Ilioinguinal (Lumbar plexus: L1, occasionally T12)	Passes through inguinal canal; divides into femoral & scrotal or labial branches	Femoral branch supplies skin over medial femoral triangle	•Surgical procedures: -lower abdominal incisions; iliac bone harvesting; appendectomy; inguinal herniorrhaphy; inguinal lymph node dissection; femoral catheter placement; hysterectomy; abdominoplasty • Pregnancy	• Hyperesthesia or hypoesthesia of the skin along the inguinal ligament • Pain in the medial groin, labia majora or scrotum, and the inner thigh • Tenderness where the nerve exits the inguinal canal

Prepared by: Amanda Lewkowski & Ashleigh Emery, 2nd Year Medicine 2006

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Relationship of the uterosacral ligament to the sacral plexus and to the pudendal nerve.

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Abstract

We describe the anatomy of the uterosacral ligament with respect to the sacral plexus. In six adult female embalmed cadavers, we identified the uterosacral ligament and its lateral nerve relations. Using the ischial spine as the starting point and measuring along the axis of the uterosacral ligament, we noted that :

The S1 trunk of the sacral plexus passes under the ligament 3.9 cm [95% confidence interval (CI), 2.1-5.8 cm] superior to the ischial spine.

The S2 trunk passes under the ligament at 2.6 cm (95% CI; 1.5, 3.6 cm) superior to the ischial spine.

The S3 trunk passes under the ligament at 1.5 cm (95% CI; 0.7, 2.4 cm), superior to the ischial spine

The S4 trunk passes under the ligament at 0.9 cm (95% CI; 0.3, 1.5 cm) superior to the ischial spine.

The pudendal nerve forms lateral to the uterosacral ligament.

Our data demonstrate that the S1-S4 trunks of the sacral plexus, not the pudendal nerve, are potentially vulnerable to injury during uterosacral ligament suspension.

The internal Iliac Artery.

Course

It arises at the bifurcation of the common iliac artery, opposite the *lumbosacral* articulation (L4 intervertebral disc), and, passing downward to the upper margin of the greater sciatic foramen, divides into two large trunks, an anterior and a posterior.

The following are relations of the artery at various points: it is posterior to the ureter, anterior to the internal iliac vein, the lumbosacral trunk, and the piriformis muscle; near its origin, it is medial to the external iliac vein, which lies between it and the psoas major muscle; it is above the obturator nerve.

Branches

The exact arrangement of branches of the internal iliac artery is variable. Generally, the artery divides into an anterior division and a posterior division, with the posterior division giving rise to the superior gluteal, iliolumbar, and lateral sacral arteries. The rest usually arise from the anterior division.

The following are the branches of internal iliac artery. Because it is variable, a listed artery may not be a direct branch, but instead might arise off a direct branch.

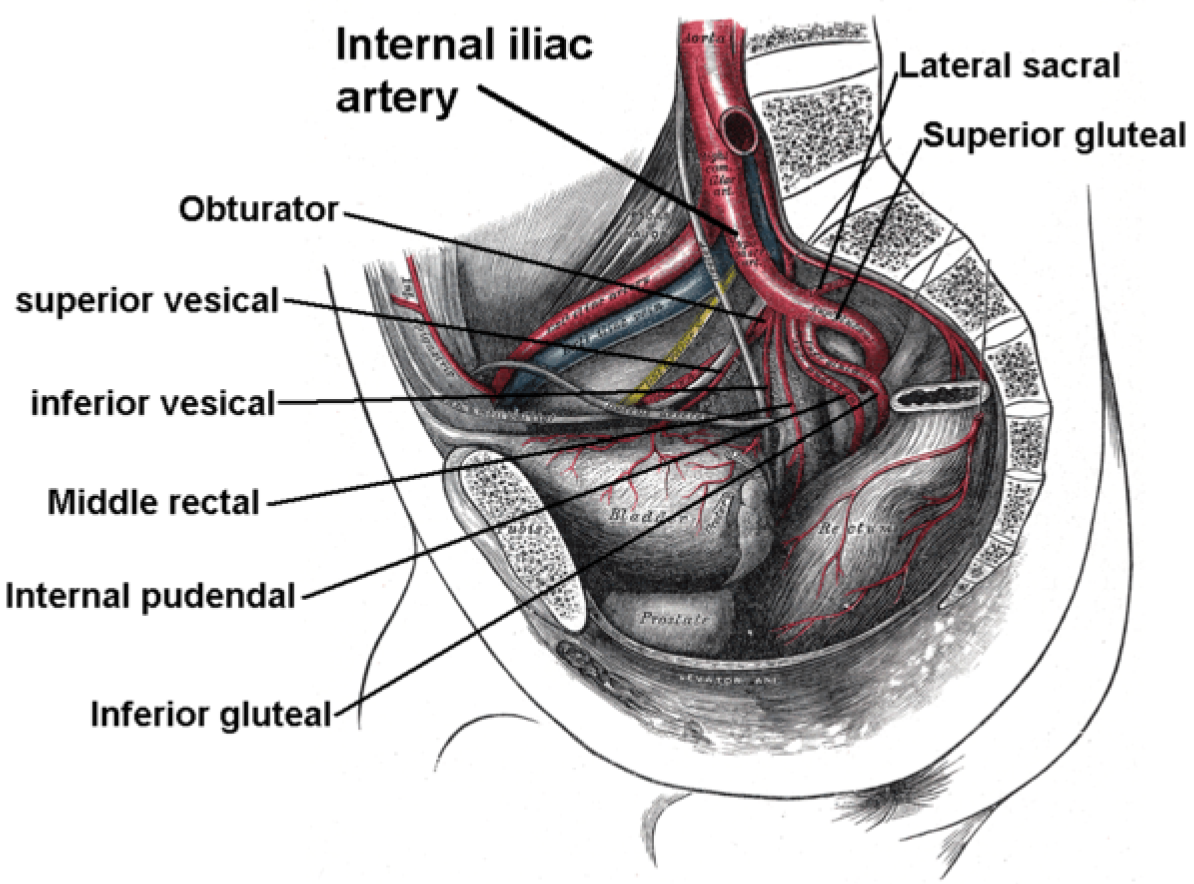
Division	Branch	Sub-branches	To/through
Posterior	Iliolumbar artery	lumbar and iliac branches	psoas major muscle, quadratus lumborum muscle, iliacus muscle
Posterior	Lateral sacral arteries	superior and inferior branches	anterior sacral foramina
Posterior	Superior gluteal artery	-	greater sciatic foramen
Anterior	Obturator artery (occasionally from inferior epigastric artery)	-	obturator canal
Anterior	Inferior gluteal artery	-	greater sciatic foramen
Anterior	Umbilical artery	superior vesical artery (usually, but sometimes it branches directly from anterior trunk)	medial umbilical ligament
Anterior	Uterine artery (females) or deferential artery (males)	superior and vaginal branches	uterus, vas deferens
Anterior	Vaginal artery (females, can also arise from uterine artery)	-	vagina
Anterior	inferior vesical artery	-	urinary bladder
Anterior	Middle rectal artery	-	rectum
Anterior	Internal pudendal artery	See next page	greater sciatic foramen

:

The internal pudendal artery gives off the following branches.

In females	In males	Description
Inferior rectal artery	Inferior rectal artery	to anal canal
Perineal artery	Perineal artery	supplies transversus perinei superficialis muscle
Posterior labial branches	Posterior scrotal branches	-
Artery of bulb of vestibule	Artery of bulb of penis	supplies bulb of vestibule/bulb of penis
Dorsal artery of clitoris	Dorsal artery of penis	-
Deep artery of clitoris	Deep artery of penis	to corpus cavernosum

Consider when you may damage the branches of the pudendal artery or its nerves and what consequence this may have to the patient.



Surgical Anatomy of the Pelvic ureter

The ureter enters the pelvis by crossing over the point where the common iliac artery divides into the internal and external iliac artery. At this point the ureter lies medial to the branches of the anterior division of the internal iliac artery and lateral to the peritoneum of the cul-de-sac. It is attached to the peritoneum of the lateral pelvic side wall. The ureter passes beneath trhe uterine artery approximately 1.5cm lateral to the cervix. As it proceeds distally, the ureter courses along the lateral side of the uterosacral ligament and enters the endopelvic fascia of the uterosacral ligamnet.Accompanied by a few vesical vessels and a component of the autonomic pelvic plexus the ureter then runs infront of the vagina to enter the bladder. The intravesical ureter is about 1.5cm long and is divided into an intramural segment that is surrounded by bladder wall and a submucosal segment about8mm longdirectly under the bladder mucosa.

The ureter is particularly vulnerable to damage at 3 sites in the pelvis.

1 At the pelvic brim when taking the infundibulo-pelvic ligament during hysterectomy.

2 At the level of the uterine vessels.

3 At the level of the cardinal ligament.

Take the opportunity to examine the path of the ureter in the cadaveric dissections, how can you avoid damage to the ureters? During what types of procedures are the ureters most at risk? During difficult abdominal surgery how would you identify the ureter?

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Clinical Anatomy 18:200–205 (2005)

ORIGINAL COMMUNICATION

Anatomical Study of the Pudendal Nerve Adjacent to the Sacrospinous Ligament

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The pudendal nerve (S3–S5) is a major branch of the sacral plexus. After branching from the sacral plexus, the pudendal nerve travels through three main regions: the gluteal region, the pudendal canal, and the perineum. In the gluteal region, the pudendal nerve lies posterior to the sacrospinous ligament. The relationship of the pudendal nerve to the sacrospinous ligament has important clinical ramifications, but there is a lack of literature examining the variations in pudendal nerve anatomy in the gluteal region. This study investigates the pudendal nerve trunking in relation to the sacrospinous ligament in 37 cadavers (73 sides of pelves) of 21 males and 16 females, ranging from 18–83 years of age. Pudendal nerve trunking could be grouped into five types: Type I is defined as one-trunked (41/73; 56.2%), Type II is two-trunked (8/73; 11%), Type III is two-trunked with one trunk as an inferior rectal nerve piercing through the sacrospinous ligament (8/73; 11%), Type IV is two-trunked with one as an inferior rectal nerve not piercing through the sacrospinous ligament (7/73; 9.5%), and Type V is three-trunked (9/73; 12.3%). In summary, 56.2% of pudendal nerves adjacent to the sacrospinous ligament were one-trunked, 31.5% were two-trunked and 12.3% were three-trunked. Fifteen inferior rectal nerves originated independently from the S4 root and never joined the main pudendal nerve. Eight of fifteen inferior rectal nerves pierced through the sacrospinous ligament, perhaps making it prone for entrapment. We measured the average diameter of the main trunk of the pudendal nerve to be 4.67 $\pm$ 1.17 mm. We also measured the average length of the pudendal nerve trunks before terminal branching to be 25.14 $\pm$ 10.29 mm. There was no significant statistical difference in the average length, average diameter, number of trunks, and pudendal nerve variations between male and female or right or left sides of the pelves. A detailed study of pudendal nerve trunking in relationship to the sacrospinous ligament would be useful for instruction in basic anatomy courses and in relevant clinical settings as well. Clin. Anat. 18:200–205, 2005. © 2005 Wiley-Liss, Inc.

Key words: inferior rectal nerve; pudendal nerve; sacrospinous ligament

INTRODUCTION

The sacral plexus is composed of the anterior rami of the fourth and fifth lumbar nerves (L4, L5) and the first, second, third, and fourth sacral nerves (S1, S2, S3, and S4). The sacral plexus gives off the pudendal nerve, which is formed from the anterior rami of the second, third, and fourth sacral nerves (S2, S3, and S4). The pudendal nerve roots emerge from the anterior sacral foramina containing both somatic and autonomic fibers, making it a mixed nerve. The pudendal nerve then accompanies the internal pudendal artery to exit the pelvis through the greater sciatic foramen, traveling anterior to the piriformis muscle and posterior to the coccygeus muscle and the sacrospinous ligament. At this point the pudendal nerve winds posteriorly around the ischial spine, medial to the pudendal vessels (Gruber et al., 2001) and deep to the sacrotuberous ligament

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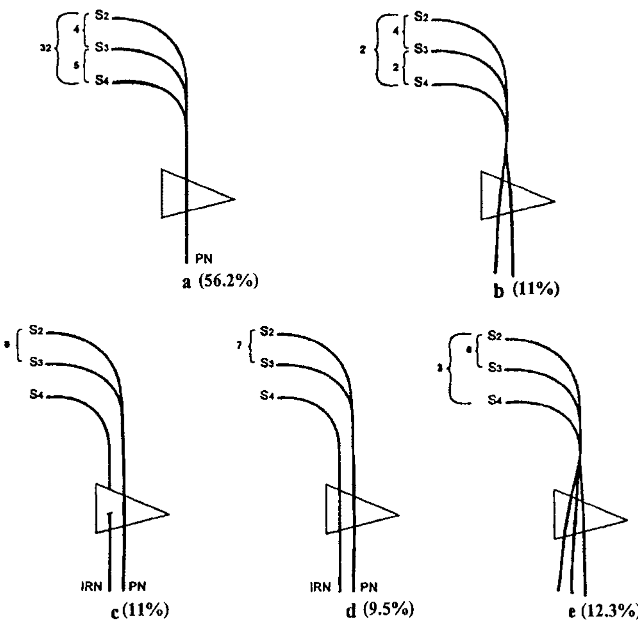

Fig. 1. Schematic depiction of pudendal nerves: types with percentage and origins. ▷ = Sacrospinous ligament. PN, pudendal nerve; IRN, inferior rectal nerve; numerals, number of pelves; $S_2S_3S_4$, sacral root 2,3,4 respectively; a–e, Type I–V, respectively.

in the biligamentary tunnel (Robert et al., 1998). It then swings anteriorly through the lesser sciatic foramen and the pudendal canal (Alcock's canal) to enter the perineum. The pudendal nerve subsequently gives off its terminal branches: the dorsal nerve of the penis or clitoris, the inferior rectal nerve and the perineal nerve. The dorsal nerve of the penis (or clitoris) supplies sensory nerve endings to the skin of the penis (or clitoris). The inferior rectal nerve supplies the external anal sphincter, the mucous membrane of the lower half of the anal canal and the perianal skin. The perineal nerve gives off deep branches to the muscles of the urogenital triangle and superficial branches to the skin on the posterior surface of the scrotum or labia majora. In summary, the pudendal nerve runs through three main regions: the gluteal region, the pudendal canal, and the perineal region (Thoumas et al., 1999).

The course of the pudendal nerve through the gluteal region has the most clinical implications. At this point, the pudendal nerve runs posterior to the sacrospinous ligament. Detailed knowledge of pudendal nerve variation and position adjacent to the sacrospinous ligament is relevant in multiple clinical scenarios. In sacrospinous colpopexy, a surgical procedure that corrects vaginal vault prolapse post-hysterectomy by suspending the vault to the sacrospinous ligament, understanding the course of the pudendal nerve is critical to avoid nerve injury (Sagsoz, 2002). The path of the pudendal nerve is also important in pudendal nerve blocks that necessitate penetration of the area with a needle (Roberts and Taylor, 1973; Thoumas et al., 1999). The anatomy of the pudendal nerve is fundamental when performing surgical procedures directly involving the nerve itself. Pudendal nerve anastomoses are carried out to innervate a functioning neosphincter in patients having undergone a rectal excision (Sato et al., 1997). Electrodes may be placed on the pudendal nerve (or its root or branches) to treat anal or urethral sphincter insufficiency (Hohenfellner et al., 1992). In the setting of nerve entrapment, a neurolysis can be carried out to release the pudendal nerve (Shafik, 1993). Pudendal nerve anatomy may also be useful in addressing chronic pelvic pain syndrome where therapeutic perineural injections of the pudendal nerve with an anesthetic and steroid can be carried out (Antolak et al., 2002). In each of these clinical settings, thorough knowledge of pudendal nerve variation near the sacrospinous ligament is necessary for a good outcome. Several basic anatomy textbooks (Clemente, 1985; Moore and Dalley, 1999), however, provide scant detail of the nerve in this area. Likewise, many surgeons have expressed unfamiliarity with pudendal nerve anatomy due to the technically difficult surgical exposure (O'Bichere et al., 2000). Review of literature also yielded few studies on pudendal nerve variation in the gluteal region. The paucity of reliable information on this subject compelled the authors to study pudendal nerve anatomy adjacent to the sacrospinous ligament. The purpose of this study is to investigate pudendal nerve variations in relation to the sacrospinous ligament for basic medical education as well as for use in appropriate clinical settings.

MATERIALS AND METHODS

Medical students carried out routine dissection on 73 pudendal nerves from 37 cadavers (21 males and 16 females) ranging from 18–86 years of age. Variations in pudendal nerve branching adjacent to the sacrospinous ligament were noted. Each pudendal nerve was traced to identify its origin and termination as accurately as possible (because mutilation of some end organs from the students' dissection was inevitable). The length of each trunk before terminal branching was measured and recorded. The diameter of each trunk two centimeters distal to the piriformis muscle's inferior border was also measured and recorded. The length of the pudendal nerve

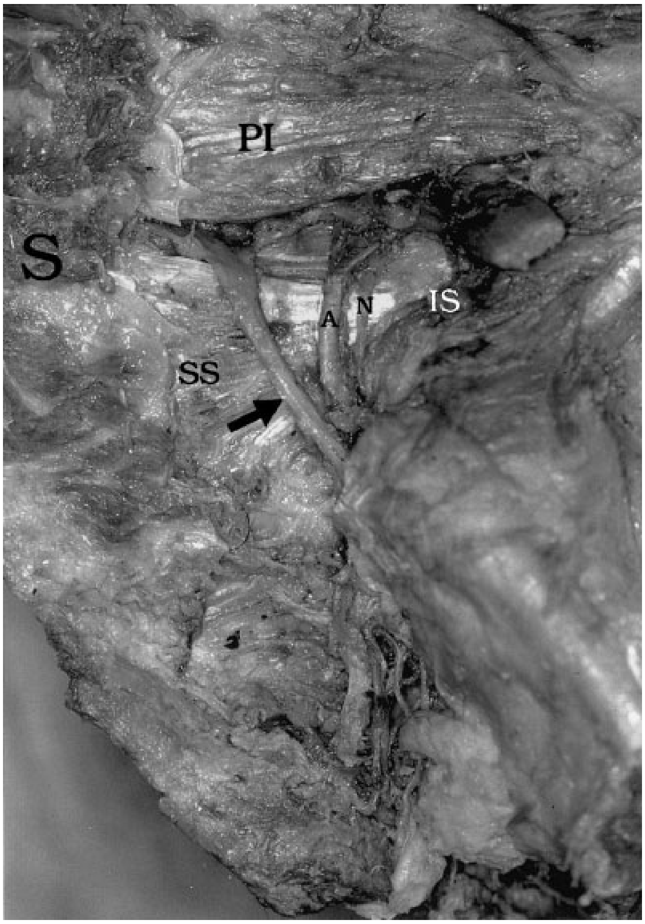

Fig. 2. Right pelvis. Type I, one-trunked (arrow). PI, piriformis muscle; S, sacrum; IS, ischial spine; SS, sacrospinous ligament; A, internal pudenal artery; N, nerve to obturator internus.

trunk was measured from the union of its component nerve roots (S2, S3, and S4) to its terminal branches. Methods of data analysis included using an SPSS program (version 7.5) for descriptive statistical analysis and an independent *t*-test.

RESULTS

Variations in the nerve trunks of the pudendal nerve adjacent to sacrospinous ligament were grouped into five types: Type I, one-trunked (41/73; 56.2%, Figs. 1a, 2); Type II, two-trunked (8/73; 11%, Figs. 1b, 3); Type III, two-trunked with one as an inferior rectal nerve piercing through the sacrospinous ligament (8/73; 11%, Figs. 1c, 4); Type IV, two-trunked with one as an inferior rectal nerve not piercing through the sacrospinous ligament (7/73; 9.5%, Figs. 1d, 5); and Type V, three-trunked (9/73; 12.3%, Figs. 1e, 6).

Pudendal nerve branching varied in number from one to three trunks, with 56.2% of the nerve specimens one-trunked, 31.5% two-trunked, and 12.3% three-trunked (Fig. 1). Of 23 two-trunked pudendal nerves, 15 were recto-pudendal with the inferior rectal nerve independently originating from the S4 root. Of these 15 inferior rectal nerves, eight pierced the sacrospinous ligament (Fig. 4) whereas seven traveled adjacent to the ligament (Fig. 5). Although 50.7% (37/73) of pudendal nerves originated from the roots of S2, S3, and S4, 39.7% (29/73) were derived only from S2 and S3 and 9.6% (7/73) were derived only from S3 and S4 (Fig. 1).

The average diameters of pudendal nerve trunks 2 cm distal to the piriformis muscle was 4.67 mm, 1.89 mm, and 1.67 mm for the first, second, and third trunk, respectively. We defined the first trunk as the main trunk, the second as the trunk medial to the main trunk, and the third as the remaining trunk (Table 1).

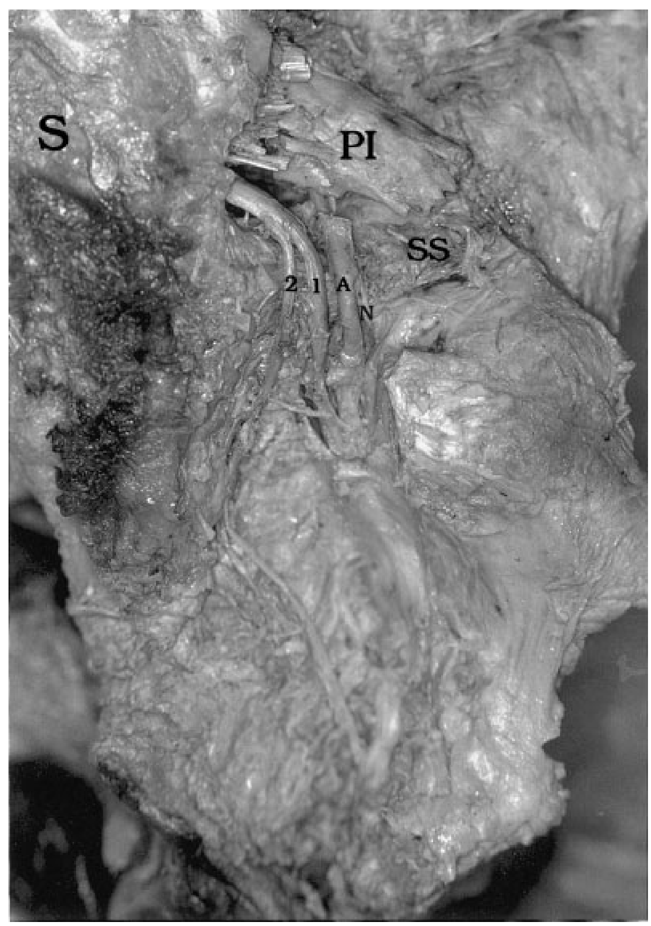

Fig. 3. Right pelvis. Type II, two-trunked. 1, main trunk; 2, second trunk; PI, piriformis muscle; S, sacrum; SS, sacrospinous ligament; A, internal pudendal artery; N, nerve to obturator internus.

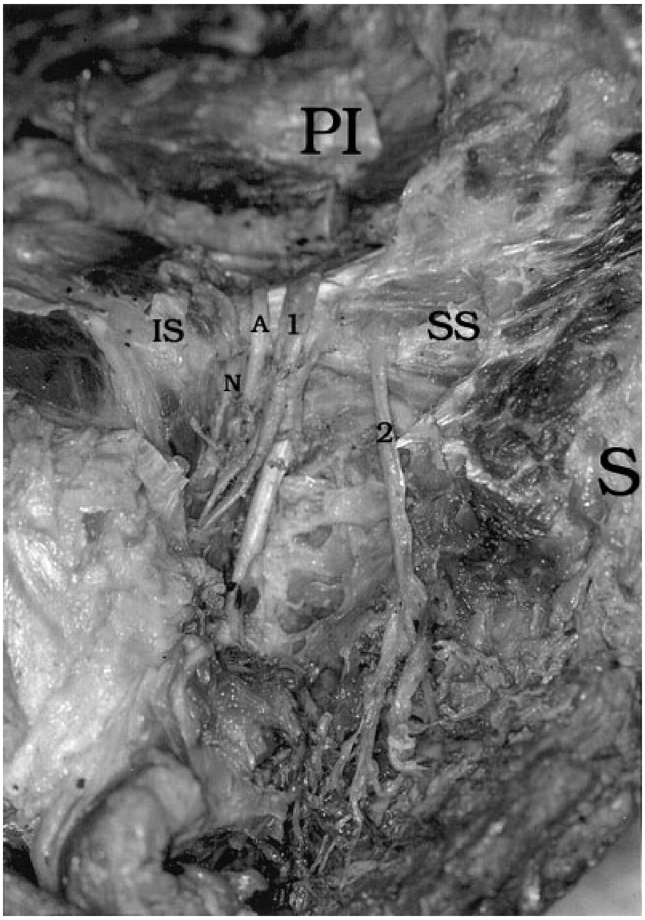

Fig. 4. Left pelvis. Type III, two-trunked with an inferior rectal nerve piercing through the sacrospinous ligament. 1, main trunk; 2, inferior rectal nerve; PI, piriformis muscle; S, sacrum; IS, ischial spine; SS, sacrospinous ligament; A, internal pudendal artery; N, nerve to obturator internus.

The average length of the pudendal nerve trunk before terminal branching was 25.14 (5–55) mm. Types II and V branched over the sacrospinous ligament and had an average length of 20.3 (5–38) mm. Types I, III, and IV branched in Alcock's canal and had an average length of 28.55 (10–55) mm (Table 2).

There was no significant statistical difference between the average length, diameter, and branching between male and female cadavers or between right and left sides of the pelves. ($P < 0.05$)

DISCUSSION

In the current study, 43.8% of the pudendal nerves had multiple trunks (Fig. 1, 32 of 73). This correlates with the findings of Gruber et al. (2001) who studied 58 cadavers and reported 40.5% of the pudendal nerves to be multi-trunked. Our results are also close to the ratio of 2:1 (normal to anatomical variations in pudendal nerves) that was reported by Sikorski et al. (1987). Although O'Bichere et al. (2000) found only 25% of the pudendal nerves to be branched in his study, his sample size was relatively small at 14 specimens. He suggested that variations would increase with increase in sample size. Gruber et al. (2001) also reported similar results to this study. In their investigation of 58 cadavers, they found 40.5% of the pudendal nerves to be multi-trunked.

Other variations in pudendal nerve anatomy have been described. O'Bichere et al. (2000) reported that 25% of the dorsal nerves of the penis (or clitoris) derived independently from the S2 nerve root. In two different studies, Shafik et al. (1995) and Shafik and Doss (1999) described an inferior rectal nerve deriving independently from S_3. Roberts and Taylor (1973) reported an inferior rectal nerve that formed independently from the sacral plexus, but did not specify which sacral root it arose from. In the current

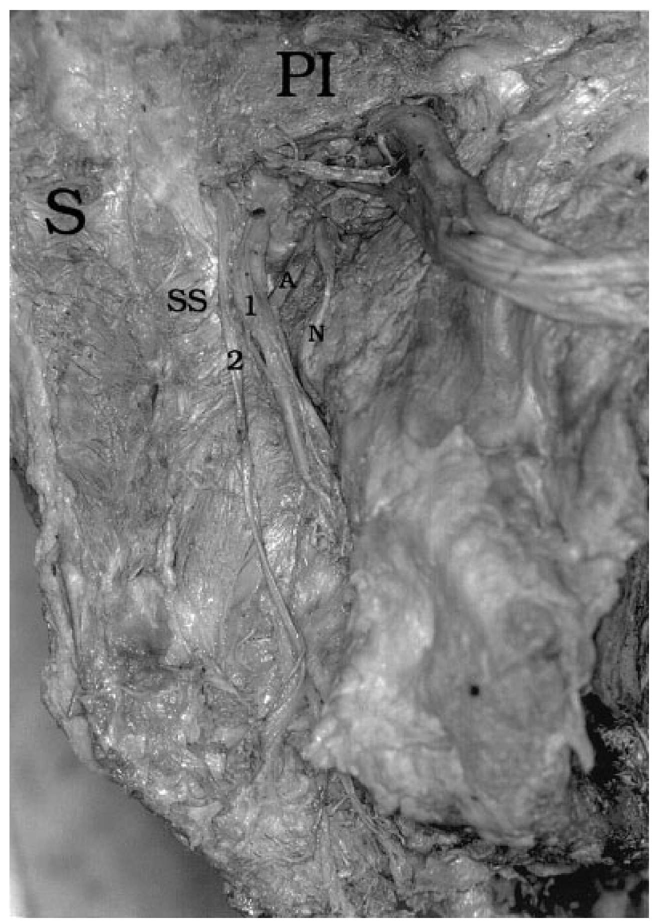

Fig. 5. Right pelvis. Type IV, two-trunked with an inferior rectal nerve not piercing through the sacrospinous ligament. 1, main trunk; 2, inferior rectal nerve; PI, piriformis muscle; S, sacrum; SS, sacrospinous ligament; A, internal pudendal artery; N, nerve to obturator internus.

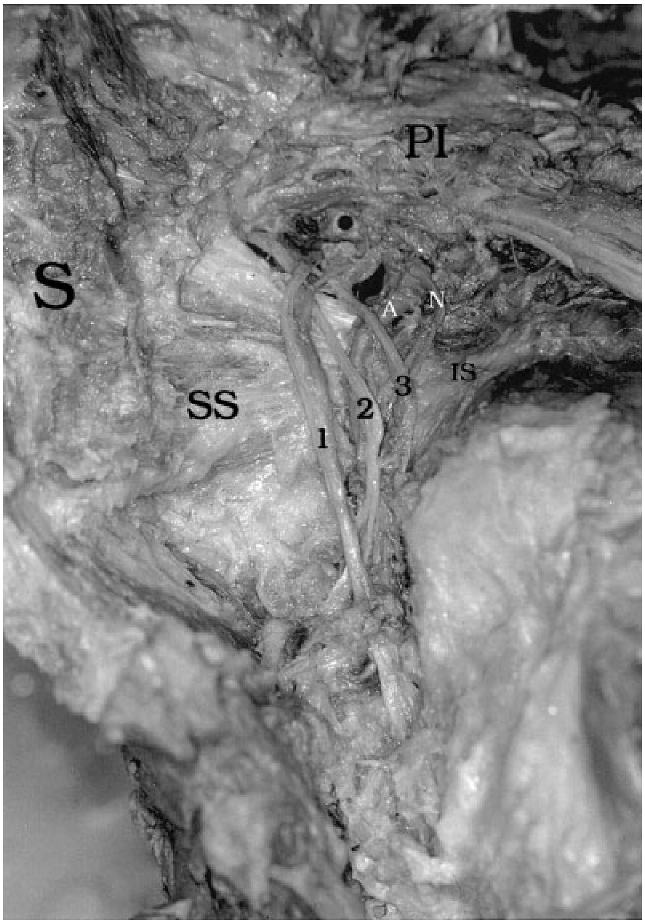

Fig. 6. Right pelvis. Type V, three-trunked. 1, main trunk; 2, second trunk; 3, remaining trunk; PI, piriformis muscle; S, sacrum; IS, ischial spine; SS, sacrospinous ligament; A, internal pudendal artery; N, nerve to obturator internus.

study, we found 15 inferior rectal nerves (20.5%) originating solely from the S_4 nerve root.

Shafik et al. (1995) also reported 30% of pudendal nerves to have component S1 and S5 nerve roots, but in the literature we found no similar reports, nor did we observe this in our own study. We found 50.7% of pudendal nerves to be derived from S_2, S_3, and S_4, 39.7% from S_2 and S_3, and 9.6% from S_3 and S_4.

TABLE 1. Average Diameter of Trunk of Pudendal Nerve[a]

Trunk	Average diameter (mm)
1st	4.67 ± 1.17
2nd	1.89 ± 0.76
3rd	1.67 ± 0.5

[a]For two trunked, 1st trunk = main trunk and 2nd trunk = the other trunk. For three trunked, 1st trunk = main trunk, 2nd trunk = the trunk just medial to the main trunk, and 3rd trunk = the remaining trunk.

TABLE 2. Average Length of Trunk Before Terminal Branching

Type	Average length (mm)	SD
Type 2.5[a]	20.3 (5–38)	10.36
Type 1,3,4[b]	28.55 (10–55)	10.33
Total	25.14 (5–55)	10.29

[a]Trunk branching over sacrospinous ligament.
[b]Trunk branching in Alcock's canal.

O'Bichere et al. (2000) also reported that the majority of pudendal nerves in his study formed solely from the S_2, S_3, and S_4 nerve roots.

We also measured the average length of the pudendal nerve before terminal branching to be 28.5 mm. This mirrors the results of Sato et al. (1997) of 29.5 (21–40) mm, but deviates from the measurement of 55 (44–75) mm of O'Bichere et al. (2000). This could be due to differences in ethnicity, lifestyle, or height between Asians and Europeans. The average diameter of the pudendal nerve trunk (4.67 mm) in our study, however, closely correlates with O'Bichere et al. (2000) findings of 5.05 mm. There was no difference between right and left sides of the pelves or between male and female cadavers.

We also observed 11% (8/73) of inferior rectal nerves piercing the sacrospinous ligament. Roberts and Taylor (1973) reported a sacrospinous ligament penetration rate of 20% in his study of inferior rectal nerve variations. We observed the penetration site to be approximately 1 cm medial to the ischial spine. Roberts and Taylor (1973) proposed that this inferior rectal nerve variation might explain instances of poor outcome in percutaneous pudendal nerve blocks. In such blocks, local anesthetic is injected at the ischial spine. In the case of an inferior rectal nerve piercing the sacrospinous ligament 1 cm medial to the ischial spine, anesthetic injected at the ischial spine would not be effective. This inferior rectal nerve variant may have other important clinical ramifications. The inferior rectal nerve might be prone to entrapment at the site of penetration of the sacrospinous ligament, resulting in the inferior rectal nerve syndrome. In this syndrome, patients describe both perianal and perineal paresthesias as well as anal sphincter insufficiency. The pudendal canal syndrome has a similar range of symptoms, but also includes urethral sphincter insufficiency because the external urethral sphincter is innervated by the perineal branch of the pudendal nerve (Barber et al., 2002). If surgical decompression is carried out to treat inferior rectal nerve syndrome, decompression should be directed at the point of penetration of the sacrospinous ligament to ensure optimal relief of symptoms.

Our findings confirm the recommendations of Sagsoz et al. (2002) for suture placement for suspension of the vaginal vault post-hysterectomy. He suggested that the medial and inferior portion of the sacrospinous ligament, close to the sacrum, is a safe site for suture placement because it is certainly quite remote from the pudendal nerve group.

In conclusion, knowledge of the anatomical variations of the pudendal nerve in relation to the sacrospinous ligament has important clinical applications in gynecologic, urologic, and colorectal surgery. In addition, such information enriches learning experiences in basic human anatomy.

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Diagnostic Criteria for Pudendal Neuralgia by Pudendal Nerve Entrapment (Nantes Criteria)

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Aims: The diagnosis of pudendal neuralgia by pudendal nerve entrapment syndrome is essentially clinical. There are no pathognomonic criteria, but various clinical features can be suggestive of the diagnosis. We defined criteria that can help to the diagnosis. **Materials and Methods:** A working party has validated a set of simple diagnostic criteria (Nantes criteria). **Results:** The five essentials diagnostic criteria are: (1) Pain in the anatomical territory of the pudendal nerve. (2) Worsened by sitting. (3) The patient is not woken at night by the pain. (4) No objective sensory loss on clinical examination. (5) Positive anesthetic pudendal nerve block. Other clinical criteria can provide additional arguments in favor of the diagnosis of pudendal neuralgia. Exclusion criteria are also proposed: purely coccygeal, gluteal, or hypogastric pain, exclusively paroxysmal pain, exclusive pruritus, presence of imaging abnormalities able to explain the symptoms. **Conclusion:** The diagnosis of pudendal neuralgia by pudendal nerve entrapment syndrome is essentially clinical. There are no specific clinical signs or complementary test results of this disease. However, a combination of criteria can be suggestive of the diagnosis. *Neurourol. Urodynam. 27:306–310, 2008.* © 2007 Wiley-Liss, Inc.

Key words: Alcock's canal; diagnosis; entrapment; neuralgia; pudendal nerve

INTRODUCTION

After having been completely neglected and poorly defined for a long time, the diagnosis of pudendal neuralgia[1,2] is now fairly easy to establish in the presence of typical perineal pain, previously considered to be psychogenic due to the absence of organic lesions demonstrated on imaging or endoscopy.[3] The price of this success is that this entity is increasingly over-diagnosed or simply diagnosed by default in the presence of pelvic, perineal and buttock pain and in the absence of a diagnosis of organic disease. All forms of pain accentuated by sitting tend to be attributed to pudendal neuralgia. Although clinical neurophysiology has considerably improved our knowledge of this disease, its limitations have also been defined; it must therefore be considered to be a complementary investigation, but can never be used to formally confirm or exclude the diagnosis of pudendal neuralgia.[4]

We have therefore tried to define diagnostic criteria for pudendal neuralgia by pudendal nerve entrapment that do not pretend to cover all clinical situations, especially as the expression of pain is eminently variable and this type of pain is particularly complex as it is often associated with multiple, perplexing functional symptoms. The objective of this study was to elaborate and publish a limited number of simple criteria designed to avoid excessive or incorrect diagnosis of pudendal neuralgia. All doctors concerned with the perineum should be familiar with these criteria, but, due to their inevitably oversimplistic nature, they may need to be reconsidered on a case by case basis by experts depending on the clinical context.

These criteria were discussed and validated by a multidisciplinary working party in Nantes (France) on 23 and 24 September 2006 (Nantes criteria) and then by members of the *Club d'électrophysiologie périnéale* (Francophone perineal electrophysiology club). These proposed criteria were approved by the SIFUP PP (*Société Interdisciplinaire Francophone d'Urodynamique et de Pelvi*-Périnéologie).

In the absence of pathognomonic imaging, laboratory and electrophysiology criteria, the diagnosis of pudendal neuralgia, like any form of neuralgia, remains primarily clinical and empirical and must constantly be reviewed in the light of the clinical course. Pudendal nerve entrapment (PNE) is the most frequent aetiology and is also established on the basis of elements of clinical suspicion. Other aetiologies have also been described:[5] post-herpetic neuropathy, stretch neuropathy (although it is usually not painful or only very slightly painful), peripheral polyneuropathy, post-radiotherapy neuropathy, neoplastic compression, etc. In fact, only the operative finding of nerve entrapment and post-operative pain relief[6] can formally confirm the diagnosis of pudendal neuralgia due to nerve entrapment (except for a possible placebo effect of surgery).

Four diagnostic domains have been defined:

- essential criteria for the diagnosis of pudendal neuralgia
- complementary diagnostic criteria
- exclusion criteria
- associated signs not excluding the diagnosis.

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ESSENTIAL CRITERIA FOR THE DIAGNOSIS OF PUDENDAL NEURALGIA BY PNE

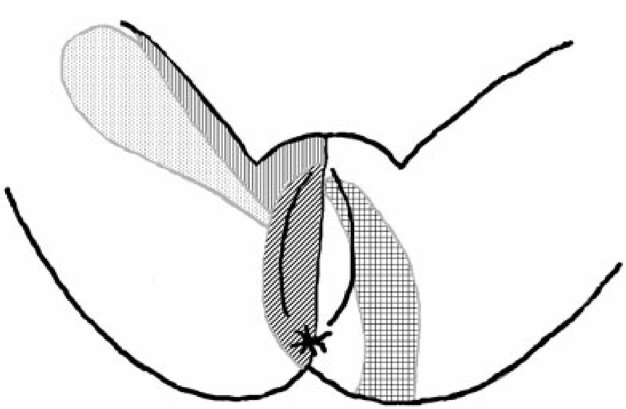
These five criteria are considered to be essential and must therefore all be present in order to conclude on a diagnosis of pudendal nerve entrapment syndrome or compressive pudendal neuralgia.

Pain in the Territory of the Pudendal Nerve: From the Anus to the Penis or Clitoris

This nerve trunk pain must be situated in the territory of the pudendal nerve, which extends from the anus to the clitoris or penis (Fig. 1). Pain may be superficial or may be situated slightly deeper in the anorectal region, vulvovaginal region and distal urethra. This criterion excludes pain exclusively confined to the coccygeal region, sacrum, buttocks, pubis and hypogastric region, but the pain of pudendal neuralgia can be referred to these zones. Although scrotal skin is innervated by sacral nerve roots and the pudendal nerve, the testis (and ovary), epididymis and vas deferens are innervated by thoracolumbar nerve roots.

Pain is Predominantly Experienced While Sitting

This is an essential clinical feature providing evidence in favor of the hypothesis of nerve compression in the context of an entrapment syndrome. Nerves must be freely mobile to avoid compression during movements (example of the ulnar nerve at the elbow) or during the pressure of sitting in the case of the pudendal nerve. Any loss of mobility of the nerve (regardless of its site) is therefore associated with a risk of compression against rigid ligamentous structures such as the falciform process of the sacrotuberous ligament.[7] Pain is due to excessive pressure and not to the sitting position, as clearly illustrated by relief of pain when sitting on a toilet seat (provided the patient sits for a sufficiently long time). This dynamic aspect is essential, as if the pain were exclusively related to a compression phenomenon, it would be continuous (although pain secondary to a tumor and experienced while standing or in bed can also be aggravated by sitting). Very often, pain is initially experienced only in the sitting position, but with time pain tends to become much more continuous even if it is still predominantly experienced while sitting.



obturator nerve
genitofemoral and ilio-inguinal nerve
pudendal nerve
inferior cluneal nerve

Fig. 1. The innervation of the perineum.

The Pain Does Not Wake the Patient at Night

This criterion is the direct consequence of the previous criterion. Many patients experience pain at bedtime and may have difficulties going to sleep. Although they can be woken by associated symptoms (e.g., need to urinate), they are never woken by perineal pain. Patients only exceptionally report a history of waking due to pain at night, but these episodes are only transient.

Pain With No Objective Sensory Impairment

This is an essential clinical finding. The presence of a superficial perineal sensory deficit is highly suggestive of a sacral nerve root lesion, particularly involving the cauda equina nerve roots, or a sacral plexus lesion. These proximal lesions usually do not cause pain and present clinically with sensorimotor deficits, especially sensory loss and sphincter motor disorders. Several hypotheses can be proposed to explain this absence of objective sensory impairment. The compression may be insufficient to induce a lesion of the fibers of superficial sensation, as observed in the case of sciatica and many cases of carpal tunnel syndrome. It may also have an anatomical explanation, as several anatomical territories overlap at this level: the territory of the pudendal nerve, the territory of the posterior femoral cutaneous nerve and its inferior cluneal branches, and the territories of nerves arising from the first lumbar nerves (especially ilioinguinal and genitofemoral).[8]

Pain Relieved by Diagnostic Pudendal Nerve Block

Anesthetic infiltration of the pudendal nerve[9] significantly relieves pain for the duration of local anesthesia. This is an essential criterion, but is not specific as it simply indicates that the pain is situated in the territory of the pudendal nerve; pain related to any perineal disease (e.g., anal) would also be relieved by pudendal nerve block and other types of nerve lesions would also have a positive diagnostic block when they are situated distal to the site of infiltration. A negative block does not formally exclude the diagnosis when it is not performed with sufficient precision or when it is performed too distally (e.g., in the pudendal canal, while the pudendal nerve lesion may be situated at the ischial spine). The infiltration technique (with or without CT guidance, with or without neurostimulation) has only a minor impact on the positive or negative response to nerve block.

COMPLEMENTARY DIAGNOSTIC CRITERIA

Burning, Shooting, Stabbing Pain, Numbness

Pudendal neuralgia presents the characteristics of neuropathic pain, which is described as burning, shooting, stabbing or aching pain and numbness, although more than four criteria of the DN4 are only rarely present[10] (clinician-administered questionnaire named DN4 consisting of both sensory descriptors and signs related to bedside sensory examination, comprises 10 criteria, 4 of which must be present for the diagnosis of neuropathic pain).

Allodynia or Hyperpathia

Allodynia or hyperpathia, highly suggestive of neuropathic pain, correspond, in the pudendal nerve territory, to intolerance of tight clothes and underwear (boxer shorts are preferred to briefs), and intolerance of vulval contact (as in vestibulodynia) with superficial dyspareunia.

Rectal or Vaginal Foreign Body Sensation (Sympathalgia)

Patients generally use fairly vivid terms to describe their deep pain, generally situated in the anus and rectum or sometimes in the vagina or urethra. They frequently describe a feeling of "foreign body," but other expressions are also suggestive: feeling of a stake, a lump, heaviness, a tennis ball, a gnawing, or crawling feeling. This symptom is sometimes incorrectly called levator ani syndrome in the absence of any correlation with levator ani hypertonia.[11] This pain has an autonomic connotation and temporary relief of these sensations by anesthetic block of sympathetic fibers of the ganglion impar suggests that they are mediated by sympathetic fibers, justifying the term "sympathalgia."

Worsening of Pain During the Day

Absence of pain in the morning on waking, slight pain in the morning, deterioration during the day reaching a peak in the evening until the patient goes to sleep is a very characteristic temporal profile of pudendal neuralgia.

Predominantly Unilateral Pain

Perineal pain is particularly suggestive of a pudendal nerve trunk lesion when it is unilateral (and when it is experienced in all of the anterior and posterior hemiperineum), but midline or central pain does not exclude the diagnosis.

Pain Triggered by Defecation

This is a feature of predominantly posterior pain; pain is not experienced immediately after defecation, but generally several minutes to one hour later.

Presence of Exquisite Tenderness on Palpation of the Ischial Spine

Palpation of the ischial spine (posterior and slightly lateral) during digital rectal or vaginal examination is very often tender. This does not constitute a true Tinel sign, as this palpation is locally tender, but does not trigger the distal pain described by the patient. Many anatomical structures are situated at this level, making this tenderness very difficult to interpret: passage of the pudendal nerve in the sacrospinous ligament, insertions of the sacrospinous ligament, ischiococcygeal fibers of levator ani muscles, diffuse hypersensitivity. Furthermore, tenderness of this region is not specific as it is also observed in asymptomatic subjects. However, unilateral tenderness at this site is suggestive.

Clinical Neurophysiology Findings in Men or Nulliparous Women

Childbirth is the commonest cause of stretch injury to the pudendal nerve, eliminating the specificity of this examination when it is performed in multiparous women. However, clinical neurophysiology data can be useful in men and nulliparous women in the absence of a history of constipation, surgery, or known proximal spinal cord or nerve root lesions.

EXCLUSION CRITERIA

Exclusively Coccygeal, Gluteal, Pubic, or Hypogastric Pain

This type of pain does not correspond to the anatomical territory of the pudendal nerve.

Pruritus

Pruritus is primarily suggestive of a dermatological lesion (atrophic lichen planus, etc.) rather than a nerve lesion. The DN4 criteria for neuropathic pain comprise "prickling," as this term may be used by patients, but the concept of pruritus includes a need to scratch which is not experienced in the context of pudendal neuralgia.

Exclusively Paroxysmal Pain

Paroxysmal shooting pain with neuropathic features is suggestive of a compressive lesion, but justifies further investigation by imaging of the pelvic region (pudendal nerve neurofibroma or schwannoma), cauda equina (sacral schwannoma) and spinal cord (meningioma). *Proctalgia fugax* is sufficiently suggestive not be confused with pudendal neuralgia, but is not sufficiently well known. Proctalgia fugax is predominantly anorectal, essentially nocturnal, recurrent pain that can last several minutes to one hour, with attacks that can occur several times a year for many years, without deterioration. Although some authors have proposed a neurological aetiology, the great majority of cases are strictly idiopathic with a controversial pathophysiology (smooth muscle spasm?).[12,13] This type of paroxysmal pain also comprises pain experienced exclusively during defecation (suggesting a proctological disease), or micturition (suggesting a urological disease), or related to sexual intercourse (vaginismus, vestibulitis).

Imaging Abnormalities Able to Account for the Pain

Medical imaging is not contributive to the positive diagnosis of pudendal neuralgia, but can be useful to exclude other diagnoses. However, imaging may reveal an intercurrent disease clearly unrelated to the neuralgia, for which treatment will not modify the course of the neuralgia. The finding of arachnoid cysts remains a difficult problem, but these cysts are classically considered to be asymptomatic. In any case, they cannot be considered to be responsible for pudendal neuralgia. Imaging is therefore essential, whenever the clinical features do not strictly meet the diagnostic criteria described in this article and will be decisive when it demonstrates a lesion able to account for the pain (especially a nerve tumor).

ASSOCIATED SIGNS NOT EXCLUDING THE DIAGNOSIS

The symptoms of pudendal neuralgia may be strictly limited to the diagnostic criteria defined above, but many patients present associated, polymorphic and perplexing symptoms that are often difficult to attribute to the pudendal nerve. Clinical experience and the course of these symptoms in response to treatment indicate that these signs do not exclude the diagnosis, although they may be difficult to explain.

Buttock Pain on Sitting

Gluteal innervation is not dependent on the pudendal nerve and isolated buttock pain, even occurring while sitting, cannot be considered to be due to pudendal neuralgia. However, the combination of perineal neuralgia and buttock pain can be explained by a common, fairly proximal conflict underneath the piriformis muscle with a concomitant lesion of the posterior femoral cutaneous nerve or inferior gluteal nerve. Buttock pain can be related to trigger points or spasm of deep gluteal muscles: obturator internus and piriformis muscles, possibly due to reflex muscle contractures secondary to pain or regional myofascial syndrome, extremely common in this context (reflecting regional hypersensitivity).

Referred Sciatic Pain

More or less truncated sciatica is extremely frequent in the context of pudendal neuralgia and can be explained by a lesion of the posterior femoral cutaneous nerve or sciatic trunk (with or without piriformis or obturator internus syndrome).[14,15] Central hypersensitivity phenomena can also be involved in view of the convergence between S1, S2, and S3 spinal levels (see effects of posterior tibial nerve stimulation on overactive bladder or perineal pain).

Pain Referred to the Medial Aspect of the Thigh

Pain referred to the obturator nerve territory may reflect an obturator internus syndrome, as this muscle is in contact with the nerve.

Suprapubic Pain

Suprapubic pain can be due to hypertonia of the puborectalis component of the levator ani muscles. Bone tenderness may suggest a complex secondary pelvic pain syndrome (low-grade reflex sympathetic dystrophy).

Urinary Frequency and/or Pain on a Full Bladder

Urinary frequency is often associated with pudendal neuralgia and tends to evolve intermittently, in parallel with the pain, allowing it to be attributed to pudendal neuralgia rather than to bladder dysfunction. There are probably synaptic interconnections associated with inappropriate processing of nociceptive messages resulting in transmission of false urges. Patients sometimes report urethral or hypogastric pain worsened by bladder filling and relieved by voiding. Such symptoms should be documented by a voiding diary; when voided volumes are small and very constant, cystoscopy under general anesthesia should be performed with bladder distension, looking for signs of painful bladder syndrome/interstitial cystitis. In contrast, very variable voided volumes are suggestive of detrusor hyperactivity, possibly part of central hypersensitivity and reflex autonomic phenomena.

Pain Occurring After Ejaculation

This isolated symptom, which is perplexing in the absence of infection (absence of seminal vesiculitis), cannot be attributed to pudendal nerve entrapment syndrome. However, it is fairly frequently associated with pudendal neuralgia and can be considered to reflect regional hypersensitivity.

Dyspareunia and/or Pain After Sexual Intercourse

The frequency of sexual intercourse is often reduced in the context of pudendal neuralgia, essentially because chronic pain decreases libido. Sexual intercourse is rarely very painful, but pain can be experienced in the case of vulval allodynia, but patients generally do not report pain during intercourse, but worsening of pain over the hours following intercourse.

Erectile Dysfunction

Pudendal neuralgia, affecting a somatic nerve, is only partially involved in erection. Classically, the main sexual function of the pudendal nerve is sensory (dorsal nerve of the penis and dorsal nerve of the clitoris), but it is also involved in pre-ejaculatory hyperrigidity and in the clonic nature of ejaculation. Patients with pudendal neuralgia frequently complain of a feeling of penile numbness, decreased sexual sensations or even decreased penile rigidity. Analgesic drugs can also have a negative impact on erection and ejaculation.

Normal Clinical Neurophysiology

Electrophysiological studies (electromyography and nerve conduction studies) only investigate large motor fibers and may not detect selective lesions of small sensory fibers. Furthermore, due to the postural nature of the pain, a neurological lesion may not always be present in the context of intermittent conflict.

CONCLUSIONS

The diagnosis of pudendal neuralgia by pudendal nerve entrapment syndrome is essentially clinical. There are no pathognomonic criteria, but various clinical features can be suggestive of the diagnosis. In the presence of the 4 essential clinical diagnostic criteria (pain in the territory of the pudendal nerve, worsened by sitting, the patient is not woken at night by the pain and no objective sensory loss) a diagnostic anesthetic pudendal nerve block should be performed and a positive block strongly supports these elements of clinical suspicion (5th criteria). However, pudendal pain is complex and interpretation of the various signs that are often

TABLE I. Diagnostic Criteria for Pudendal Neuralgia by Pudendal Nerve Entrapment

Essential criteria
Pain in the territory of the pudendal nerve: from the anus to the penis or clitoris
Pain is predominantly experienced while sitting
The pain does not wake the patient at night
Pain with no objective sensory impairment
Pain relieved by diagnostic pudendal nerve block
Complementary diagnostic criteria
Burning, shooting, stabbing pain, numbness
Allodynia or hyperpathia
Rectal or vaginal foreign body sensation (sympathalgia)
Worsening of pain during the day
Predominantly unilateral pain
Pain triggered by defecation
Presence of exquisite tenderness on palpation of the ischial spine
Clinical neurophysiology findings in men or nulliparous women
Exclusion criteria
Exclusively coccygeal, gluteal, pubic or hypogastric pain
Pruritus
Exclusively paroxysmal pain
Imaging abnormalities able to account for the pain
Associated signs not excluding the diagnosis
Buttock pain on sitting
Referred sciatic pain
Pain referred to the medial aspect of the thigh
Suprapubic pain
Urinary frequency and/or pain on a full bladder
Pain occurring after ejaculation
Dyspareunia and/or pain after sexual intercourse
Erectile dysfunction
Normal clinical neurophysiology

associated may improve the understanding and management of this disease (Table I).

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Uterosacral Ligament: Description of Anatomic Relationships to Optimize Surgical Safety

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***Objective*: To determine the optimal site in the uterosacral ligament for suspension of the vaginal vault with regard to adjacent anatomy and suspension strength.**

***Methods*: Fifteen female cadavers were evaluated between December 1998 and September 1999. Eleven hemisected pelves were dissected to better define the uterosacral ligament and identify adjacent anatomy. Ureteral pressure profiles with and without relaxing incisions were done on four fresh specimens. Suture pullout strengths also were assessed in the uterosacral ligament.**

***Results*: The uterosacral ligament was attached broadly to the first, second, and third sacral vertebrae, and variably to the fourth sacral vertebrae. The intermediate portion of the uterosacral ligament had fewer vital, subjacent structures. The mean ± standard deviation distance from ureter to uterosacral ligament was 0.9 ± 0.4, 2.3 ± 0.9, and 4.1 ± 0.6 cm in the cervical, intermediate, and sacral portions of the uterosacral ligament, respectively. The distance from the ischial spine to the ureter was 4.9 ± 2.0 cm. The ischial spine was consistently beneath the intermediate portion but variable in location beneath the breadth of the ligament. Uterosacral ligament tension was transmitted to the ureter, most notably near the cervix. The cervical and intermediate portions of the uterosacral ligament supported more than 17 kg of weight before failure.**

***Conclusion*: Our findings suggest that the optimal site for fixation is the intermediate portion of the uterosacral ligament, 1 cm posterior to its most anterior palpable margin, with the ligament on tension. (Obstet Gynecol 2001;97:873–9. © 2001 by The American College of Obstetricians and Gynecologists.)**

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Symptomatic pelvic organ prolapse comprises a large portion of gynecologic practice, with up to 10–15% of women seeking surgical correction during their lifetimes.[1,2] Most surgeons agree that reconstructive procedures to maintain vaginal function should address all support defects including anterior, posterior, and apical defects.

There are many techniques for reestablishing support of the vaginal apex. Unilateral or bilateral fixation of the apex to the sacrospinous ligament is widely advocated and used.[3–5] Whereas the technique provides sustained support of the vaginal apex, it is associated with a high incidence of recurrent anterior vaginal wall prolapse, believed to be the result of nonanatomic posterior deflection.[6,7] Another option is to suspend the vaginal vault bilaterally from the fascia of the iliococcygeus muscle, just anterior to the ischial spine.[6] That approach has the advantage of maintaining the normal alignment of the vaginal vault, but the attachment site is caudad to the normal position of the vaginal apex and might cause foreshortening of the vagina.

In 1927, Miller[8] first described bilateral suspension of the vaginal vault to the uterosacral ligaments. He secured the vaginal apex with "lifting sutures" in the peritoneum and underlying fascial and muscular structures at the base of the sacrouterine ligament, approximately 1.5 inches below the promontory of the sacrum. Tying those sutures down carries the entire vagina high up into the pelvis and back toward the fixed point of the lifting sutures. Bilateral suspension of the vaginal vault from the origins of the uterosacral ligaments was also described by McCall,[9] who combined it with an extensive culdoplasty that plicated the uterosacral ligaments and closed the cul-de-sac. More recently, uterosacral suspension was described from a vaginal[10] and laparoscopic approach[11] without plication of the uterosacral ligaments. Advocates believe that fixation closer to the

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origins of the uterosacral ligaments, if sufficiently strong on both sides, allows for better vaginal depth with normal vaginal alignment.[8,12]

There is relatively little information regarding efficacy of using the uterosacral ligament as an anchorage for suspending the vaginal vault. McCall[9] reported no recurrent enteroceles during a 3-year follow-up and Given[13] reported a 5% failure rate with an average follow-up of 7 years. The few data in part reflect the popularity of other anchorage sites, but also might echo surgeons' concerns about subjacent structures. Harris et al[14] demonstrated that this reconstructive procedure is one of the most apt to result in unsuspected ureteral compromise. Elkins et al[12] also cautioned about proximity of the uterosacral ligaments to ureters; in their report of dissections in 12 unembalmed cadavers, the ureter was an average of 1.4 cm from the uterosacral ligament at the cervix.

Our goal was to identify the location of the uterosacral ligaments and their relationship to the adjacent structures, especially the ureter. We also planned to assess how tension on the uterosacral ligament affected the ureter and determine the strength of the uterosacral ligament as a site for suture anchorage. Using cadaveric dissections in fresh and preserved female pelves, anatomic and functional data were recorded.

Materials and Methods

This descriptive study was performed in three phases: inspection of the uterosacral ligament attachments and delineation of adjacent structures potentially jeopardized by the uterosacral suspension, assessment of potential ureteral obstruction in different uterosacral ligament segments, and evaluation of relative tensile strength in different uterosacral segments. We defined the uterosacral ligament anatomically based on gross findings of its fibers coursing from sacrum to cervix along the pelvic sidewall. During the last two phases of the study, the uterosacral ligament was defined based on palpation.

Female cadavers were collected from the Maryland State Anatomy Board. They were excluded if the subjects had previous pelvic or abdominal surgery or prior dissection that might have disturbed normal pelvic anatomy, or if there was gross evidence of disease that distorted pelvic anatomy. Medical, surgical, and obstetric histories were not available. We evaluated 27 specimens between December 1998 and September 1999. Ten preserved and two fresh specimens were excluded from our study and were used only for refining the dissection technique. Eleven hemisected specimens were dissected and provided data for anatomic description of the uterosacral ligament and adjacent structures. Four intact specimens were used to evaluate ureteral pressures and to assess the tensile strength of uterosacral ligaments.

Pelvic specimens were made using a transverse cut with a high-powered band saw through the entire body wall at the level of the fourth or fifth lumbar vertebrae. Lower limbs were removed by transverse cuts made 4–5 cm beyond the greater trochanter. Eleven hemisected specimens (eight preserved and three fresh) were thus prepared and dissected. Each hemipelvis was photographed and three specimens were sketched in resting position and with anterior tension on the uterus.

Gross attachments of the uterosacral ligament at the sacrum, cervix, and adjacent structures were noted and documented. The location of the ischial spine was found by sharp dissection and direct posterior view and by anterior palpation, and the position of the spine under the levator ani muscles was marked anteriorly with a small pushpin. The uterosacral ligament was then dissected with the relationship to subjacent anatomy noted. The ureter, pelvic neurovascular structures, and the sacral nerve routes were clearly identified for each specimen in relationship to the uterosacral ligament. For descriptive purposes, the uterosacral ligament was divided into three equal segments: the cervical portion, intermediate portion, and sacral portion. The descriptive scheme was similar to that of Campbell[15] and allowed for clinically useful description of the location of subjacent structures and pelvic sidewall details.

Dissection of the pelvis began with careful removal of the peritoneum overlying the pelvic sidewall. The rectum and extraperitoneal fat were removed to see the uterosacral ligament from origin on the anterior surface of the sacrum to insertion at the cervix. Several measurements were then taken to describe completely the course of the uterosacral ligament in relation to other pelvic structures. Curvilinear measurements were made with string applied directly to surface contour being measured. The string was subsequently straightened and measured with a graduated ruler to the nearest 0.1 cm. Measurements were also made from ureter to all three portions of the uterosacral ligament. The distance from the ischial spine to the ureter and the relationship of ischial spine to uterosacral ligament also were assessed. Measurements were made in duplicate and averaged.

When defined clearly, the uterosacral ligament was elevated from its origin at the sacrum and reflected anteromedially toward its insertion at the cervix. Structures subjacent to the ligament were identified and their relationship to the cervical, intermediate, and sacral portions of the ligament recognized. Dissection then was carried down to the level of the bony pelvis to define the course of the uterosacral ligament in reference to a known landmark, the ischial spine.

We used four intact fresh cadaveric pelves to identify ureteral pressure profiles and uterosacral ligament strength. Those specimens were not bisected to avoid possible weakening of the ligament by cutting midline attachments of uterosacral ligaments or adjacent supporting tissues. Data from right and left sides of the four intact specimens were evaluated individually for ureteral pressure studies and combined for strength assessment of uterosacral ligaments.

Ligaments were identified by palpation aided by tension applied to the vaginal apex by grasping and elevating the vaginal tissue immediately adjacent to the uterine cervix. Three sutures of 0-polygalactin 910 (Ethicon Inc., Somerville, NJ) were placed in each uterosacral ligament, one in each portion. All sutures were perpendicular to ligament fibers with the ligament on tension. Sutures were placed with a CT-1 needle (Ethicon Inc.), using only the most distal 1 cm of the needle. This method allowed for precise suture placement and equal purchase of tissue within each suture. The first suture was placed in the cervical segment of the uterosacral ligament 1 cm proximal to the vaginal apex; the second at the level of the ischial spine; and the third within 2 cm of the sacrum on the palpable uterosacral ligament. Sutures were not tied down to eliminate mechanical effects of individual knots, and were tagged and placed laterally.

A right-angle clamp was placed in the vagina to localize the vaginal apex. A 2–3-mm wide incision was made on each lateral aspect of the vaginal posterior fornix for passage of the sutures through the vagina. Incisions were in the usual location where the vaginal apex and uterosacral ligaments would be attached after hysterectomy. Sutures were then placed through the appropriate incision at the vaginal apex and verified as cervical, intermediate, or sacral in origin. Each suture was then tied as a loop within 10 cm of the vaginal introitus. Hemipelvises were oriented in the low lithotomy position and secured in place on an apparatus designed to stabilize specimens and allow for axis traction to be applied to each uterosacral ligament suture individually.

A 4-French fiberoptic pressure catheter (MedAmicus Corp., Plymouth, MN) was used to measure ureteral pressure profiles. The pressure catheter was passed through the urethra into the bladder and a cystotomy was used to pass the catheter retrograde through the ureteral orifice, through each ureter to the level of the pelvic brim. Tension on the uterosacral ligament was applied by attaching weight to the individual suture loops in the uterosacral ligament. With fixed tension applied to various portions of the uterosacral ligament, the pressure catheter was slowly withdrawn from the ureter similarly to urethral pressure profiles. Adding known volumes of water to a preweighed container precisely varied the weight. The container was connected to suture loops by a ⅛-inch braided steel rope over a 2-inch, single-action pulley system and was suspended freely off the end of our dissection table.

Ureteral pressures were measured with 115-, 615-, and 1115-g weights applied to the uterosacral ligament sutures. Pressures were measured in duplicate or triplicate, providing agreement between measurements of up to 10%. Ureteral pressures were assessed with only a container weighing 115 g attached to the respective suture in the uterosacral ligament and subsequently adding 500 and 1000 mL of fluid to the same container. Ureteral pressures also were measured at 2000 and 2500 g for the first two specimens.

After ureteral pressure profiles, relaxing incisions were made to determine whether they had any affect on ureteral pressure. Incisions 3–4 cm long were made in the peritoneum above the uterosacral ligament and ureteral pressure profiles were repeated.

We assessed bilateral uterosacral ligament suspension strength by determining the weight each fixation point would support before failure of the suspension. We attempted to reconstruct the normal axis of traction after the cuff was appropriately suspended by bilateral uterosacral ligament suspension procedure. At each portion of the ligament, suture loops from the right and left sides were subjected to tension simultaneously. Tension was increased incrementally by the slow addition of fluid into the suspended container until the suture material pulled through the uterosacral ligament or the uterosacral ligament was detached from its usual attachments. The total volume of fluid that resulted in failure of the suspension was measured. The fluid volume used was converted to weight in grams and recorded as weight in kilograms.

Descriptive statistics were used to describe mean and standard deviation for measurements. Analysis of variance was used to describe the relationship between ureteral pressure profiles and uterosacral ligament portion assessed. The two-tailed, paired t test was used to evaluate the effect of relaxing incisions that compared ureteral pressure profiles before and after making relaxing incisions. The Mann–Whitney U test was used for comparison of mean maximum ureteral pressures and suture pullout strength recorded at the cervix, spine, and sacrum along the uterosacral ligament.

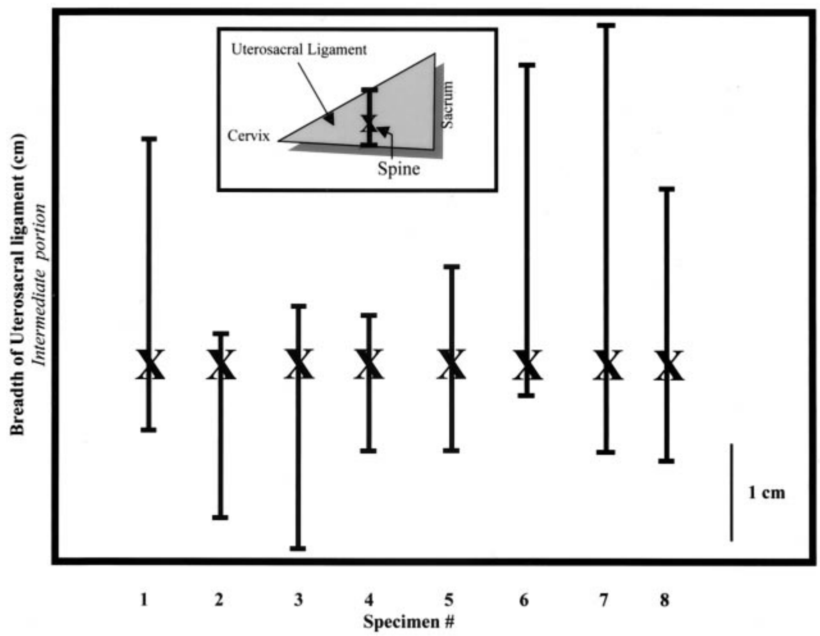

Figure 1. Ischial spine location beneath the uterosacral ligament. The "I-bars" represent the scaled width of the intermediate portions of the uterosacral ligament. The "X" represents the precise location of the ischial spine directly beneath each uterosacral ligament.

Results

Placing tension on the distal aspects of the uterosacral ligament clearly showed the anterior edge of the ligament. Although the posterior edge was not visible before dissection, it was identifiable after removal of the peritoneum and reflection of the rectum. The origin of the uterosacral ligament was fanlike at the sacrum, narrowing to its smallest width just proximal to the cervix. Fibers of uterosacral and cardinal ligaments were intermingled consistently at the cervical portion, which created a smaller, fanlike insertion with fibers that extended anteriorly above the internal cervical os and posteriorly onto the proximal third of the vagina. The mean width ± standard deviation (SD) of the uterosacral ligament was 5.2 ± 0.9, 2.7 ± 1.0, and 2.0 ± 0.5 cm in the sacral, intermediate, and cervical portions, respectively. The ischial spine was found beneath the intermediate portion of the ligament consistently; however, its position beneath the ligament varied greatly (Figure 1). The ligament was attached broadly to the first three sacral vertebrae and variably to the fourth. We also noted fibrous attachments of uterosacral ligament to the sacral periosteum.

The superior gluteal vein, which lay medial to the superior gluteal artery, consistently was found directly beneath the sacral portion of the ligament (Figure 2). In the intermediate portion, the middle rectal artery was found consistently near the inferior margin of the uterosacral ligament (Figure 2).

The ureter was always found in proximity to the anterior margin of the uterosacral ligament (Figure 3). The mean (±SD) distance from the ureter to the uterosacral ligament at the level of the sacrum was 4.1 ± 0.6 cm. The mean (±SD) distance from the ureter to the uterosacral ligament at the level of the ischial spine was 2.3 ± 0.9 cm. The mean distance (±SD) from the ureter to the uterosacral ligament at the level of the cervix was 0.9 ± 0.4 cm. Also, the mean (±SD) distance from the ureter to the ischial spine was 4.9 ± 2.0 cm.

The maximum ureteral pressures are shown in Figure 4. At all weights tested, the effect on the ureter was greatest at the level of the cervix ($P < .001$). There was no statistically significant difference between measurements before and after relaxing incisions; however, with significance of $P < .05$, the power of this test was only .24.

At the levels of the cervix and spine, the tissues supported a force exceeding 17.0 kg (37.5 lb) before failure. The tissue in the sacral region of the ligament was less strong; it failed at just over 5.0 kg (11.0 lb) of force. A trend of lower pullout strengths at the sacral portion of the ligament was observed and might have important clinical ramifications, though statistical significance was not reached ($P = .121$; with significance of $P < .05$, the power of this test was 1.0.)

Discussion

Although the uterosacral ligament is reported to originate from the second through fourth sacral vertebrae, we noted attachments consistently originating from the inferior aspect of the first three sacral vertebrae and

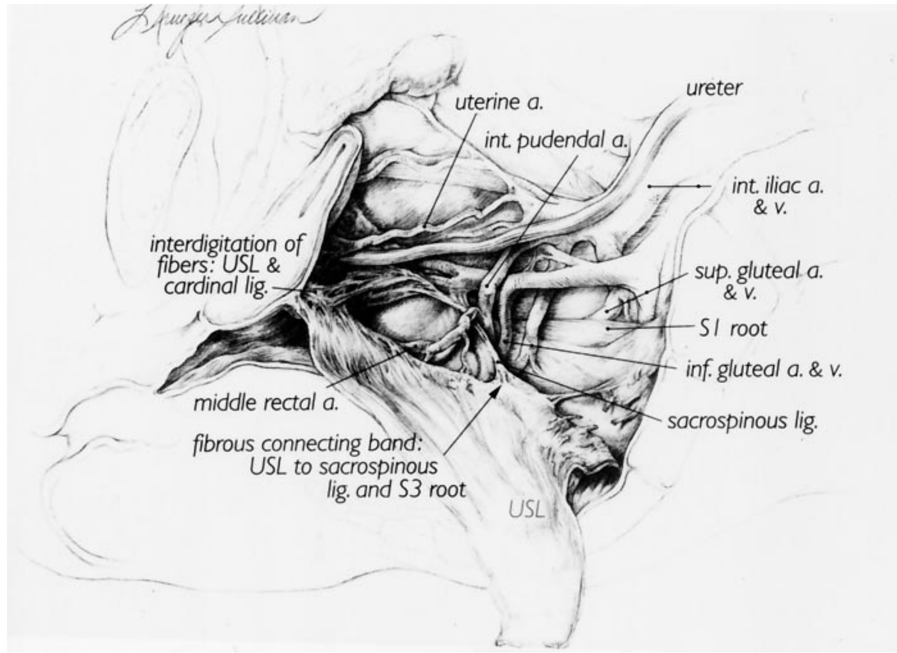

Figure 2. Right hemipelvis; sagittal view. The uterosacral ligament has been reflected to show subjacent anatomy.

occasionally the fourth. Other more dense fibrous attachments to the sacrum and sacrospinous ligament were found that might contribute to the overall strength of the ligament.

Our findings from the anatomic dissections confirm the intimate relationship of the uterosacral ligament to the ureter noted by other researchers,[12,14,15] a finding that is particularly true near the cervix. Besides direct injury from proximity, the ureter is also vulnerable to forces transmitted from nearby sutures, which are most likely caused by attachments between the cervical portion of the uterosacral ligament and the fibrous tissue of the ureteral sheath.

An important concept is that the most easily accessible and palpable region of the ligament, the cervical portion, is also the most vulnerable with regard to the ureter. Using that portion of the ligament for vaginal vault suspension greatly increases risk of ureteral in-

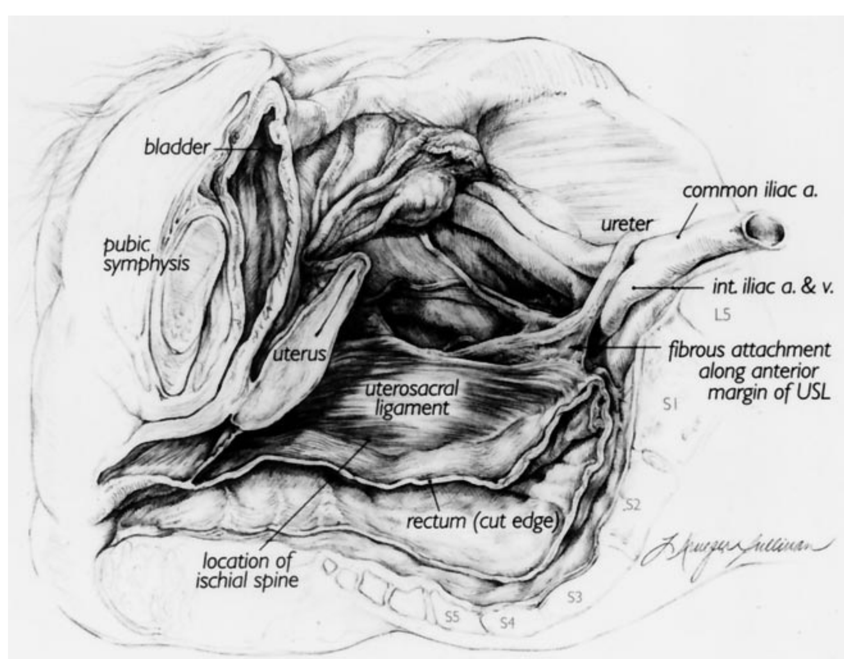

Figure 3. Right hemipelvis sagittal view. The peritoneum has been removed and the uterosacral ligament was left intact to show the proximity of the ureter in this specimen.

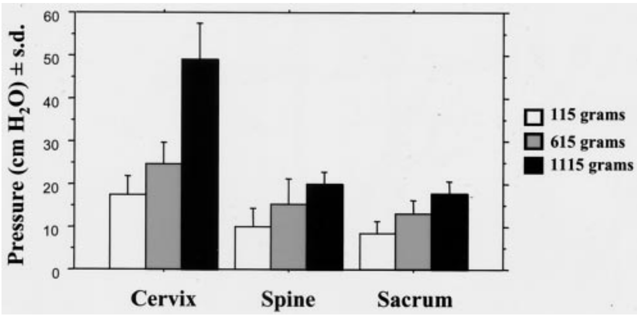

Figure 4. Maximal ureteral pressure. Maximal ureteral pressure at each portion of the uterosacral ligament is presented for each weight tested. At all weights tested, the effect was greatest at the cervical portion of the ligament.

jury, which can be from direct incorporation of the ureter in a suture or ureteral kinking from traction on adjacent tissue. By measuring ureteral pressure profiles we found a graded response between uterosacral ligament tension and increased intraluminal ureteral pressures.

In all our specimens, anterior displacement of the uterus allowed easy identification of the ligaments. Caudal displacement of the uterus, as with vaginal hysterectomy, is not nearly as effective for finding the ligament. During vaginal hysterectomy, anterior displacement of the ligament pedicles usually facilitates identification. Concurrent rectal examination with lateral palpation of the ligament might help as an adjunct for locating the ligament.

The intrapelvic ureter, along the lateral pelvic sidewall, lies close to the insertion of the uterosacral ligament at the cervix. Understanding that association between the ureter and the uterosacral ligament is crucial to routine gynecologic and urogynecologic surgeries. However, the courses of the ureter and uterosacral ligament diverge farther as the ureter courses over the pelvic brim, anterior to the uterosacral ligament. The proximity of the ureter to the distal uterosacral ligament warrants concern during vaginal vault repairs that use the ligament.

A limitation to assessing breaking strength is that this measurement implies that the mechanism of failure is related to breaking strength of the tissue. Tissue breakage, however, might occur from sutures cutting through tissue over time, or many other possibilities that cannot be simulated in cadaveric material. This study also should be evaluated in light of the fact that the age, parity, and extent of pelvic organ prolapse remained unknown. Our specimens appeared to have grossly normal vaginal support, although accurate assessment of support in cadavers is difficult. In addition, it is not yet known whether uterosacral ligament support defects represent stretching or breaking of the ligament. Anatomic relationships between the uterosacral ligaments and ureters might have been different in those scenarios.

Several corollaries between Campbell's studies and ours deserve further discussion. Campbell[15] grossly evaluated the uterosacral ligament in 33 cadavers, ten preserved and 23 fresh, 12 of which were evaluated histologically. Both studies identified attachments of the cervical portion of the ligament to the posterior lateral aspects of the vagina and the cervix by an interweaving connective tissue meshwork. Both also noted discrete strands of fibrous tissue that attached the sacral portion of the ligament directly to the presacral fascia. Campbell identified three distinct histologic regions of the ligament. At the cervical attachment, the ligament was made up of closely packed bundles of smooth muscle, abundant medium-sized and small blood vessels, and small nerve bundles. The intermediate third of the ligament was composed of predominantly connective tissue and only a few scattered smooth muscle fibers, nerve elements, and blood vessels. The sacral third was almost entirely composed of loose strands of connective tissue and intermingled fat, few vessels, nerves, and lymphatics. That provides a potential explanation for the observed lower pullout strengths in the sacral region, based on histologic composition of the ligament.

Our findings suggest that the optimum site of fixation is in the intermediate portion of the ligament, which appears to have fewer vital adjacent structures that could be compromised during reparative procedures. In addition, the intermediate portion is a strong fixation site, where tension has little effect on the ureter. The ischial spine can be used reliably to identify the intermediate portion of the ligament, but should not be used as a specific point of measure for suture placement because of the location variability of the spine relative to the ligament. Sutures at the level of the ischial spine, 1 cm posterior to the anterior-most palpable margin of the uterosacral ligament on tension, should provide an adequate fixation site for vaginal vault suspension while limiting injury to adjacent anatomy.

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