Innervation of the female levator ani muscles

Matthew D. Barber, MD,[a,e] Ronald E. Bremer, BS,[c] Karl B. Thor, PhD,[b,c,f] Paul C. Dolber, PhD,[b,c] Thomas J. Kuehl, PhD,[d] and Kimberly W. Coates, MD[d]

Durham and Morrisville, NC, Temple, Tex, and Cleveland, Ohio

OBJECTIVE: The objective of this study was to characterize the innervation of the human female levator ani muscles.

STUDY DESIGN: Detailed dissections of the peripheral innervation of the iliococcygeal, pubococcygeal, puborectal, and coccygeal muscles were performed in 12 fresh-frozen female cadavers (aged, 32-100 years) with the use of transabdominal, gluteal, and perineal approaches. Both the pudendal nerve and the sacral nerve roots that enter the pelvis from the cephalic side were followed from their origin at the sacral foramina to their termination. Pelvic floor innervation was described with reference to fixed bony landmarks, particularly the coccyx, the ischial spine and the inferior pubis. Photographs were taken, and nerve biopsies were performed to confirm the gross findings histologically. Biopsy specimens were stained with Masson's trichrome.

RESULTS: In each dissection, a nerve originated from the S3 to S5 foramina (S4 alone, 30%; from S3 and S4, 40%; from S4 and S5, 30%), crossed the superior surface of the coccygeal muscle (3.0 ± 1.4 cm medial to the ischial spine [range, 1.0-4.2 cm]), traveled on the superior surface of the iliococcygeal muscle innervating it at its approximate midpoint, and continued on to innervate both the pubococcygeal and puborectal muscles at their approximate midpoint. The pudendal nerve originated from the S2 to S4 foramina, exited the pelvis through the greater sciatic foramen, traversed Alcock's canal, and branched to innervate the external anal sphincter, the external urethral sphincter, the perineal musculature, the clitoris, and the skin. Despite specific attempts to locate pudendal branches to the levator ani, none could be demonstrated. Nerve biopsy specimens that were obtained at gross dissection were confirmed histologically.

CONCLUSION: Gross dissections suggest that the female levator ani muscle is not innervated by the pudendal nerve but rather by innervation that originates the sacral nerve roots (S3-S5) that travels on the superior surface of the pelvic floor (levator ani nerve). Because definitive studies (eg, nerve transection or neurotracer studies) cannot be performed in humans, further studies that will use appropriate animal models are necessary to confirm and extend our findings. (Am J Obstet Gynecol 2002;187:64-71.)

Key words: Levator ani muscle, pelvic floor, pudendal nerve

The pelvic floor is comprised of a complex group of muscles that includes the levator ani muscles (iliococcygeal, pubococcygeal, and puborectalis muscles) and the coccygeal muscle. The levator ani is a dynamic muscle group with unique physiologic features that are integral in the maintenance of urinary and fecal continence.[1,2] The muscles of the levator ani differ from most other skeletal muscles in that they (1) maintain constant tone, except during voiding, defecation, and the Valsalva maneuver; (2) have the ability to contract quickly at the time of an acute stress, such as a cough or sneeze, to maintain continence; and (3) distend considerably during parturition to allow the passage of a term infant and then contract after delivery to resume normal functioning. Despite the importance that the levator ani has in daily functioning, it is among the most neglected and least understood parts of the human body.[3]

Abnormalities in the structure or function of this group of muscles have been implicated in the development of pelvic organ prolapse, sexual dysfunction, several chronic pelvic pain syndromes, voiding and defecatory dysfunction, and urinary and fecal incontinence.[4] Much of pelvic floor dysfunction (especially pelvic organ prolapse, urinary incontinence, and fecal incontinence) have been associated with damage to the pelvic floor during vaginal childbirth. Many studies suggest that parturi-

From the Department of Obstetrics and Gynecology, Division of Gynecologic Specialties,[a] and the Department of Surgery, Division of Urology,[b] Duke University Medical Center, the Durham Veterans Administration Medical Center,[c] the Department of Obstetrics and Gynecology, Scott and White Clinic,[d] the Department of Gynecology and Obstetrics, Cleveland Clinic Foundation,[e] and PPD Genupro.[f]

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Reprint requests: Matthew D. Barber, MD, MHS, 9500 Euclid Ave, A81, Cleveland Clinic Foundation. Cleveland, OH 44145; E-mail: barberm2@ccf.org.

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tion causes denervation injury of the levator ani, which in turn results in weakness and dysfunction.[5-9]

Despite the obvious importance of pelvic floor innervation for the maintenance of pelvic visceral support and continence, there is a considerable degree of confusion regarding normal pelvic floor muscle innervation.[10] Various sources of innervation of the levator ani muscle have been described grossly, but many of these descriptions have not been verified experimentally, and there is no clear consensus in the literature. Many researchers suggest that the levator ani is dually innervated by the pudendal nerve and direct branches of S3-S4.[2,3] For instance, postmortem dissection studies suggest that both the puborectal muscle innervation and the external anal sphincter innervation are through the pudendal nerve from the caudal side of the muscle.[11] However, in vivo nerve conduction studies in humans[12,13] and neuroanatomic tracer studies in animals[14,15] suggest that the levator ani is directly innervated through the third and fourth sacral nerve roots from the cephalic side of the muscle, without any contribution from the pudendal nerve. To fully elucidate the impact that parturition and denervation injury has on the development, treatment, and prevention of pelvic floor dysfunction, a clearer understanding of the pattern of innervation of the levator ani is necessary. The primary objective of this study is to determine the peripheral innervation of each of the pelvic floor muscles and, specifically, to determine the relative contribution of the pudendal nerve and direct sacral nerve roots to the innervation of the pelvic floor in women. A second objective was to carefully describe the course of these nerves within the pelvis and perineum, with reference to important anatomic and surgical landmarks.

Material and methods

Detailed pelvic dissections were performed in 12 female cadavers with a mean age (± SD) of 69 ± 20 years (range, 32-100 years) at the Human Fresh Tissue Laboratory of the Duke University Medical Center between May 2000 and April 2001. Ten cadavers were fresh-frozen; 2 of the cadavers were lightly embalmed. The fresh-frozen cadavers were frozen at –17°C within 48 hours of death and thawed a minimum of 4 days before dissection. Fresh-frozen cadavers were used because they provide excellent tissue quality without the distortion that can occur with embalming. The 2 embalmed cadavers were fixed with a mixture of 0.6% formaldehyde, 0.5% methanol, and water. This technique allows for longer tissue preservation than the fresh-frozen technique, while preserving anatomic relationships. All cadavers had grossly normal lower genitourinary and gastrointestinal tracts, with the exception 5 cadavers that had undergone hysterectomy.

Detailed dissections of the peripheral innervation of the iliococcygeal, pubococcygeal, puborectal, and coccygeal muscles were performed. Both the pudendal nerve and the sacral nerve roots that enter the pelvis from the cephalic side were followed from their origin at the sacral foramina to their termination. Dissections were performed with transabdominal, gluteal, and perineal approaches. Three cadavers were dissected from the transabdominal approach alone; 2 cadavers were dissected with only the gluteal and perineal approaches, and 7 cadavers were dissected with all 3 approaches. Four of the 7 cadavers that were dissected from all 3 approaches were divided in the midline sagittal plane before dissection.

From the transabdominal approach, pelvic floor innervation was described with reference to fixed bony landmarks, particularly the coccyx, the ischial spine, and the inferior pubis. Care was taken to leave the pelvic visceral organs in situ whenever possible so that relationships between the nerves to the pelvic floor muscles and the bladder, vagina, and anus/rectum could be described accurately. Dissections from the gluteal and perineal approaches were performed by the technique described by Shafik et al.[11,16] From this vantage, the course of the pudendal nerve (and its branches) were described from the point at which it entered the ischiorectal fossa through the greater sciatic foramen to its termination. Particular attention was made to identify any contribution of the pudendal nerve to the innervation of the levator ani muscles. The pudendal nerve branches were described with reference to fixed bony landmarks (such as the coccyx, the ischial spine, the ischial tuberosity, the inferior pubis, and perineal structures such as the external anal sphincter, the muscles of the perineum, the vagina, the urethra, and the clitoris). In all dissections, care was taken not to disturb existing spatial relationships. Measurements were made with a 10-cm clear plastic ruler. Measurements are described as means ± SD (range) in centimeters. Dissections were documented with representative photographs and/or digital video recordings.

Nerve biopsy specimens were obtained to confirm gross findings. Full-thickness biopsy specimens of 3 mm to 4 mm in length were obtained at the approximate mid portion of suspected nerves. They were fixed in 4% paraformaldehyde and embedded in paraffin. Sections were stained with Masson's trichchrome. All histologic sections were examined by one of the authors (P. C. D.) who has formal training in both anatomy and pathology.

Results

Nerve to the levator ani muscles. In all dissections that were performed from the transabdominal approach (n = 10), a nerve originated directly from the third (S3), fourth (S4), and/or fifth (S5) sacral foramina then crossed the superior surface of the pelvic floor to innervate the iliococcygeal, pubococcygeal, and puborectal muscles. In 3 cadavers (30%), the nerve originated from

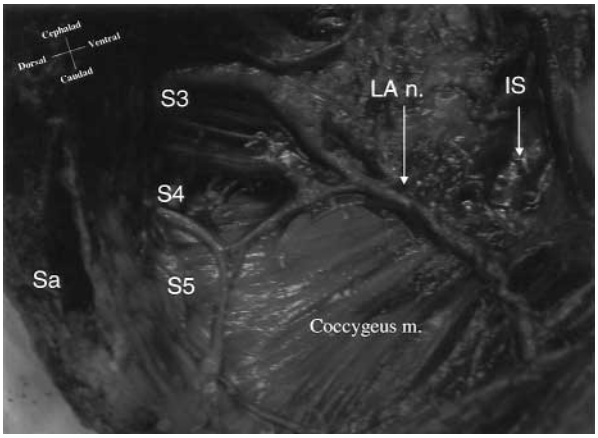

Fig 1. Sagittal view of origin of levator ani nerve. This is a photograph of a dissection of a left hemipelvis, with the visceral organs reflected out of the field. Note the 3rd and 4th sacral nerve roots that exit the sacral foramina to fuse into the levator ani nerve (*LA n.*) then travel to cross the surface of the coccygeal muscle (*Coccygeal m.*) medial to the ischial spine (*IS*). *Sa,* Sacrum; *S3,S4,S5,* sacral nerve roots that exit the sacral foramina.

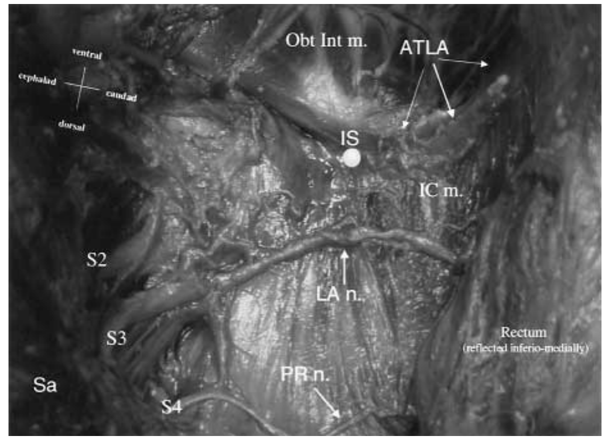

Fig 2. Sagittal view of levator ani nerve course on the surface of the pelvic floor. The same left hemipelvis seen in Fig 1 has been rotated to show a larger view of the pelvic floor and the course of the levator ani nerve (*LA n.*). The rectum and visceral organs have been reflected anteriomedially. The nerve travels across the surface of the coccygeal muscle and the iliococcygeal muscle (*IC m.*) inferior to the arcus tendinous levator ani (*ATLA*). The nerve to the puborectal muscle is separate in this cadaver and originates from S4 and S5 (not seen). *IS,* Ischial spine; *Sa,* sacrum; *S2,S3,S4,* sacral nerve roots that exit the sacral foramina; *Obt Int m.*, obturator internal muscle.

S4 alone. In 4 cadavers (40%), the nerve originated from both S3 and S4, and in 3 cadavers (30%), the nerve originated from S4 and S5. In no case did the nerve that innervated the levator ani muscles originate from all 3 foramina. After exiting the sacral foramina, the nerve crossed the superior surface of the coccygeal muscle 3.2 ± 1.2 cm (range, 1.2-4.2 cm) medial to the ischial spine (Figs 1 and 2). It then coursed along the superior surface of the iliococcygeal muscle and sent off ≥1 branches to penetrate the iliococcygeal muscle. The major branch that entered the iliococcygeal muscle did so at a point approximately halfway between the pubic bone and the ischial spine and 2 to 3 cm below the tendinous insertion of the iliococcygeal muscle on the obturator internus fascia (arcus tendinous levator ani; Fig 3). The nerve then continued on to enter the pubococcygeal muscle and then the puborectalis muscle. The major branch that innervated the pubococcygeal and puborectal muscles did so at a point midway between the inferior pubis and the coccyx. In several cadavers, a small nerve branch that originated from S4/S5 coursed independently to innervate the mid portion of the puborectalis muscle (Figs 2 and 3).

In all, the nerve to the levator ani muscles gave off between 1 and 5 major branches. Fig 4 demonstrates the typical course and branch points of this nerve. In 5 cadavers (50%), the nerve to the levator ani muscles was firmly invested in the fascia that overlay the pelvic floor muscles. In the remainder, the nerve was only loosely applied to the pelvic floor muscles as it traveled along its course and proximally demonstrated firmer attachments to the medial visceral organs, particularly the rectum. Histologic evaluation of biopsy specimens that were taken at the time of dissection confirmed that structures that were identified grossly were, in fact, nerve. The coccygeal muscle was innervated by small nerve branches that originated from the S3, S4, and/or S5 foramina on the superior surface of the muscle in all cases.

Pelvic nerve plexus. The pelvic nerve plexus, or inferior hypogastric plexus, arose from a confluence of nerves from (1) the superior hypogastric plexus, (2) the pelvic sympathetic plexus, and (3) the pelvic splanchnic nerves. Nerves from the superior hypogastric plexus, a parasympathetic nerve plexus located in the lower lumbar region, entered the pelvis after bifurcating into 2 loosely organized bundles above the pelvic brim. Each bundle traveled just anterior to the sacrum and at the level of, or just medial to, the sacral foramina before intermingling with the pelvic sympathetic plexus and pelvic splanchnic nerves to form the pelvic plexus. The pelvic sympathetic plexus was a direct continuation of the lumbar sympathetic trunk and entered the pelvis from either side of the lumbar spine to travel along the sacrum, medial to the sacral foramina. The pelvic sympathetic nerve trunk was closely adhered to the sacrum, in contrast to the hypogastric nerve bundles that traveled within the loose connective tissue anterior to the sacrum and posterior to the upper rectum and lower sigmoid colon. The pelvic splanchnic (parasympathetic) nerves exited the second, third, and fourth sacral foramina. Unlike the levator ani nerve branches that exited the sacral foramina to travel inferiorly along the pelvic floor or the nerve roots forming the sacral plexus and pudendal nerve that exited the pelvis through greater sciatic fora-

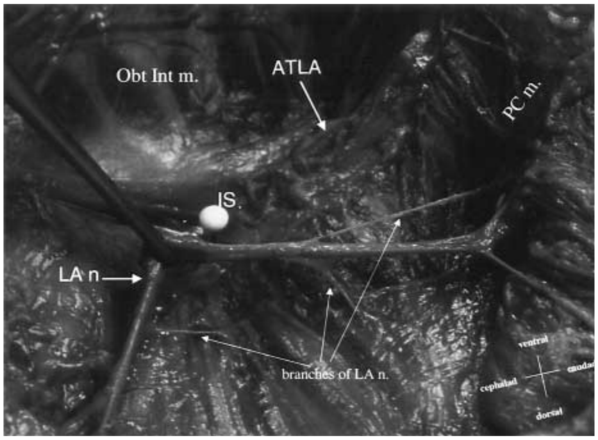

Fig 3. Sagittal view of the levator ani nerve, which is elevated to demonstrate small nerve branches that penetrate the levator ani muscles. The same left hemipelvis seen in Figs 1 and 2 has been rotated further to show a more anterior view of the pelvis. The visceral organs have been reflected inferiomedially, and the levator ani nerve (*LA n.*) has been elevated with forceps to demonstrate branches that penetrate the coccygeal muscle, the iliococcygeal muscle, and the pubococcygeal muscle (*PC m.*). *Obt Int m.*, obturator internal muscle; *ATLA*, arcus tendinous levator ani; *IS*, ischial spine.

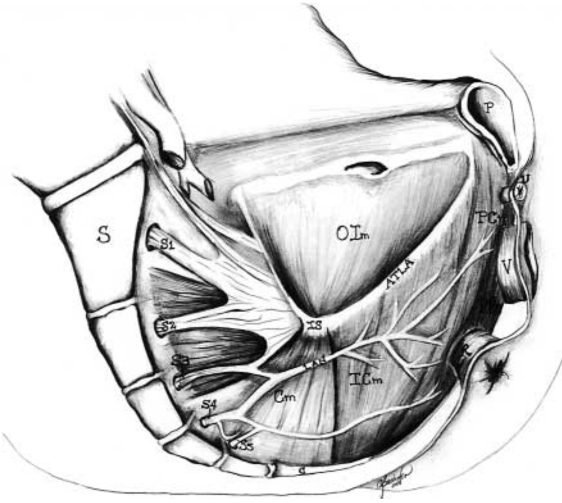

Fig 4. Illustration of the course of the levator ani nerve (left hemipelvis, sagittal view). *S*, Sacrum; *S1-S5*, sacral foramina; *Cm*, coccygeal muscle; *LAN*, levator ani nerve; *IS*, ischial spine; *ICm*, iliococcygeal muscle; *OIm*, obturator internal muscle; *PCm*, pubococcygeal muscle; *PRm*, puborectal muscle; *ATLA*, arcus tendinous levator ani; *C*, coccyx; *V*, vagina; *U*, urethra; *R*, rectum.

men, the pelvic splanchnic nerves traveled directly anterior and several centimeters above the pelvic floor to combine with the hypogastric plexus and pelvic sympathetic nerves to form the pelvic nerve plexus. This plexus of nerves left the sacral surface to fan out on either side of the rectum approximately 3 to 4 cm superior to the pelvic floor muscles. The plexus then continued distally to invest the lateral aspects of the vagina, particularly the upper third, and then invested the detrusor muscle at the level of the bladder base. The pelvic nerve plexus did not contribute to the innervation of the levator ani muscles in any cadaver.

Pudendal nerve. Dissections from the transabdominal approach confirmed that the pudendal nerve originated from a confluence of nerves from the S2, S3, and S4 foramina (with the S3 segment providing the largest contribution) that traveled on the ventral surface of the piriform muscle. The pudendal nerve passed behind the sacrospinous ligament (and overlying coccygeal muscle) just medial to the ischial spine and exited the pelvic cavity through the greater sciatic foramen. The extrapelvic course of the pudendal nerve was examined in 9 cadavers with the gluteal and perineal approach. The typical course of the pudendal nerve and its branches are shown in Figs 5 and 6.

After passing behind the sacrospinous ligament, the pudendal nerve entered the gluteal region inferior to the piriform muscle and just medial to origin of the superior gemellus muscle then traveled along the posterior surface of the obturator internal muscle. Along this course, it divided into upper and lower trunks. The upper trunk traveled just medial to the ischial spine; the lower trunk crossed 1 to 2 cm medial to the ischial spine. Both trunks then traveled to enter the pudendal canal (Alcock's canal) on the medial surface of ischium. The upper and lower pudendal nerve trunks further divided into smaller branches within, or just before entering, the pudendal canal. The pudendal canal had a mean length of 3.0 ± 0.3 cm (range, 2.8-3.6 cm). In 7 cadavers (78%), the lower pudendal trunk gave rise to the inferior rectal nerve within the pudendal canal, which then penetrated through the medial wall of the pudendal canal at its approximate mid point. It then crossed the ischiorectal fossa coursing inferiomedially to divide into multiple small branches that innervated the external anal sphincter and perianal skin (Fig 5). However, in 2 cadavers (22%), the inferior rectal nerve branched from the lower pudendal trunk and crossed the ischiorectal fossa without ever entering the pudendal canal. In each dissection, the lower trunk of the pudendal nerve provided at least 1 additional branch, which after exiting the pudendal canal coursed forward to provide cutaneous innervation to an area lateral to that supplied by the inferior rectal nerve.

The dorsal nerve to the clitoris was derived from the upper trunk of the pudendal nerve in all cases. After exiting the pudendal canal, this nerve branch coursed along the margin of the inferior pubic ramus to terminate at the clitoris. The dorsal nerve of the clitoris was the least superficial of all the pudendal nerve branches and lay directly on the perineal membrane deep to the perineal musculature. The remaining branch of the pudendal nerve, the perineal nerve, arose from either upper (22%) or lower trunk (11%) or both (66%) and con-

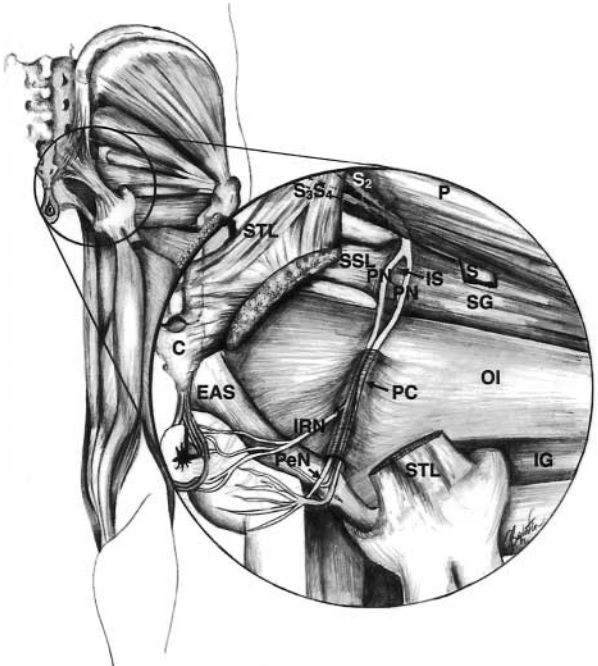

Fig 5. Course of the pudendal nerve through gluteal region and ischiorectal fossa (transgluteal view). The gluteus maximus and the sacrotuberous ligament have been removed. *S2-S4*, Sacral nerve roots; *P*, piriform muscle; *STL*, sacrotuberous ligament; *SSL*, sacrospinous ligament; *PN*, pudendal nerve; *IS*, ischial spine; *S*, sciatic nerve; *SG*, superior gemellus muscle; *C*, coccyx; *EAS*, external anal sphincter; *PC*, pudendal canal; *OI*, obturator internal muscle; *IRN*, inferior rectal nerve; *PeN*, perineal nerve; *IG*, inferior gemellus muscle.

sisted of 2 to 3 major terminal branches. After exiting the pudendal canal, the perineal nerve branches provided innervation to the ischiocavernous, bulbocavernous, and superficial transverse perineal muscles and the striated urethral sphincter and labial skin. These branches were more superficial than the dorsal nerve of the clitoris and, in most cases, traveled on the superior surface of the perineal musculature. The nerve to the striated urethral sphincter traveled superiomedially on the surface of the bulbocavernous muscle then dived deep to innervate the sphincter from the lateral aspects.

Despite specific and exhaustive attempts to locate pudendal nerve branches to the iliococcygeal, pubococcygeal, and puborectalis muscles, none could be demonstrated in any cadaver. Gross dissection did reveal branches of the pudendal artery and vein that entered the levator ani muscles. Histologic analysis confirmed that all branches that entered the levator muscles contained only vascular tissue without evidence of somatic nerves.

Comment

Many well-regarded medical texts and review articles on this subject suggest that the pelvic floor muscles are dually innervated by the pudendal nerve and direct branches of the third and fourth sacral motor nerve roots.[3,17,18] These suggestions are supported by several postmortem dissection studies in humans. Lawson[19] dissected 13 fetal or neonatal pelves and found nerves that directly innervated the superior surface of the levator ani muscles that originated from S3-5 and 2 branches of the pudendal nerve that passed below the pelvic floor along the medial wall of the ischiorectal fossa to supply the undersurface of the "pubosphinteric" portion of the levator ani. Sato[20] found dissections of 9 adult cadavers (8 male and 1 female) in which the levator ani muscles were innervated primarily by a nerve that originated from the sacral plexus that coursed along the pelvic surface of the pelvic floor muscles and was distributed to the iliococcygeal, pubococcygeal, and puborectalis muscles. However, he also noted that the perineal and inferior rectal branches of the pudendal nerve penetrated the rectal attachments of the puborectalis. In dissections of the pudendal nerve, Shafik et al[11,16] indicated that branches that arose from the inferior rectal nerve penetrated the undersurface of the levator ani muscles. They did not examine or comment on any source of innervation from the pelvic side of the muscles, however.

Despite the general acceptance that the levator ani muscles are dually innervated by direct sacral innervation and branches from the pudendal nerve, several studies (including this one) suggest this may not be the case. After performing detailed dissections of sacral innervation on 3 male cadavers and electrical stimulation studies in 5 patients with neurogenic lower urinary tract dysfunction, Juenemann et al[21] concluded that the levator ani muscles were innervated by a nerve that originated from S2-4 that branches at a point proximal to the ischial spine (before the pudendal nerve roots reach the sacrospinous ligament) and then innervates the levator ani muscles on their pelvic surface. No contribution of the pudendal nerves to levator ani innervation was noted. Additionally, many electrophysiologic studies have demonstrated that the levator ani muscles and the external anal sphincter have physiologically distinct innervations and that the pudendal nerve does not appear to innervate the iliococcygeal, pubococcygeal, or puborectalis muscles.[9,12,13]

We found that the levator ani muscles were innervated solely by a nerve that originated from S3-5 that traveled along the superior surface (pelvic side) of the muscles before penetrating each of the pelvic floor muscles at their approximate mid point. In none of our 12 dissections were we able to find a pudendal nerve branch that innervated any of the 3 levator ani muscles, in spite of specific attempts to locate such a contribution. The pudendal nerve innervated the external anal sphincter, the external urethral sphincter, the perineal muscles, and the perineal skin but not the levator ani muscles. This "nonpudendal" innervation of the levator ani has been called various names in literature and textbooks: "direct innervation by S2-S4 spinal roots,"[3,17] "the nerve to the levator ani,”[20] “intrapelvic somatic nerve,”[22] and several others.[23] For simplicity sake, we have labeled this distinct innervation the “levator ani nerve.” Admittedly, small nerve branches can be missed, even in the most careful gross dissections. Thus, this type of study cannot be considered definitive. However, given the consistency of our findings, it is safe to conclude that the major innervation to the iliococcygeal, pubococcygeal, and puborectalis muscles in women is the levator ani nerve, which originates from S3-5 and travels along the superior surface of the pelvic floor. Any contribution of the pudendal nerve to levator ani innervation is minor, if it exists at all.

There are several potential explanations that our findings differed from other authors who investigated levator ani innervation using gross dissection. First, we confirmed our gross findings with histologic evaluation of nerve biopsy specimens, while other studies have not. One limitation of gross dissection is that it is sometimes difficult to distinguish small nerve branches from fascia or blood vessels. On several occasions during our dissection of the pudendal nerve course, we identified structures that originated from the pudendal neurovascular bundle and traveled to the levator ani muscle so that we could not tell with any certainty from gross inspection whether they were small nerve branches or small blood vessels. In each case, histologic analysis confirmed that the structures were vascular tissue and not somatic nerve. Studies that use gross dissection to follow the course of small structures that do not confirm their findings with histologic evidence leave open the possibility that some structures may be misidentified.

Second, we performed dissections on women only. There is some evidence to suggest that pelvic floor and perineal innervation may differ between men and women. Shafik and Doss[16] described an accessory rectal branch of the pudendal nerve that had both cutaneous and muscle components. The muscle branch traveled anteriomedially in the ischiorectal fossa to innervate the inferior aspect of the levator ani muscle. In their study, they found this accessory rectal branch in all 7 male cadavers but in none of the 13 female cadavers. Certainly, further studies are necessary to confirm any sexual differences in levator ani innervation that may exist.

Finally, the muscle fibers of the external anal sphincter are often fused with the fibers of the dorsal aspect of the puborectal muscle. Because of this, a determination of the transition point between the upper external anal sphincter and the lower edge of the puborectal muscle is challenging, if not somewhat arbitrary. As mentioned previously, Sato[20] found that the major innervation of the levator ani muscles (including the puborectal muscle) was the levator ani nerve, but that branches from the inferior rectal and perineal branch of the pudendal nerve innervated the portion of the puborectal muscle that attached to the rectum. Because of the interrelationship between the external anal sphincter and the perirectal portion of the puborectal muscle, his findings are not necessarily inconsistent with ours and could represent a difference in the perceived transition between the external anal sphincter and the puborectalis muscle. We observed that each nerve branch from the inferior rectal nerve that terminated in this area terminated on muscle fibers that completely encircled the anus; therefore, we feel confident that the inferior rectal nerve innervates the external anal sphincter but not the puborectalis muscle. However, the establishment of this with absolute certainty through gross dissection is difficult, if not impossible. Some investigators have suggested that the interconnection of the fibers of the external anal sphincter and puborectalis muscle that are seen grossly in adults implies that the 2 muscles are of similar embryologic origin and therefore must have the same innervation.[16,24] However, work by Levi et al[25] with fetuses demonstrate that the external anal sphincter and puborectalis muscle are embryologically distinct, thereby refuting this argument.

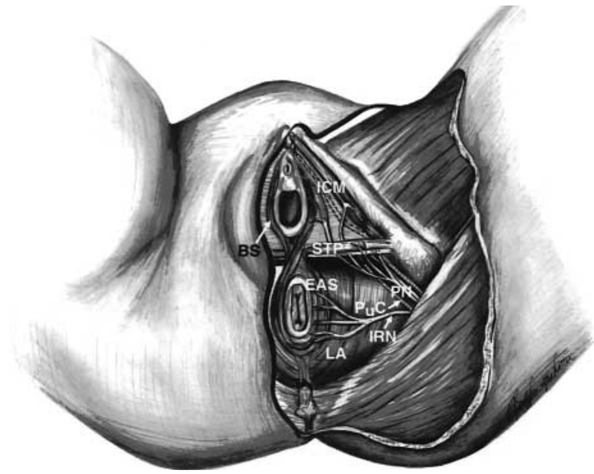

Fig 6. Terminal branches of the pudendal nerve (perineal view). *IC*, Ischiocavernous muscle; *BS*, bulbocavernous muscle; *STP*, superficial transverse perineal muscle; *EAS*, external anal sphincter; *PC*, pudendal canal; *IRN*, inferior rectal nerve; *LA*, levator ani muscles; *PN*, pudendal nerve.

Experiments that have the potential to establish definitively the innervation of the levator ani muscles (such as studies that involve nerve transection or neuroanatomic tracers) cannot be performed in humans; therefore, appropriate animal models are necessary to confirm our findings. The finding of a distinct “nonpudendal” innervation of the pelvic floor is supported by neuroanatomic tracer studies in the rat[26] and cat model.[14,15] These studies demonstrate that tracers that were injected into the levator ani muscle labeled neurons in the mid portion of the ventral horn, but not in Onuf’s nucleus[14,15] where all pudendal nerve motor neurons are located.[26-28] Also, the morphologic condition of motor neurons that are labeled by an injection of tracers into the levator ani muscles resembled general somatic neurons,[15] not pudendal motor neurons.[26] Preliminary experiments in the rat from our laboratory have shown muscle atrophy in the levator ani muscles after transection of the levator ani nerve but not after pudendal nerve transection (unpublished data). We have recently begun similar experiments in the squirrel monkey. The squirrel monkey model provides a particularly good animal model to study this question because they are known to experience parturition-related pelvic floor injury and are an animal model in which pelvic organ prolapse develops.[29,30]

The relationship between vaginal childbirth and dysfunction of the pelvic floor, particularly urinary incontinence, fecal incontinence, and pelvic organ prolapse, is well recognized. Overall, pelvic floor disorders are associated with clinical, electrophysiologic, and histologic features of chronic partial denervation of the pelvic floor muscles, especially the levator ani, external urethral, and anal sphincters.[9] The damage to pelvic floor muscle innervation has been correlated with increasing vaginal parity, heavier babies, and operative vaginal delivery.[31,32] The findings of our study may have important implications in the understanding of childbirth that is related to denervation injury and the subsequent development of pelvic floor disorders. Specifically, the distinct innervation of the levator ani muscles by the levator ani nerve and the external anal and urethral sphincters by the pudendal nerve provide a mechanism to explain the varying types of pelvic floor disorders that can occur in women after childbirth. For instance, it may explain the reason that some women experience urinary incontinence or fecal incontinence and that other women experience pelvic organ prolapse. Studies are necessary to elucidate the different mechanisms of vaginal birth and their differential impact on the pudendal and levator ani nerves.

The course of the levator ani nerve has important implications in pelvic reconstructive surgical procedures as well. One of the more popular surgical techniques for the correction of prolapse of the vaginal vault in the United States is the sacrospinous ligament fixation. In this procedure, the suspensor sutures for the vaginal apex are placed through the sacrospinous ligament at a point approximately 2 fingerbreadths medial to the ischial spine.[33] The sutures are placed in this location to avoid injury to the pudendal neurovascular bundle, which crosses behind the sacrospinous ligament at the level of the ischial spine. We have found that the levator ani nerve crosses the coccygeal muscle in many cases at precisely the point at which sacrospinous ligament fixation sutures are placed, thus making the possibility of injury or entrapment of this nerve highly probable with this procedure. Several studies have noted a high rate of anterior vaginal prolapse after sacrospinous ligament fixation (18%-92%), which has caused some physicians to abandon it for other vault suspension techniques.[33,34] It has traditionally been thought that the nonanatomic lateral and posterior deflection of the vagina that occurs with sacrospinous ligament fixation exposes the anterior vaginal wall to increased force during increases in abdominal pressure, which result in postoperative anterior wall prolapse.[33] The potential for injury to the levator ani nerve and subsequent pelvic floor denervation and atrophy provided another possible explanation for the high occurrence of anterior vaginal wall prolapse that has been reported with this procedure. Other surgical procedures that seem to have the potential to compromise the levator ani nerve include the iliococcygeal vaginal vault suspension and the paravaginal defect repair, particularly when performed from a vaginal approach. Given the potential impact that the levator ani nerve injury may have on the long-term success of pelvic reconstructive surgical techniques, an understanding of the course of this nerve may prove essential for surgeons who perform these operations. Future studies to evaluate neuromuscular function of the levator ani muscles before and after procedures that have the potential of injuring this nerve should be performed to assess their impact on the pelvic floor and to assist in the determination of the most appropriate reconstructive techniques.

To fully elucidate the impact that parturition and denervation injury has on the development, treatment, and prevention of pelvic floor dysfunction, a clear understanding of the pattern of innervation of the levator ani is necessary. In this study, gross dissections suggest that the female levator ani muscle is not innervated by the pudendal nerve, but rather by innervation that originates from the S3-5 nerve roots that travel on the superior surface of the pelvic floor. This finding is contrary to traditional teaching and has many important clinical and research implications. Because definitive studies cannot be performed in humans, further studies with appropriate animal models are necessary to confirm and expand our findings.

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