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Feasibility of a femoral nerve motor branch for transfer to the pudendal nerve for restoring continence: a cadaveric study:

Laboratory investigation

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Abstract

Object—Nerve transfers are an effective means of restoring control to paralyzed somatic muscle groups and, recently, even denervated detrusor muscle. The authors performed a cadaveric pilot project to examine the feasibility of restoring control to the urethral and anal sphincters using a femoral motor nerve branch to reinnervate the pudendal nerve through a perineal approach.

Methods—Eleven cadavers were dissected bilaterally to expose the pudendal and femoral nerve branches. Pertinent landmarks and distances that could be used to locate these nerves were assessed and measured, as were nerve cross-sectional areas.

Results—A long motor branch of the femoral nerve was followed into the distal vastus medialis muscle for a distance of 17.4 ± 0.8 cm, split off from the main femoral nerve trunk, and transferred medially and superiorly to the pudendal nerve in the Alcock canal, a distance of 13.7 ± 0.71 cm. This was performed via a perineal approach. The cross-sectional area of the pudendal nerve was 5.64 ± 0.49 mm², and the femoral nerve motor branch at the suggested transection site was 4.40 ± 0.41 mm².

Conclusions—The use of a femoral nerve motor branch to the vastus medialis muscle for heterotopic nerve transfer to the pudendal nerve is surgically feasible, based on anatomical location and cross-sectional areas.

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Keywords

incontinence; reinnervation; nerve transfer; urethra; anal canal; perineum

In a survey study of 681 patients with spinal cord injury, regaining bladder and bowel function was of shared importance to both individuals with paraplegia and quadriplegia.¹ At least one-quarter of patients seen at the Spinal Cord Injury Center of Philadelphia Shriners Hospital for Children have flaccid urinary bladder paralysis and incontinence resulting from lower motor neuron lesions. This is especially prevalent in children who sustain lap-belt injuries leading to cauda equina deficits. Neurological injury to lower lumbar and sacral nerves also occurs in cases of unstable pelvic and sacral fractures,^{7,12,18,22} obstetrical patients with vacuum deliveries, hemorrhoidectomies, and in multiparous women.^{19,22} Our long-term goals are to develop surgical approaches to reinnervate the lower motor neuron–lesioned urinary bladder and urethral sphincter.

The idea of restoring urinary control through nerve transfers has been pursued numerous times with varying degrees of success.^{4,5,9,14,21,23,24} There are recent reports of successful somatic nerve transfers, in animal models and in patients, for restoration of bladder function.^{8,10,13,15–17,24,25} Using a canine model, we have shown that bladder reinnervation after sacral ventral root transection can be achieved through nerve transfer and surgical coaptation of coccygeal roots to the severed sacral roots, or transfer of the genitofemoral nerve to the pelvic nerve, as evidenced by increased bladder pressure on functional electrical stimulation.^{15–17} Effective detrusor contractions were elicited with stimulation of the reinnervated pelvic nerve. Retrograde fluorogold tracing from the bladder confirmed the regrowth of axons from the spinal cord through the nerve repair sites to the bladder wall.^{15–17} Anterograde axonal tracing confirmed regrowth of axons into the bladder detrusor muscle.²

It is our hope that similar heterotopic nerve transfer, in conjunction with nerve-cuff electrode methods when necessary, can be used in patients to restore function of the urethral and anal sphincters for continence. Although cases of surgical management of lumbosacral plexus injuries or peripheral pudendal nerve injuries have been reported, nerve reconstruction remains uncommon.²² To do this, motor nerves need to be transferred to the pudendal nerve, which originates in the S2–4 ventral rami and provides the primary motor innervation to perineal structures, including the external anal sphincter and the external urethral sphincter. Gustafson et al.⁶ have clarified the anatomy of the pudendal nerve in a series of studies,^{3,6,11} as has Shafik¹⁹ in a review article. Gustafson et al. also examined the possibility of a transgluteal approach to the pudendal nerve in which the sacrotuberous ligament was transected to access the pudendal nerve for nerve-cuff electrode placement.⁶ However, we are proposing a perineal approach for closer proximity to the femoral nerve (which originates in the L2–4 ventral rami) in its anteromedial thigh location to coapt motor branches for nerve transfer to the pudendal nerves.

Our objectives in this cadaveric pilot study were to explore the following: 1) landmarks and pertinent distances that might be used to locate the pudendal nerve in the perineum, and 2) the feasibility of using an anterior thigh approach to expose motor branches of the femoral nerve that could be transferred to the pudendal nerve in the Alcock canal (the pudendal canal) via a perineal approach. This would allow similar surgical positional access to both nerves. Specifically, we are proposing to use femoral nerve branches that innervate the vastus medialis muscle because these branches descend nearly to the knee and are thus quite long.

Methods

Twenty-two perineal, pelvic, and anterior thigh regions were dissected in 11 formalin-fixed cadavers (5 female and 6 male cadavers). All but one of the cadavers were used by others for nonlower-extremity and nonpelvic anatomical studies. The specimens were inspected to ensure that the perineal, pelvic, and anterior thigh anatomy was intact, including: pelvic and perineal floors, lumbosacral spinal cords and lower-extremity peripheral nerves, and lower genitourinary tracts. Specimens that were not intact were excluded from the study. One-half of the included cadavers underwent hemisection to facilitate the perineal dissections. One cadaver was used solely for this project.

In each cadaver, gross dissection proceeded with a perineal approach for the pudendal nerve, and then an anterior thigh approach to identify the femoral nerve and its branches. The perineal dissection involved identifying the ischial tuberosity, Alcock canal, the pudendal nerve within that canal, and the internal pudendal vessels. The terminal branches of the pudendal nerve were traced through the ischiorectal fossa. An anterior thigh approach was used to identify the femoral nerve, its relationship to the inguinal ligament, femoral artery, great saphenous nerve, and the location and length of its motor branches, particularly those to the distal part of the vastus medialis muscle. The following measurements were performed using both a caliper (Mitutoyo Vernier Pointed Jay Caliper, model 536–121) and a flexible measuring tape with centimeter markings: 1) pertinent distances that could be used to locate the pudendal nerve in relationship to the ischial tuberosity, anus, and pubic symphysis, and 2) pertinent distances that could be used to locate the femoral motor nerve branch to the vastus medialis in relationship to the inguinal ligament, main trunk of the femoral nerve, and pudendal nerve. These measurements are presented as the mean $\pm$ SEM.

The cross-sectional areas of the pudendal nerve and the femoral motor nerve branch to the vastus medialis were determined by measuring the long and short diameters with engineering calipers, and then by multiplying these two numbers together, dividing by 2, and multiplying by π (3.14159). Thin cross-sections were also collected by scalpel, placed onto microscope slides, and cross-sectional areas were verified using a bright-field dissecting microscope, a $\times 5$ objective, and image analysis software (Bioquant).

Results

Landmarks of the ischiorectal fossa—the pubic symphysis, anus, and ischial tuberosity—were identified (Fig. 1A). The distances between these structures were measured (Table 1). After removing the overlying skin and adipose tissue, the Alcock canal was exposed. This canal was located 1.73 ± 0.67 cm immediately superior to the ischial tuberosity (Fig. 1A and B). The dorsal genital nerve branch and perineal branch of the pudendal nerve were identified and traced. The dorsal genital nerve was traced to the clitoris and labial skin in females, and to the dorsal penis and scrotal skin in males. The dorsal genital nerve branched off of the pudendal nerve at a site 10.32 ± 0.48 cm from the pubic symphysis, 7.4 ± 0.31 cm from the anus, and 2.0 ± 0.15 cm from the ischial tuberosity (Table 1). Several superficial and deep branches of the perineal branches to the external urinary complex were identified and traced to their targets (Fig. 1B and C). The inferior rectal branch of the pudendal nerve was traced to the anus.

Pertinent distances that could be used to locate the pudendal nerve in relationship to the pubic symphysis, anus and ischial tuberosity were determined (Table 1 and Fig. 1A). The pudendal nerve in the Alcock canal was located 12.3 ± 0.48 cm from the pubic symphysis, 6.9 ± 0.40 cm from the anus, and 1.73 ± 0.67 cm from the ischial tuberosity.

The femoral nerve, its anterior-division cutaneous branches, and its posterior-division motor branches were exposed in the upper anteromedial thigh. Pertinent distances that could be used to locate its main trunk with regard to its relationship to the inguinal ligament at the uppermost point of the midsagittal thigh are shown in Fig. 2A. It was located in the upper anteromedial thigh immediately lateral to the femoral artery and the great saphenous vein (Fig. 2A–C). At this anterior thigh site, the femoral nerve is medial to the rectus femoris muscle (Fig. 2B and C). We then exposed more of the femoral nerve distally, following its branches inferiorly until the muscular branch to the vastus medialis muscle was identified as it descended inferiorly toward the knee through the proximal part of the adductor canal. We propose using electrophysiology when choosing this nerve during surgery to verify that it is the nerve to the vastus medialis muscle because it is located immediately lateral to the saphenous nerve (a cutaneous nerve). Each was located lateral to the femoral vessels when in this proximal adductor canal region. The nerve to the vastus medialis muscle enters the muscle at about its midpoint, but it continues inferiorly as a branch to the articular capsule of the knee.

We also identified 2–3 branches per cadaver to the vastus intermedius muscle that could also be used for this same transfer purpose. Figure 2C shows additional branches located between the nerve to the vastus medialis and the rectus femoris. These latter branches enter the anterior surface of the vastus intermedius muscle at about midhigh.

We next separated the femoral nerve into its component fascicles. The components of the nerve innervating the vastus medialis and vastus intermedius muscles were teased out from the remaining branches. The location of the branch site of these motor branches from the main trunk of the femoral nerve was 13.7 ± 0.71 cm inferior to the inguinal ligament (Table 1 and Fig. 2). These branches were easily teased apart proximally from the main femoral nerve trunk. The motor branch to the vastus medialis could be traced 17.4 ± 0.8 cm inferiorly into the vastus medialis muscle. The distance from its branch site from the main trunk of the femoral nerve in the upper thigh to the proximal pudendal nerve in the Alcock canal (that is, the length of nerve needed for nerve transfer) was 13.6 ± 0.33 cm (Fig. 3). This branch is more than long enough to be transferred without stretching to the site of the pudendal nerve within the Alcock canal (Fig. 3).

The cross-sectional area of the pudendal nerve at the site of its exit from the Alcock canal was 5.64 ± 0.49 mm². The cross-sectional area of the femoral nerve motor branch was 4.40 ± 0.41 mm² at our suggested transection site, located 17.4 ± 0.8 cm distal to its division from the main femoral nerve trunk in the upper medial thigh. Thus, these chosen branches of the femoral nerve are large enough to be surgically coapted to the pudendal nerve branches at the site of the Alcock canal.

Discussion

We were able to easily locate the pudendal nerve in the perineum at the site of its exit from the Alcock canal as well as motor branches of the femoral nerve on the anteromedial thigh in each cadaver. The motor branches of the femoral nerve were long enough to be transferred to the pudendal nerve in the Alcock canal via a perineal approach without stretching the transferred nerve. Also, the coapted motor femoral nerve branch was long enough to be transferred to the pelvic nerve in its retroperitoneal position on the bladder wall. Last, cross-sectional areas of each were sufficiently equivalent to allow surgical reanastomosis.

It has been suggested by Gustafson and coworkers⁶ that surgical access to the pudendal nerve is complicated by the lack of a detailed anatomical description. Thus, we briefly

review this anatomy here. See also a review by Shafik.¹⁹ The pudendal nerve originates from the S2–4 ventral rami of the spinal cord. Its path from the pelvis into the perineum is through the greater sciatic foramen. At that point, the pudendal nerve crosses behind the sacrospinous ligament close to its attachment to the ischial spine, in a medial relationship to the internal pudendal vessels.¹⁹ The pudendal nerve then accompanies the internal pudendal vessels through the lesser sciatic foramen into the Alcock canal located on the lateral wall of the ischiorectal fossa. The pudendal nerve gives off the inferior rectal nerve in this canal. At the end of the canal, the pudendal nerve divides into 2 terminal branches, the perineal nerve and the deep dorsal nerve of the penis or clitoris.^{6,19} Our observations matched these latter findings. A 4th branch, the accessory rectal nerve, has been identified in one-third of dissected cadavers.¹⁹ The course of these branches should be considered so as to avoid injuring them during surgery. The path of the inferior rectal branch to the external anal sphincter is a direct route and innervates the anal sphincter at the 3 and 9 o'clock positions. The perineal branches to the external urethral sphincter first pierce the perineal membrane before innervating this latter sphincter, also at the 3 and 9 o'clock positions.¹⁹ Importantly, the maps of individual fascicles within the pudendal nerve prior to branching have been clearly delineated, and show that the compound pudendal nerve is divided into distinct groups, which will allow surgical separation and then selective stimulation of distal nerves.^{3,6} These maps may also prove useful for separating out selective branches for end-on-end anastomoses in nerve transfer surgeries. Last, the perineal approach used to locate the pudendal nerve avoided transection of any nerves to the gluteus muscles.

The femoral nerve anatomy observed in this study matched that described in *Gray's Anatomy*²⁰ and will thus not be described further. However, we should note that the femoral nerve's origin is from the L2–4 ventral rami. In a retrospective study of 407 patients with pelvic fractures, 46% were found to have unstable pelvic fractures and persistent neurological damage. The neurological deficits were limited to the L5–S5 roots, with predominance in the L5–S1 roots, thus sparing the roots to the femoral nerve.⁷ It has also been noted that involvement of the S2–5 roots may be overlooked because no obvious sensorimotor paralysis of the lower extremities is observed, although urinary and anal continence as well as sexual function may be affected by their injury.¹⁸

Limitations of the present study include its use of cadavers rather than patients. However, we felt that the feasibility of the method needed to be established prior to performing these surgeries in a patient population. A second limitation was the inability to determine axon counts in the nerves due to fixation methods used for cadavers and the long period between fixation and dissection because these were cadavers either used for or slated for medical educational purposes.

Conclusions

We propose the use of lumbar nerve transfers from the thigh region upward to sacrally denervated musculature. A freed femoral nerve branch could be used for nerve transfer to the pudendal nerve to induce reflex or triggered-spasm–induced sphincter contractions for voluntary sphincter control.

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Fig. 1.

Location of the pudendal nerve. **A:** Diagram showing the location of the pudendal nerve (PN) in the Alcock canal (pudendal canal) located medial to the ischial tuberosity (IT) and lateral to the anus (An). After exiting the Alcock canal, the pudendal nerve divides into several branches that course to the anus, external urethral complex (U; nerve indicated by *small arrows*), and clitoris. The location of the femoral nerve (FN) on the anterior thigh is also indicated in the diagram. **B:** Photograph of the pudendal nerve (held by a needle driver) as it exits the pudendal canal. Its path toward the urethra (U) is indicated by the *small arrows*. The location of the ischial tuberosity (IT) is indicated by a *large arrow*. **C:** Enlarged photograph of the pudendal nerve as it exits the Alcock canal. Its path toward the urethra is indicated by the *arrows*. Note the several small branches from the pudendal nerve as it nears its terminal targets.

Fig. 2.

Location of the femoral nerve and branches. **A:** Diagram showing the location of the femoral nerve (FN) and several of its branches in the anteromedial thigh prior to removal of the subcutaneous fascia. Note its relationship to the great saphenous vein (Gr Saph V). **B:** Photograph of a female cadaver showing the femoral nerve (elevated by forceps) exiting the femoral triangle medial to the rectus femoris (RF) and coursing inferiorly on the anterior thigh toward the knee. The medial relationship of the great saphenous vein to the femoral nerve is indicated. **C:** Enlarged photograph indicating the medial relationship of the femoral artery (FA) and great saphenous vein (Gr Saph V) to the femoral nerve (elevated by forceps), and the lateral relationship of the rectus femoris (RF) muscle to the nerve.

Fig. 3.

Feasibility of transferring a motor branch of the femoral nerve to the pudendal nerve. **A:** Photograph of anterior thigh showing the location of a motor branch of the femoral nerve (FN, indicated by 2 string loops, and the surgeon's hand). The location of the pudendal nerve (PN) within the perineum and its proximity to the femoral nerve are shown. **B:** Photograph of the anterior thigh and perineal regions showing the transfer of the femoral nerve branch (FN, string loop and *arrow*) from its anterior thigh position to the pudendal nerve (PN, string loop and *arrow*). **C:** Diagram showing the transfer of a femoral nerve branch to the proximal pudendal nerve as it exists from the Alcock (pudendal) canal. **D:** Photograph showing the transfer of a large branch of the femoral nerve from its original anterior location (Fem N, indicated by the *dashed line* at the right margins of image), medially across the thigh, to the site of the proximal pudendal nerve in the Alcock canal (small clip and *large gray arrow*). *Large black arrow* and metal marker indicate the location of ischial tuberosity (IT). An = anus.

TABLE 1
Mean distances between structures in the perineum, Alcock canal, and anterior thigh regions*

Structure/Site	Distance Between Sites (cm)				
	Pubic Symphysis	Anus	Ischial Tuberosity	Inguinal Ligament [†]	Site of FN Transection Site
anus	17.2 ± 0.70	—	6.9 ± 0.47	NA	NM
ischial tuberosity	16.0 ± 0.96	6.9 ± 0.47	—	NA	NM
proximal PN in Alcock canal	12.3 ± 0.48	6.9 ± 0.40	1.7 ± 0.67	NA	13.6 ± 0.33
DGN branch of PN	10.3 ± 0.48	7.4 ± 0.31	2.0 ± 0.15	NA	15.6 ± 0.78
site of femoral motor nerve on the thigh	NM	NA	NA	13.7 ± 0.71	17.4 ± 0.8
FN transection site	NM	NA	NA	33.2 ± 1.25	NA

* Values are presented at the mean ± SEM. Abbreviations: DGN = dorsal genital nerve; FN = femoral nerve; NA = not assessed; NM = not measured; PN = pudendal nerve; — = not applicable.

[†] Inguinal ligament at the midsagittal thigh location as shown in Fig. 2.