Published in final edited form as:

J Neurosurg Spine. 2012 October ; 17(4): 357–362. doi:10.3171/2012.7.SPINE12214.

Anatomical feasibility of performing intercostal and ilioinguinal nerve to pelvic nerve transfer: a possible technique to restore lower urinary tract innervation

Justin M. Brown, M.D.¹, Mary F. Barbe, Ph.D.², Michael E. Albo, M.D.³, H. Henry Lai, M.D.⁴, and Michael R. Ruggieri Sr., Ph.D.^{5,6,7}

¹Division of Neurosurgery, University of California San Diego School of Medicine, San Diego, California

²Department of Anatomy & Cell Biology, Temple University School of Medicine, Philadelphia

³Division of Urology, University of California San Diego Medical Center, San Diego, California

⁴Division of Urology, Washington University School of Medicine, St. Louis, Missouri

⁵Department of Urology, Temple University School of Medicine, Philadelphia

⁶Department of Pharmacology, Temple University School of Medicine, Philadelphia

⁷Shriners Hospital of Philadelphia, Pennsylvania

Abstract

Object—Nerve transfers are effective for restoring control to paralyzed somatic muscle groups and, recently, even to denervated detrusor muscle in a canine model. A pilot project was performed in cadavers to examine the feasibility of transferring somatic nerves to vesical branches of the pelvic nerve as a method for potentially restoring innervation to control the detrusor muscle in humans.

Methods—Eleven cadavers were dissected bilaterally to expose intercostal, ilioinguinal, and iliohypogastric nerves, along with vesical branches of the pelvic nerve. Ease of access and ability to transfer the former 3 nerves to the pelvic vesical nerves were assessed, as were nerve cross-sectional areas.

Results—The pelvic vesical nerves were accessed at the base of the bladder, inferior to the ureter and accompanied by inferior vesical vessels. The T-11 and T-12 intercostal nerves were too short for transfer to the pelvic vesical nerves without grafting. Ilioinguinal and iliohypogastric nerves (L-1 origin) were identified retroperitoneally and, with full dissection, were easily transferred to the pelvic vesical nerves intraabdominally. The mean cross-sectional area of the dominant pelvic

Address correspondence to: Michael R. Ruggieri Sr., Ph.D., Temple University School of Medicine, 3400 North Broad Street, Philadelphia, Pennsylvania 19140. rugg@temple.edu.

Disclosure

This publication was made possible by Grant Number 1R01NS070267 from the NIH-NINDS (National Institute of Neurological Disorders and Stroke) to Drs. Ruggieri and Barbe. This publication's contents are solely the responsibility of the authors and do not necessarily represent the official views of the NIH-NINDS. The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Ruggieri, Brown, Barbe. Acquisition of data: Ruggieri, Brown, Barbe. Analysis and interpretation of data: all authors. Drafting the article: Brown, Barbe. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Ruggieri. Statistical analysis: Ruggieri, Brown, Barbe. Administrative/technical/material support: Ruggieri, Brown, Barbe. Study supervision: Ruggieri, Brown, Barbe.

vesical branch was $2.60 \pm 0.169 \text{ mm}^2$; ilioinguinal and iliohypogastric branches at the suggested transection site were $2.38 \pm 0.32 \text{ mm}^2$ (the means are expressed $\pm$ SEM).

Conclusions—Use of the ilioinguinal or iliohypogastric nerves for heterotopic transfer to pelvic vesical nerves is surgically feasible, based on anatomical location and cross-sectional areas.

Keywords

intercostal nerve; ilioinguinal nerve; pelvic nerve; bladder; cadaver dissection; anatomy

In the US, 265,000 individuals are affected by SCI.⁸ Fifty-two percent of individuals with SCIs are considered paraplegic, and 47% are quadriplegic. At least one-quarter of the patients seen at the Philadelphia Shriners Hospital for Children's Spinal Cord Injury Center have flaccid urinary bladder paralysis and incontinence resulting from conus and cauda equina injuries. This is especially prevalent in children who sustain lap belt injuries leading to thoracolumbar spinal fractures. Neurological injury to lower lumbar and sacral nerves also occurs in patients with unstable pelvic fractures and sacral fractures, with incidence rates that range from 30% to 54%.^{3,7,13,16} Our long-term goals are to develop surgical approaches to reinnervate the urinary bladder so that patients with SCIs affecting lower nerves can regain control of bladder emptying. We are looking at eliminating spontaneous emptying and incontinence in spastic bladders, with the hope of providing control of bladder continence as well.

Recently, reports have emerged of successful somatic nerve transfers in animal models and in patients for restoration of bladder function.^{1,4,6,9,12,17,18} For example, using a canine model, we showed that bladder reinnervation after sacral ventral root transection can be achieved via nerve transfer and surgical coaptation of coccygeal roots to the severed sacral roots, or transfer of the genitofemoral nerve to vesical branches of the pelvic nerve, as evidenced by increased bladder pressure after functional electrical stimulation of the transferred nerve.¹¹ We also showed that functional bladder reinnervation can occur after delayed transfer of genitofemoral nerves (originating from upper lumbar spinal cord segments) to the vesical branches of the pelvic nerve up to 3 months after nerve transection and repair.¹⁰ In the majority of animals in each group, effective detrusor contractions were elicited by stimulation of the reinnervated pelvic vesical branches. Retrograde fluorogold tracing from the bladder confirmed the regrowth of axons from the upper lumbar spinal cord through the nerve repair sites to the bladder wall.^{10–12} Anterograde axonal tracing also confirmed regrowth of axons from the proximal genitofemoral nerve into the bladder detrusor muscle after these heterotopic somatic nerve transfers.²

Stemming from our success with heterotopic somatic nerve transfer for bladder reinnervation in the canine model, it is our long-term hope that surgical transfer of somatic nerves to the vesical branches of the pelvic nerve might serve as a surgical treatment for peripheral nerve, sacral root, or SCI-induced bladder dysfunction in humans. This pilot study in human cadavers is the first step in determining whether that is possible, by exploring the anatomical feasibility of transferring the following nerves: 1) lower thoracic intercostal nerves, and 2) ilioinguinal, or even the iliohypogastric nerve (both of L-1 origin), to the vesical branches of the pelvic nerve by using a retroperitoneal approach.

Methods

Twenty-two pelvic and thoracolumbar retroperitoneal regions were dissected in 11 formalin-fixed cadavers (5 female and 6 male cadavers). All but 2 of the cadavers had been used by others for nonlower-extremity and nonpelvic anatomical studies. The cadavers were inspected to ensure that the following anatomy was intact: 1) pelvic floor; 2) lower, lateral

thoracic wall; and 3) the lumbosacral plexus. Any nonintact specimens were excluded. In one-half of the included cadavers, hemisection was performed to facilitate the dissections. Two cadavers were used solely for this project and were not pre-dissected by others.

Gross dissection techniques were used. In each cadaver the dissection proceeded via the following approaches: 1) a pelvic approach for vesical branches of the pelvic nerve and inferior vesical vessels; 2) a lateral thoracic approach to identify and expose intercostal nerves and branches; and 3) an intraabdominal and retroperitoneal approach to identify the ilioinguinal and iliohypogastric nerves. Careful examination of the dissected fields was made.

The cross-sectional areas of the nerves were determined by making thin cross-sections with a scalpel, placing these onto microscope slides, and then determining the areas by using a bright-field dissecting microscope, a 5× objective, and image analysis software (Bioquant II).

Results

Identification of Vesical Branches of the Pelvic Nerve

The pelvic dissection involved a midline longitudinal laparotomy (Fig. 1A) followed by a retroperitoneal approach to expose the bladder in its retroperitoneal position immediately internal to the pubic symphysis and then locating vesical branches of the pelvic nerve at the proximal aspect of the lateral wall of the bladder (Fig. 1B). Either 1 large trunk of vesical branches of the pelvic nerve (the most common finding) or 2 medium-sized trunks (shown in Fig. 1B) were located at the proximal aspect of the lateral wall of the bladder, inferior to the ureter and adjacent to the inferior vesical artery and vein. In fact, we were able to use the inferior vesical vessels on the bladder as landmarks to locate vesical branches of the pelvic nerve. In most cases, a large trunk of vesical branches of the pelvic nerve could be tracked superiorly on the bladder wall toward its superior apex in each cadaver.

Identification and Transfer of Intercostal Nerves to Vesical Branches of the Pelvic Nerve

A lateral thoracic approach was used to identify and expose intercostal nerves and branches, as shown in Fig. 2. Several intercostal nerves, including T-12, were exposed (Fig. 2B). Although these nerves were large enough (as shown in Fig. 2C), none were long enough to reach vesical branches of the pelvic nerve without using a nerve graft (Fig. 2D and E). Figure 3 shows a diagram of our proposed use of the lateral femoral cutaneous nerve as a graft between the intercostal nerve and the dominant vesical branch of the pelvic nerve.

Identification and Transfer of Ilioinguinal/Iliohypogastric Nerves to the Pelvic Nerve

An intraabdominal and retroperitoneal approach was used to identify the ilioinguinal nerve, as shown in Fig. 4A. Its length ranged from 14 cm to 15.5 cm (Fig. 4B), before arborizing into smaller branches within the abdominal muscles (see Fig. 5 left). After opening the parietal peritoneum, this nerve was then directly transferred intraabdominally to ipsilateral vesical branches of the pelvic nerve at the base of the bladder (Fig. 4C–E). The ilioinguinal nerves appeared similar in diameter to the dominant vesical branch of the pelvic nerve (Fig. 4F).

The iliohypogastric nerve originated from the same lumbar spinal cord segment (L-1) as the ilioinguinal nerve, and had a similar path and diameter as that nerve (data not shown, diagrams shown in Fig. 5 left). It was also long enough to be transferred to the ipsilateral dominant vesical branch of the pelvic nerve at the base of the bladder, as depicted in Fig. 5 right.

Cross-Sectional Areas of the Nerves

Finally, to determine if the nerve branch was appropriate for surgical anastomosis to vesical branches of the pelvic nerve, we measured the cross-sectional areas of each nerve. The mean cross-sectional area of the dominant vesical branch of the pelvic nerve was $2.60 \pm 0.169 \text{ mm}^2$, and it was $2.38 \pm 0.32 \text{ mm}^2$ for the ilioinguinal and iliohypogastric nerves (measurements for both areas are expressed as the mean $\pm$ SEM).

Discussion

We were able to easily locate vesical branches of the pelvic nerve on the lateral bladder wall. The intercostal nerves, including T-12 (also known as the subcostal nerve), were not long enough to reach the pelvic nerve at the base of the bladder. However, the ilioinguinal and iliohypogastric nerves, before their diffuse branching within the abdominal wall musculature, were long enough to be transferred to the ipsilateral pelvic nerve vesical branches in the nerve's retroperitoneal position. Last, cross-sectional areas of the ilioinguinal nerves were sufficiently equivalent to the dominant vesical branch of the pelvic nerve to allow surgical coaptation.

Typically 1 but sometimes 2 dominant vesical trunks of the pelvic nerve were identified on each side of the bladder in each cadaver. These large vesical branches of the pelvic nerve were associated with inferior vesical branches of the internal iliac vessels. This finding is similar to that observed by Stelzner and colleagues;¹⁴ they also observed 2 main bundles of the pelvic splanchnic nerves that join the pelvic plexus on either side of the bladder at a position that is dorsal and inferior to the entrance of the ureter into the bladder wall. Although there were some additional small nerves or nerve branches that also innervated the detrusor muscle, such as branches from the hypogastric nerve, use of this main vesical branch of the pelvic nerve will probably allow reinnervation of a large part of the detrusor wall. The proximity of vesical branches of the pelvic nerve to the inferior vesical branches of the internal iliac artery allowed easy identification of these pelvic nerve branches. These large vesical branches of the pelvic nerve appeared to be quite distinct from other elements of the pelvic plexus that innervate the pelvic floor and genital structures. Thus, sacrifice of this dominant vesical branch of the nerve should not interfere with intact erectile function.

Whereas other methods of reinnervating the bladder have focused on transfers at the level of the spine, we believe that our approach at the level of the target organ may provide a more robust intervention. This strategy would avoid the long distances of regeneration from the spinal rootlets to the bladder. Additionally, this would avoid loss of donor axons into noncontributory distributions such as bowel innervation, sacral sensory dermatomes, and other somatic distributions. Such distal nerve transfers performed using direct transfers to the pelvic nerve have demonstrated efficacy in multiple undertakings by different groups. Trumble's experiments in 1935,¹⁵ in which he transferred the obturator nerve to the pelvic nerve in dogs, demonstrated effective detrusor contraction with direct stimulation of the transferred nerve after a delay of 6–12 months for axonal regeneration. In 1966, Kimmel⁵ demonstrated similar effective restoration of bladder contraction in rats with the same strategy of an obturator to pelvic nerve transfer. Recently we used a similar approach in a canine model in which the genitofemoral nerve was used for direct transfer to vesical branches of the pelvic nerve. We have demonstrated its efficacy in 3 distinct conditions, as follows: 1) immediate transection and transfer of the genitofemoral nerve to vesical branches of the pelvic nerve; 2) transections of vesical branches of the pelvic nerve, followed by a 1-month delay before transferring the genitofemoral nerve; and finally 3) transection followed by a 3-month delay before reconstruction. In the majority of animals in each group, effective detrusor contractions were elicitable with stimulation of the reinnervated vesical branches of the pelvic nerve.^{10,11}

This nerve transfer would be limited to patients with a very low SCI or injury to the nerves subserving bladder function. The patient must retain active control over lower abdominal musculature. Successful reinnervation would then be triggered by sustained attempted activation of the abdominal musculature. Unlike somatic to somatic transfers, in which there is an immediate response in the recipient muscle with activation of the donor nerve, detrusor contraction requires persistent sustained input. A patient who is struggling to void the bladder commonly uses a Valsalva maneuver, which generally recruits all of these abdominal muscles. Thus, retraining should be relatively straightforward. Concerns about the intervention include whether other common functions that result in sustained abdominal contraction would result in unintentional voiding. Further studies will be required to answer these questions.

Conclusions

Limitations of this study include its use in cadavers rather than in patients. However, we believed that the feasibility of the method needed to be established prior to performing these surgeries in a patient population. The anatomical approach in patients would probably not be substantially different from those in cadaver dissections, assuming that patients had not previously undergone intraabdominal, retroperitoneal, or major bladder surgeries such as bladder augmentation, which can cause significant adhesions. Importantly, prior to drawing the conclusion that these methods lead to detrusor reinnervation, we need to demonstrate that stimulation of these particular branches leads to detrusor contractions in humans. A second limitation is the inability to determine axon counts in the nerves due to fixation methods used for the cadavers and due to the long time period between fixation and dissection (because most of the cadavers were either used for or slated for medical educational purposes).

Acknowledgments

The artwork was prepared and provided by David Baker, DNA Illustrations, Inc., of Asheville, North Carolina (www.dnaillustrations.com).

Abbreviation used in this paper

SCI spinal cord injury

References

1. Agelan A, Braverman AS, Dean GE, Ruggieri MR Sr. Refinement in the management of the denervated canine urinary bladder using an abdominal vesicostomy. *ILAR J*. 2008; 49:E8–E14. [PubMed: 18506057]
2. Barbe MF, Ruggieri MR Sr. Innervation of parasympathetic postganglionic neurons and bladder detrusor muscle directly after sacral root transection and repair using nerve transfer. *Neurourol Urodyn*. 2011; 30:599–605. [PubMed: 21254198]
3. Huittinen VM. Lumbosacral nerve injury in fracture of the pelvis. A postmortem radiographic and patho-anatomical study. *Acta Chir Scand Suppl*. 1972; 429:3–43. [PubMed: 4509015]
4. Johnston L. Human spinal cord injury: new and emerging approaches to treatment. *Spinal Cord*. 2001; 39:609–613. [PubMed: 11641813]
5. Kimmel DL. Urinary bladder function in rats following regeneration of direct and crossed nerve anastomoses. *Chic Med Sch Q*. 1966; 26:1–12. [PubMed: 5930858]
6. Livshits A, Catz A, Folman Y, Witz M, Livshits V, Baskov A, et al. Reinnervation of the neurogenic bladder in the late period of the spinal cord trauma. *Spinal Cord*. 2004; 42:211–217. [PubMed: 15060517]

7. Matta JM, Saucedo T. Internal fixation of pelvic ring fractures. *Clin Orthop Relat Res*. 1989; (242): 83–97. [PubMed: 2706863]
8. National Spinal Cord Injury Statistical Center. Spinal Cord Injury Facts and Figures at a Glance. Birmingham, AL: National Spinal Cord Injury Statistical Center; Feb. 2011 (https://www.nscisc.uab.edu/PublicDocuments/nscisc_home/pdf/Facts%202011%20Feb%20Final.pdf)
9. Patil A. Intercostal nerves to spinal nerve roots anastomosis (spinal cord bypass) and Harrington rod fusion in traumatic paraplegia—technical note. *Acta Neurochir (Wien)*. 1981; 57:299–303. [PubMed: 7282451]
10. Ruggieri MR, Braverman AS, D’Andrea L, Betz R, Barbe MF. Functional reinnervation of the canine bladder after spinal root transection and genitofemoral nerve transfer at one and three months after denervation. *J Neurotrauma*. 2008; 25:401–409. [PubMed: 18373487]
11. Ruggieri MR, Braverman AS, D’Andrea L, McCarthy J, Barbe MF. Functional reinnervation of the canine bladder after spinal root transection and immediate somatic nerve transfer. *J Neurotrauma*. 2008; 25:214–224. [PubMed: 18352835]
12. Ruggieri MR, Braverman AS, D’Andrea L, Simpkins B, Kozin SH, Pontari MA, et al. Functional reinnervation of the canine bladder after spinal root transection and immediate end-on-end repair. *J Neurotrauma*. 2006; 23:1125–1136. [PubMed: 16866625]
13. Schmidek HH, Smith DA, Kristiansen TK. Sacral fractures. *Neurosurgery*. 1984; 15:735–746. [PubMed: 6390245]
14. Stelzner S, Holm T, Moran BJ, Heald RJ, Witzigmann H, Zorenkov D, et al. Deep pelvic anatomy revisited for a description of crucial steps in extralevator abdominoperineal excision for rectal cancer. *Dis Colon Rectum*. 2011; 54:947–957. [PubMed: 21730782]
15. Trumble HC. Experimental reinnervation of the paralyzed bladder. *Med J Aust*. 1935; 1:118.
16. Tung TH, Martin DZ, Novak CB, Lauryssen C, Mackinnon SE. Nerve reconstruction in lumbosacral plexopathy. Case report and review of the literature. *J Neurosurg*. 2005; 102 (1 Suppl):86–91. [PubMed: 16206740]
17. Xiao CG. Reinnervation for neurogenic bladder: historic review and introduction of a somatic-autonomic reflex pathway procedure for patients with spinal cord injury or spina bifida. *Eur Urol*. 2006; 49:22–29. [PubMed: 16314037]
18. Xiao CG, de Groat WC, Godec CJ, Dai C, Xiao Q. “Skin- CNS-bladder” reflex pathway for micturition after spinal cord injury and its underlying mechanisms. *J Urol*. 1999; 162:936–942. [PubMed: 10458412]

Fig. 1.

Photographs documenting identification of vesical branches of the pelvic nerve. **A:** The abdomen was opened (legs are located on the upper left side of this panel). **B:** The vesical branches of the pelvic nerve (*arrow*) were identified at the base of the bladder in the retroperitoneal space. Two dominant branches arose from the plexus in this cadaver, although several other cadavers showed only 1 dominant trunk. Forceps have been placed inferior to vesical branches of the pelvic nerve at the base of the bladder (which is being held superiorly by the blue-gloved hand at the upper right side of the panel). The index finger of the beige-gloved hand indicates the inferior epigastric artery and vein.

Fig. 2.

Photographs showing an attempt to transfer the left subcostal (T-12) and T-11 intercostal nerves to the left vesical branches of the pelvic nerve. **A:** The subcostal and T-11 intercostal nerves were identified on the thoracic wall and are indicated by *arrows*. **B:** The subcostal nerve was traced through the intercostal space, as was the T-11 intercostal nerve (*arrows*). **C:** The width of the subcostal nerve was measured using a metric ruler, and was noted to be 2 mm in diameter. **D:** Both nerves were traced as far anteriorly as possible on the thoracic wall. *Arrows* indicate the subcostal (T-12) nerve. **E:** Note the distance between vesical branches of the pelvic nerve (P; indicated by *green arrow* and lying on a green surgical cloth) and the subcostal nerve (I; *black arrow*). We determined that the distance between vesical branches of the pelvic nerve and the intercostals was too large to make this a viable nerve transfer without an additional nerve graft.

Fig. 3. Artist's illustration showing the transfer of a lower intercostal nerve to the dominant branch of the pelvic nerve to the bladder, using a lateral femoral cutaneous nerve as a graft.

Fig. 4.

Photographs showing transfer of the ilioinguinal nerve (L-1) to vesical branches of the pelvic nerve. **A:** The ilioinguinal nerve was identified on the lateral abdominal wall in the retroperitoneal space (left side in photograph; legs are located on the right side of the panel) and is indicated by the *black suture*. **B:** The length of the ilioinguinal nerve is indicated by a ruler (> 14 cm). **C:** The main vesical branch of the pelvic nerves is indicated by the *black suture* at the base of the bladder (BI). The ilioinguinal nerve was transferred to the base of the bladder and placed onto a piece of green surgical cloth. The legs are located on the right side of the panel; the muscle reflected over the pubic wall is the rectus abdominis muscle. **D:** Higher-power photograph of the same image as in panel C. **E:** The main vesical branch of

the pelvic nerve (P) is at the base of the bladder, proximal to its branches to the bladder. Both the main vesical branch of the pelvic nerve (P; right nerve) and the ilioinguinal nerve (Ilio; left nerve) are now on the green cloth. **F:** Higher- power photograph showing how the 2 nerves were “anastomosed.” Note that they are of similar diameters. The visceral peritoneum that covers the intestines is located on the left side of this panel.

Fig. 5.

Artist's illustrations showing the transfer of the iliohypogastric nerve (L-1) to the dominant branch of the pelvic nerve to the bladder. **Left:** Both the ilioinguinal and iliohypogastric nerves branch extensively once they reach the abdominal wall musculature. **Right:** The iliohypogastric nerve (or the ilioinguinal nerve) can be transected before the site of extensive branching and then transferred to the bladder and sutured to the main vesical branch(es) of the pelvic nerve.