Selective sacral rootlet rhizotomy for hypertonic neurogenic bladder

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The authors describe a highly selective transsacral microsurgical procedure for sacral nerve rootlet interruption in five patients with hypertonic neurogenic bladder. Magnification and systematic stimulation of sacral roots provided accurate identification of motor fibers supplying bladder detrusor muscle and differentiation of efferent components to the legs and anal sphincter. Although the technique prevented incontinence and adverse effects of nerve section on rectal and lower extremity function, improvement in voiding patterns and diminution of urinary sepsis was of brief duration in three of the five patients. Physiological data from these procedures reaffirms the importance of S-3 and S-4 motor roots in detrusor innervation, but clinical responses bring into question the possibility of sustained improvement from such a highly selective procedure at the sacral level. The authors suggest that alternative pathways, not apparent on initial stimulation, may develop after section of sacral root components, and that dissection and stimulation of fibers at the level of the conus medullaris should be investigated as an alternative procedure.

KEY WORDS • rhizotomy • nerve root • spastic neurogenic bladder
• electrical stimulation • microsurgery

VESICOURETERAL reflux associated with a hypertonic neurogenic bladder leads to significant morbidity and mortality. The ideal treatment of the hypertonic bladder should increase the time interval between voiding and eliminate reflux. Adverse effects of rhizotomy on the rectum, genitalia, and legs must be avoided in ambulatory patients with only minor neurological deficit. Non-selective sacral rhizotomy or neurotomy has been successful in paraplegic patients,2-10 but variability of the predominant roots to the bladder and overlapping of vesical, rectal, and perineal innervation makes the procedure impractical in nonparaplegic patients.

In this study we used microsurgical and electrophysiological techniques to define specific motor components of the sacral roots to detrusor muscle in selected patients with spastic neurogenic bladder. Denervation of the detrusor was accomplished by surgical exposure of the sacral roots, and selective sectioning of only those fiber bundles contributing to bladder innervation.
TABLE 1

Summary of five cases of hypertonic neurogenic bladder

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Clinical Diagnosis</th>
<th>Age at Onset of Symptoms</th>
<th>Neurological Involvement</th>
<th>Age at Onset of Symptoms of Spastic Neurogenic Bladder</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>21</td>
<td>multiple sclerosis</td>
<td>14</td>
<td>minor, ambulatory</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>49</td>
<td>multiple sclerosis</td>
<td>40</td>
<td>moderate, ambulatory</td>
<td>39</td>
</tr>
<tr>
<td>3</td>
<td>54</td>
<td>C5-6 fracture, dislocation</td>
<td>54</td>
<td>Brown-Séquard, ambulatory</td>
<td>54</td>
</tr>
<tr>
<td>4</td>
<td>19</td>
<td>AVM cervico-dorsal spine, hemorrhage, paraplegia</td>
<td>16</td>
<td>paraplegia, T-2 level</td>
<td>17</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>T-6 fracture, dislocation</td>
<td>18</td>
<td>paraplegia, T-6 level</td>
<td>19</td>
</tr>
</tbody>
</table>

Clinical Material and Methods

Selection of Patients

Patients were accepted for this procedure when the following preoperative criteria were met:

1. Previous conservative treatment had failed.
2. The bladder had preserved elasticity.
3. Obstructive lesions within the bladder and urethra had been ruled out.
4. Uninhibited activity on cystometrogram disappeared after selective procaine block of sacral nerves or saddle block anesthesia.
5. Improvement of micturition occurred after selective procaine block of sacral nerves or saddle block anesthesia without causing incontinence.

Observation of five patients after selective sacral rhizotomy for treatment of neurogenic spastic bladder provided clinical experience and anatomicopathological data on bladder and rectal sphincter innervation. Patients selected for treatment included two with multiple sclerosis and three with previous injuries of the spinal cord far above the sacral micturition center. Table 1 includes biographical and neurological data on all patients and Table 2 illustrates the urological data, results of surgical treatment, and duration of improvement. Table 3 lists the roots from which fibers were sectioned.

Technique

Surgery was performed under light halothane or nitrous oxide anesthesia to eliminate discomfort and movement that would distort cystometric and rectal recording. Patients were placed in the prone position, and pressure on the abdomen was carefully avoided. An indwelling Foley catheter was connected to the cystometrograph.* An endotracheal tube with a water-filled balloon connected to a water manometer was inserted into the rectum for recording anal sphincter contractions.† Sacral laminectomy was performed. The dura mater was opened and retracted by sutures, and the second, third, and fourth sacral roots were identified. The bladder was emptied and then filled with normal saline to a volume slightly below that measured after the nerve block. The Physio-Stimulator‡ with output of spike or sharp sawtooth-shaped waves was set for stimulation. Stimulation frequency was 25 to 30 Hz and voltage was 0.5 to 5 V. The whole roots of S-2, S-3, and S-4 were stimulated separately while the cystometrogram, rectal manometer pressures, and leg movements were observed. Preliminary stimulation indicated which roots caused detrusor contraction and to what magnitude.

* Lewis cystometer manufactured by American Cystoscope Makers, Inc. Pelham Manor, New York.
† Physio-Stimulator manufactured by Codman and Shurtleff, Inc., Randolph, Massachusetts.
TABLE 2

Neuro-urological history of five patients with hypertonic neurogenic bladder

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Treatment</th>
<th>Duration of Improvement (mos)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
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</tr>
<tr>
<td>3</td>
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<tr>
<td>4</td>
<td>30</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
<td>continued at present time</td>
</tr>
</tbody>
</table>

* Voiding by Credé maneuver.

Using an operating microscope or magnifying loupe, each root was elevated and divided into several bundles. Each bundle of fibers was stimulated separately. The bundles were further divided until only detrusor muscle contraction was produced with no evidence of motor effects in the legs. Only bundles that exclusively affected the detrusor were sectioned. The proximal and distal ends of sectioned bundles were stimulated separately to confirm that fibers of the anterior root were cut. Specimens of sectioned bundles were obtained for anatomical comparison with horizontal sections of whole anterior sacral roots obtained from cadavers (Fig. 1).

Case Reports

Case 1

A 21-year-old woman was well until the age of 14 when she first noted urinary frequency and occasional incontinence. Increasingly frequent forceful voiding of small quantities of urine was associated with constant low abdominal pain. During pregnancies at ages 15 and 17, she had severe frequency which persisted after the birth of her second child. She was able to control voiding to some extent during the daytime, but she suffered nocturnal enuresis. At the age of 16 years the patient began to notice weakness of the legs, bilateral ptosis, and diplopia.

She was admitted for the first time in June, 1969, with a urinary tract infection. Urine
culture revealed *Escherichia coli* and the patient was treated with antibiotics. A cystometrogram showed uninhibited bladder activity. Cystoscopy revealed a very small bladder with large trabeculae. On intravenous pyelography (IVP) both collecting systems and ureters were well visualized and the bladder was small with an irregular wall. Complete neurological evaluation established the diagnosis of multiple sclerosis.

She was readmitted on January 3, 1969, because of urinary frequency every 10 to 15 minutes, dribbling of urine, and cramping pain in the lower abdomen which was not controlled by anticholinergic drugs. Her gait was spastic and the anal sphincter tone was decreased. Frequency and incontinence did not change significantly after antibiotic therapy. Cystometrogram showed uninhibited detrusor activity and leaking around the catheter after 155 ml of bladder filling.

**First Operation.** After sacral block of S-2, S-3, and S-4 on three occasions the average bladder capacity was 350 ml. Bilateral selective S-3 anterior sacral rhizotomy was performed on January 29, 1969, after which the patient became continent and free of cramping pain in the lower abdomen. She had good sensation of bladder fullness and initiated voiding by the Credé maneuver. For 6 months she had a satisfactory 3- to 4-hour voiding pattern, but gradually she returned to her preoperative status, voiding every hour; however she remained continent. She again became pregnant, and by the latter half of this third pregnancy she had almost constant dribbling with voiding every 15 minutes, with urinary tract infection and suprapubic pressure pain. Immediately after delivery (January 1, 1970) she improved for 2 to 3 weeks, but then again noted almost constant dribbling and low cramping abdominal pain.

The patient was admitted again on August 13, 1970. Cystometrogram showed a bladder capacity of 175 ml and uninhibited detrusor activity. Residual urine was 100 ml. Cystogram again demonstrated a small trabeculated bladder. Sacral nerve procaine block abolished uninhibited detrusor activity and increased bladder capacity to 300 ml.

**Second Operation.** The sacral laminectomy site was reopened on September 4, 1970. Stimulation of all the sacral roots on the left side produced only strong plantar flexion of the foot. On the right side, two small bundles were separated from the medial portion of what we thought was S-3. One of these bundles gave pure, strong bladder detrusor contraction on stimulation. However, stimulation of the second bundle caused a strong bladder detrusor response and plantar flexion of the foot. It was possible to separate the motor component producing plantar flexion and two small bundles of fibers (Fig. 1 C) remained for final stimulation; both gave strong detrusor contraction only. Both were cut and distal ends stimulated separately. No detrusor reaction was observed, but when proximal ends were stimulated, bladder response was reproduced, indicating that these were posterior rootlets. After surgery, Stimulation of a small bundle of fibers separated from the most medial portion of the S-2 root gave both plantar flexion of the foot and a strong bladder contraction (15 to 20 cc of water) during several stimulation attempts. The fibers to the bladder were then isolated and cut. An identical small bundle of fibers was separated from the medial portion of the S-2 root on the right side with a very similar stimulation result. Distal end stimulation on both sides produced detrusor muscle contraction.

The selective rhizotomy of S-2 abolished uninhibited detrusor activity, again increasing bladder capacity to 350 ml. The patient's cramping pain ceased but she remained incontinent, although to a smaller extent than before surgery. Her neurological status was otherwise unchanged. She again had an intractable urinary tract infection associated with pain in the lower abdomen. A urinary diversion procedure was proposed but the patient refused.

She was admitted again on April 8, 1971, with urinary frequency (5 to 10 minutes) and dribbling. A cystometrogram was consistent with a spastic bladder of 125 ml capacity. The cystogram showed evidence of reflux to the left ureter. No significant progression of neurological signs had occurred. Procaine block of the sacral nerves increased bladder capacity to 275 ml without leakage around the catheter; after the block the patient's voiding pattern improved for a few hours.

**Third Operation.** On May 3, 1971, the sacral laminectomy was reopened and stimulation of all the sacral roots on the left side produced only strong plantar flexion of the foot. On the right side, two small bundles were separated from the medial portion of what we thought was S-3. One of these bundles gave pure, strong bladder detrusor contraction on stimulation. However, stimulation of the second bundle caused a strong bladder detrusor response and plantar flexion of the foot. It was possible to separate the motor component producing plantar flexion and two small bundles of fibers (Fig. 1 C) remained for final stimulation; both gave strong detrusor contraction only. Both were cut and distal ends stimulated separately. No detrusor reaction was observed, but when proximal ends were stimulated, bladder response was reproduced, indicating that these were posterior rootlets. After surgery,
the patient became continent and free of abdominal cramping pain, voiding approximately every 3 hours. She used the Credé maneuver for initiation of voiding. As a result of the operation, however she had slightly decreased sensation to pinprick in the right perianal area.

When seen 2 months after surgery, the patient was voiding every 3 to 4 hours, continent, and free of pain. She was admitted elsewhere for ileocutaneous ureterostomy and died of pneumonia after surgery in December, 1971.

Case 2

This 49-year-old man had slowly progressive multiple sclerosis. His first symptoms were urinary disturbances followed by progressive incoordination of extremities, slurred speech, and swallowing difficulties. Cerebral angiography and ventriculography performed when he was 43 years old were normal. Three years later he had a severe urinary tract infection, and the diagnosis of spastic neurogenic bladder was established. The infection was controlled by antibiotics. He was re-evaluated with sacral blocks and a selective sacral rhizotomy was performed (Table 2).

During the first postoperative days, he remained continent up to 6 hours. He had occasional nocturnal dribbling, which was prevented if he voided before going to bed. He was taught to use the Credé maneuver for bladder emptying. The anal sphincter functioned well. He was seen 1 and 6 months after surgery and had the same voiding pattern although his general neurological status had deteriorated. Shortly after the 6-month visit he noticed dribbling of urine and was advised to use an external catheter; he had no urinary infections.

Three years after surgery, an excretory urogram showed evidence of bilateral ureterectasis with mild pyelocaliectasis on the left. Cystogram revealed a typical "Christmas tree" deformity with excessive bilateral vesicoureteral reflux. Panendoscopy showed bladder trabeculations with cellule formation, but no diverticula was noted on cystoscopy. Bladder capacity was 300 cc, and the first desire to void was present at 75 to 100 cc; the residual urine was not significant. No uninhibited contractions were documented on cystometrography.

Case 3

This 57-year-old man was initially quadriplegic after falling down stairs on November 10, 1970, and sustaining a C5-6 fracture. After anterior fusion and rehabilitation he had good right-sided function and moderate return of left-sided strength and was able to walk with support of braces and cane. Four months after the injury, he had urinary frequency and overflow incontinence intractable to Pro-Banthine, and a urinary tract infection. Cystometric examination demonstrated a bladder capacity of 50 cc with the pattern of uninhibited activity. There was trabeculation of the bladder with small diverticulae and multiple cellules, hyperemia of the mucosa, urethral reflex on the right side, and benign prostatic hypertrophy. The patient responded to sacral root blocks (Table 2), and selective sacral rhizotomy was performed on November 12, 1971. His voiding pattern after surgery was satisfactory, bladder capacity increased, and the reflux disappeared. He was not successful in using the Credé technique because of left hand weakness. He again developed a urinary tract infection in January, 1972, and cystometrics revealed uninhibited activities typical for spastic bladder. Bladder capacity was 200 cc. An ileocutaneous ureterostomy was performed 3 months after his rhizotomy.

Case 4

This 17-year-old man was admitted on September 20, 1971, with established paraplegia at the T-2 level from hemorrhage of an arteriovenous malformation (AVM) of the cervical spinal cord. He had urinary incontinence and chronic cystitis. After satisfactory treatment of the urinary tract infection, the cystometrogram demonstrated a hypertonic bladder with a capacity of 75 ml. After saddle block anesthesia, the bladder capacity increased to 400 ml (Table 2). Cystography revealed early coning of the bladder with an hour-glass shape, neurogenic bladder neck pattern, and hypertonicity of the sphincter. There was scattered submucosal hemorrhages and enlargement of the ureteral orifices. Retrograde pyelography revealed 3+ bilateral ureteral pyelocaliectasis. Selective sacral rhizotomy for treatment of the spastic neurogenic bladder was done on October 8, 1971 (Table 2). A cystometrogram performed
on October 20, 1971, demonstrated increase in the bladder capacity up to 250 ml. There was no leakage around the catheter. The patient was continent and was taught to void by the Credé maneuver. He was depressed and hostile toward the staff and did not cooperate well with this procedure. Although his bladder capacity increased, an external catheter was used 1 month after surgery because of incontinence (dribbling). Four months after surgery a cystometrogram demonstrated a somewhat hypertonic bladder with a 175-ml capacity. Spinal cord angiogram was performed revealing persistence of the AVM supplied by the costocervical trunk. The AVM was treated surgically and he suffered postoperative meningitis with delayed postsurgical recovery. His bladder volume again contracted to 75 ml.

Case 5

This 20-year-old man had a motorcycle accident in February, 1970, causing a T-6 fracture-subluxation and complete paraplegia below this level. He had two previous admissions for treatment of a recurrent urinary tract infection. He was treated with anticholinergic drugs with no success, and used an external catheter because of constant dribbling.

At the present admission the urinary infection was relatively well under control with a few white cells in the urine and 3+ bacteria. An IVP disclosed normal appearance of both kidneys and ureters and the bladder showed trabeculation and dilatation of the membranous urethra. Retrograde cystogram and cystoscopy revealed hypertonicity and spasticity of the bladder and no evidence of ureteral reflux. Cystometrogram demonstrated a bladder capacity of 75 ml. Under spinal anesthesia the bladder capacity was 240 ml. Selective anterior sacral rhizotomy was done, transecting selected fibers to bladder detrusor from S-3 and S-4 roots bilaterally (Tables 2 and 3). S-2 roots were also stimulated but did not cause bladder contraction. Anal sphincter responses were obtained from stimulating a few fibers of S-2, S-3, and S-4.

After surgery, the patient was continent and able to void by Credé maneuver at 4-hour intervals. When discharged on the eleventh postoperative day, dribbling had ceased, and he did not need a catheter. However, dribbling appeared again in approximately 1 month. After rigid medical urological management he is now continent without a catheter; he voids efficiently by Credé, is free of infection, and cystometrography reveals that he has a hypotonic bladder with a 450-ml capacity.

Discussion and Conclusions

Table 3 depicts findings on stimulation of sacral roots in all five patients. Stimulation revealed that the S-3 root was absolutely dominant in innervation of bladder detrusor in all patients. Root S-4 also contributed, but significantly less. The S-2 root produced leg motor activity, and no bladder detrusor contraction from stimulation during the first operation in any patient. However, in Case 1 significant detrusor activity was demonstrated on stimulation of the most medially located fibers of the S-2 root during the second operative procedure (using the same type of stimulation).

In all cases, the fibers innervating bladder detrusor muscle were located in the most medial portions of the S-3 and S-4 roots. When the anal sphincter contraction was measured (Cases 1, 3, and 5) the data indicated that S-2, S-3, and S-4 roots had equally contributing fibers. Fibers to the

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Detrusor Muscle (divided)</th>
<th>Detrusor Innervation (not divided)</th>
<th>Anal Sphincter Innervation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>rt S-3</td>
<td>rt S-2, S-3, S-4</td>
<td></td>
</tr>
<tr>
<td>1st op.</td>
<td>lt S-3</td>
<td>lt S-2, S-3, S-4</td>
<td></td>
</tr>
<tr>
<td>2nd op.</td>
<td>rt S-2</td>
<td></td>
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</tr>
<tr>
<td>lt S-2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd op.</td>
<td>rt S-3?</td>
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<td></td>
</tr>
<tr>
<td>afferent fibers</td>
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<td></td>
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<tr>
<td>2</td>
<td>rt S-3</td>
<td>rt S-4</td>
<td></td>
</tr>
<tr>
<td>lt S-3</td>
<td>lt S-4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(strong)</td>
<td>(weak)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>rt S-3, S-4</td>
<td>rt S-2, S-3, S-4</td>
<td></td>
</tr>
<tr>
<td>lt S-3, S-4</td>
<td>lt S-2, S-3, S-4</td>
<td></td>
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<tr>
<td>4</td>
<td>rt S-3, S-4</td>
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<tr>
<td>5</td>
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<td>rt S-2, S-3, S-4</td>
<td></td>
</tr>
<tr>
<td>lt S-3, S-4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
bladder detrusor and the anal sphincter were in close anatomical relationship in roots S-3 and S-4, but it was possible to separate them anatomically under magnification in most cases. Additional motor activity on stimulation of S-3 and S-4 roots were represented by plantar flexion of the feet, but these fibers were always easy to separate from those supplying bladder and anal sphincter.

These experiences indicate that it is possible to divide roots S-2, S-3, and S-4 (and others) down to small elements, and to separate fibers to the bladder detrusor muscle from those innervating the anal sphincter and muscles of the legs. These elements are fascicles (bundles) of fibers probably representing rootlets. However, to be certain that they are rootlet fibers, one would have to trace them to the conus medullaris, a procedure not advisable in the clinical situation. In previous laboratory studies on 10 dogs we were able to trace fibers to the spinal cord and concluded that these fibers represented the whole rootlet.

Our long-term clinical results indicate that some improvement in micturition may be obtained when selective rhizotomy is followed by careful urological management. Two patients with multiple sclerosis had very satisfactory results for approximately 6 months. Then, in Case 1, pregnancy and recurrent infections complicated the clinical course. However, with each additional operation, this patient improved for short periods of time. In Case 2, improvement had been maintained reasonably well from the standpoint of increased bladder capacity, longer intervals between voiding, and fewer urinary tract infections.

Patients with spinal cord injuries improved for much shorter periods of time after surgery. The patient in Case 3 was physically unable to void by Credé and because of pressure due to his type of employment chose to have early urinary diversion. The patient in Case 4 had many emotional problems and was uncooperative, and this reflected on the rhizotomy results, but the patient in Case 5 was extremely well motivated and showed a good micturition pattern. His condition deteriorated 1 month after surgery, but he recovered and remains continent and free of infection.

A possible explanation for the failure of selective rhizotomy (if urinary tract infections are eliminated) is the development of alternative sacral reflex pathways which were secondary and inactive during initial stimulation. An example of this is seen in Case 1. During the second operation, minute bundles of fibers, separated from the S-2 roots bilaterally, showed extremely strong detrusor muscle contractions when stimulated. In the third operation, afferent fibers of S-3 produced enough activity through the sacral micturition center to initiate bladder contraction through undetermined efferents.

Selective sacral rhizotomy is a safe procedure and should be considered as an adjunct to vigorous urological treatment. Good results should be expected when a patient is self-disciplined and cooperates well. However, it is our belief that the proper method of treatment for spastic neurogenic bladder requires further investigation and long-term observation. In this effort, we have attempted selective sacral rhizotomy at the level of the conus medullaris where fibers to the bladder seem to be more concentrated.

References
11. Toczek SK, Boggs JS, McCullough DC: Unpublished data

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