available at www.sciencedirect.com
journal homepage: www.europeanurology.com

European Association of Urology

Review - Neuro-urology

Reinnervation for Neurogenic Bladder: Historic Review and Introduction of a Somatic-Autonomic Reflex Pathway Procedure for Patients with Spinal Cord Injury or Spina Bifida

Chuan-Guo Xiao [a,b]

[a] *Department of Urology, Xiehe Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China*
[b] *Department of Urology, New York University School of Medicine; New York, NY, USA*

Article info

Article history:
Accepted October 10, 2005
Published online ahead of print on November 2, 2005

Keywords:
Neurogenic
Spinal cord injury
Spina bifida
Bladder reinnervation
Neurosurgical procedure

Abstract

Neurogenic bladder caused by SCI or spina bifida is a major problem. Research in restoring functional micturition has mainly focused on electrical stimulation for many decades with good progress, but it is still not the definitive solution for majority of the SCI patients.

An alternative approach has been to investigate restoring innervation to the lower urinary tract after spinal SCI. Different animal and clinical studies were reviewed historically in this article, focused on mainly cross over nerve surgery for reinnervation of the bladder. An artificial somatic-autonomic reflex pathway procedure and its mechanisms were introduced. Clinical application and the satisfactory results of the new procedure were reviewed in details in restoring voluntary bladder control in patients with SCI or spina bifida.

E-mail address: xiaocg@mails.tjmu.edu.cn.

1. Historic review of studies on neurogenic bladder

Neurogenic voiding dysfunction after spinal cord injury (SCI) presents a major medical and social problem. In industrialized nations the mortality related to renal problems after SCI has significantly decreased since World War II, but the morbidity has remained significant, chiefly because of poorly controlled bladder and bowel functions [1,2]. In underdeveloped countries where medical resources are limited, no significant progress has been reported on the mortality and morbidity of SCI survivors.

Another huge population with neurogenic voiding dysfunction is children with spina bifida which effects one per thousand newborns [3]. Despite rigorous pharmacologic and surgical treatment, incontinence, urinary tract infections and upper tract deterioration remains problematic. The combination of pharmacological agents, surgical bladder augmentation and clean intermittent catheterization has limited success [4].

Research in restoring functional micturition has mainly focused on electrical stimulation for many decades. After the failure of initial attempts to induce voiding via electrical stimulation of the

0302-2838/$ – see front matter © 2005 Elsevier B.V. All rights reserved. doi:10.1016/j.eururo.2005.10.004

spinal cord, [5] or direct electrical stimulation on bladder muscle or pelvic nerve, [6] significant progress has been achieved through stimulation of sacral ventral roots with transaction of the sacral dorsal roots. Brindley et al. reported the first 50 cases of its clinical application in 1986, with restored reservoir function, re-established continence and complete bladder evacuation in a high percentage of treated SCI patients from a highly selected group [7]. Tanagho et al. [8] also applied the technique to neurogenic bladder patients with various causes besides SCI [8]. Despite being used in a few centers for nearly 2 decades, this procedure, however, has not been the treatment of choice for the majority of SCI victims, because it involves major surgery and the clinical results is far from universal [9]. In addition, other disadvantages are: (1) failure of the electrodes, which may be difficult to re-implant, (2) mechanical and electrical damage of the nerve, which may be permanent, and (3) undesirable consequence that transaction of the sacral dorsal roots in incomplete SCI patients sacrifice any residual sensory function.

An alternative approach has been to investigate restoring innervation to the lower urinary tract after spinal SCI, though surprisingly few animal and clinical studies has been reported. Various techniques were tested such as Omentovesicopexy [10] Reinnervation of the rat bladder with a somatic nerve and a striated muscle flap [11] spinal implants of olfactory ensheathing cells [12] and free vascular transfer of latissimus dorsi muscle flap innervated by intercostals nerve and deep interior epogastric nerve for SCI patients with bladder acontractility [13,14]. Major efforts on bladder reinnervaton, however, has been cross over nerve surgery. Cross over nerve surgery was conceptualized by Kilvington in 1907, though his experiment on 3 dogs did not demonstrate any bladder contraction related to lumbar to sacral nerve reinnervation [15]. Trumble [16] tried anastomosis between hypogastric nerve and pelvic nerve, or between obturator nerve and pelvic nerve in dogs. After 6 to 12 month regeneration, stimulation of the obturator nerve when anastomosted to a pelvic nerve, produced bladder contraction, but only very week bladder contraction was initiated by stimulation on the hypogastric nerve anastomosed to the pelvic nerve. Trumble believed that the result was due to that obturator nerve had more modulated fibers than the hypogastric nerve. Since this technique was only suitable for cauda equina lesions, Trumble did not try it on patients in worry about the neurological deficit by paralyzing the adductors [16]. There were also a few reports of animal studies aimed at bladder reinnervation by obtrutor nerve to detrusor (ottaviani and binotto, 1939), sacral ventral roots and dorsal roots reconstruction (Carlsson and Sundin, 1968), intercostal nerve to sacral nerve (Browne and Snyder, 1971), reconstruction of transected roots of the cauda equina (Conzen and Sollmann, 1982), lumbar nerve to sacral nerve with/out graft (Vorstman, Schlossberg and Kass, 1985) and root reconstruction similar to Sundin and Carlsson (Chuang DC, et al., 1991) [17,18]. In summary they all reported positive results in different degrees, and concluded that bladder reinnervation by cross over nerve surgery was possible, though little was done systematically in terms of morphology, electrophysiology, and neural transmitters of the reinnervation. In terms of clinical trial, remarkable attempts was reported by Chiasserini in 1935 on 4 SCI patients [17]. Three of his 4 patients underwent intercostal nerves to cauda equina anastomosis showed favorable responses in 2–3 months postoperatively. Unfortunately, the short time course of restoring functions can not attribute to the nerve cross surgery and reinnervation. Carlsson and Sundin (1967 & 1980) reported relative success in reconstruction of efferent and afferent pathways to bladder with nerve roots above the spinal lesion anastomosed to S2/S3 roots. Although only 2 of several patients had favorable response and they had only partial upper motor neuron lesion, the time course for changes favors a successful reinnervation [19]. Recently, Livshits et al. [20] from Russia reported an extremely successful study with intercostal nerve to spinal nerve root anastomosis, a similar surgery that Chiasserini reported in 1935, on 11 chronic SCI patients. They observed significant improvements in bladder function during the 10th to 12th postoperative months and restoration of reflex voiding occurred in all patients [20].

2. An artificial somatic-CNS-autonomic reflex arc procedure to restore bladder function

By evaluation of pros and cons of all available approaches for treatment of neurogenic bladder, it became clear that reinnervation was feasible and promising, but the previous efforts with cross over nerve surgery would not work well because there was no control over the reinnervation, i.e., even if the regeneration was successful, there was no way to activate the regenerated axons to initiate a coordinated voiding. In addition, using the nerve above spinal cord lesion to reinnervate bladder would usually need nerve grafting and a long time to complete regeneration, and it was also not practical for higher SCI. We proposed in 1989 to establish an artificial 'skin-CNS-bladder' reflex pathway below the spinal cord lesion (or just above the lesion for sacral cord injury) as a means of restoring controllable micturition after SCI [21]. The assumption underlying this work is that the motor axons of a somatic reflex arc may be able to regenerate into autonomic preganglionic nerves and thus reinnervate the bladder parasympathetic ganglion cells and thereby transfer somatic reflex activity to the bladder smooth muscle. This reflex pathway which is basically a somatic reflex arc with a modified efferent branch that transfers somatic motor impulses to the bladder, has been designed to allow SCI patients to initiate voiding by scratching the skin [Fig. 1]. The new concept was tested first in rat [22]. An artificial cross over 'skin-CNS-bladder' reflex pathway was established in by intradural microanastomosis of the left L4 ventral root to L6 ventral root which innervated the bladder and external urethral sphincter in rats, while leaving the L4 dorsal root intact as a starter of micturition. After axonal

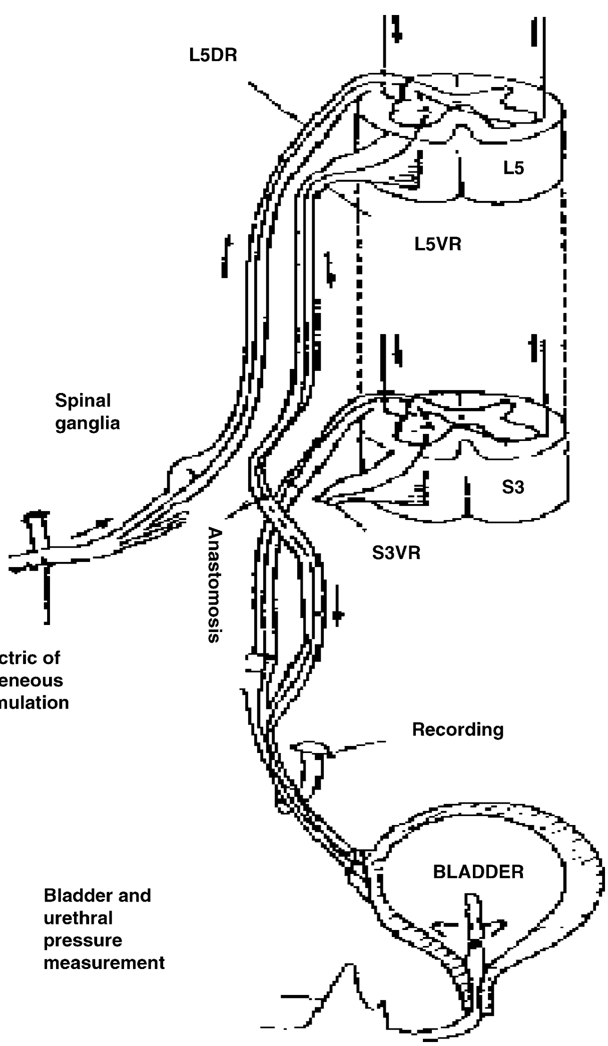


Fig. 1 – Skin-CNS-bladder reflex pathway (From Xiao CG et al., J Urol 2003, with permission).

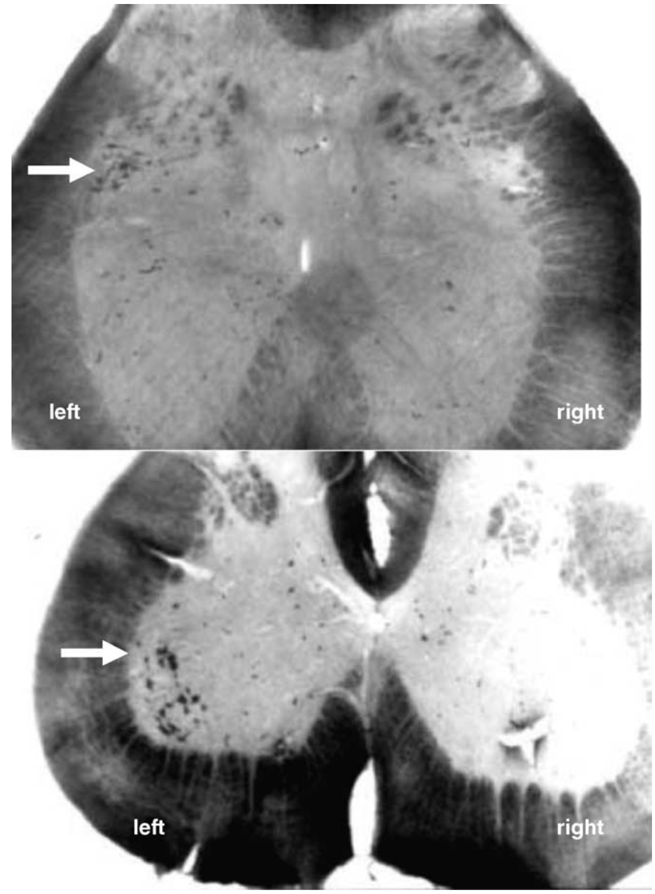


Fig. 2 – Above: Neural tracing by applying HRP to the pelvic ganglion show that the normal bladder was innervated by preganglionic neurons (Arrow) located in the lateral band of the L6 and S1 segments in the rat. Below: In the rats with the somatic-CNS-Autonomic reflex pathway, somatic motor neurons (Arrow) in the left L4 ventral horn were labeled when HRP was applied to left L6 spinal nerve or left pelvic ganglion.

regeneration, 15 of the 24 rats with the new pathway underwent electrophysiological study. Single stimuli (0.3–3 mA, 0.02–0.2 ms duration) to the left L4 nerve resulted in evoked potentials (0.5–1 mV) recorded from the left L6 nerve distal to the anastomosis. The bladder detrusor contraction was very quickly initiated by trains of the stimuli and bladder pressures increased rapidly to levels similar to controls. Neural tracing study with horseradish peroxidase (HRP) on six rats with the pathway demonstrated that the somatic motor axons regenerated successfully into the pelvic nerve, and the bladder was reinnervated by the L4 somatic motor neurons [Fig. 2]. The bladder contraction could also be initiated by electrostimulation of left sciatic nerve as well as scratching the L4 related skin. A new concept may be derived from the skin-CNS-bladder reflex pathway: the impulses delivered from the efferent neurons of a somatic reflex arc can be transferred to initiate responses of an autonomic effector [22].

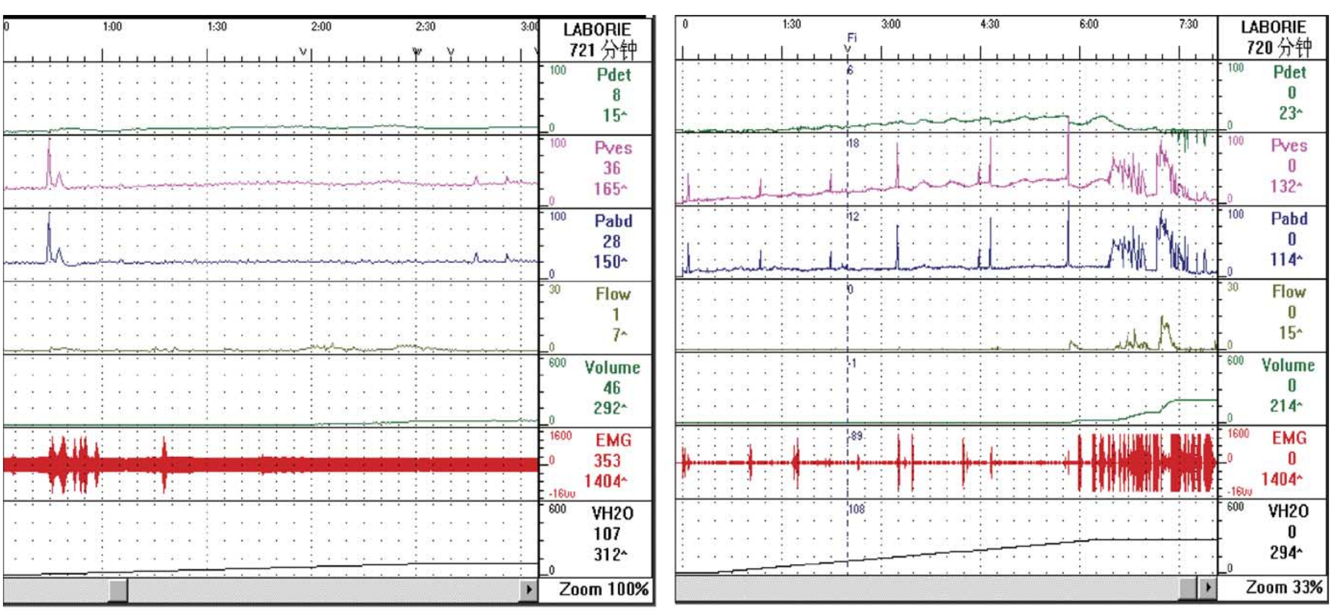
Continued animal experiment was focused on the underlying mechanism of the somatic-autonomic reflex pathway for micturition. The skin-CNS-bladder reflex was established in the cat by intradural microanastomosis of the left L7 ventral root (VR) to the S1 VR while leaving the L7 dorsal root (DR) intact to conduct cutaneous afferent signals that can trigger the new micturition reflex arc [23]. After allowing 11 weeks for axonal regeneration, urodynamic, pharmacological and electrophysiological studies were conducted in pentobarbital or chloralose anesthetized animals. Results showed that a detrusor contraction was initiated at short latency by scratching the skin or by percutaneous electrical stimulation in the L7 dermatome. Maximal bladder pressures during this stimulation were similar to those activated by bladder distension in control animals. Electrophysiological recording revealed that single stimuli (0.3 to 3 mA, 0.02 to 0.2 msec duration) to the left L7 spinal nerve in which the efferent axons had degenerated evoked action potentials (0.5 to 1 mV) in the left S1 spinal nerve distal to the anastomosis. In addition, increases in bladder pressure were elicited by trains of the stimuli (5 to 20 Hz, 5 seconds) applied to the L7 spinal nerve. Urodynamic studies including external sphincter EMG recording demonstrated that the new reflex pathway could initiate voiding without detrusor-external urethral sphincter dyssynergia. Atropine (0.05 mg/kg, i.v.) or trimethaphan (5 mg/kg, i.v.), a ganglionic blocking agent, depressed the bladder contractions elicited by skin stimulation. The skin-CNS-bladder reflex could also be elicited after transecting the spinal cord at the L2-L3 or L7-S1 levels. In summary, the cross-wired somato-autonomic bladder reflex is effective in initiating bladder contractions and coordinated voiding in cats with an intact neuraxis and can also induce bladder contractions after acute transection of the lumbar spinal cord. The new pathway is mediated by cholinergic transmission involving both nicotinic and muscarinic receptors. The somatic motor axons can innervate bladder parasympathetic ganglion cells and thereby transfer somatic reflex activity to the bladder smooth muscle [23].

A clinical trial of the artificial somatic-CNS-autonomic reflex arc procedure was started in 1995 [24]. Fifteen male volunteers with hyperreflexic neurogenic bladder and detrusor-external sphincter dyssynergia (DESD) caused by complete suprasacral SCI underwent limited hemi-laminectomy and ventral root (VR) micro-anastomosis, usually between the L5 and S2/3 VRs. The L5 dorsal root (DR) was left intact as the trigger of micturition after axonal regeneration. Mean follow-up period was 3 years. All patients underwent urodynamic evaluation before surgery and during follow-up. Among the 15 patients, 10 (67%) regained satisfactory bladder control within 12–18 months after VR microanastomosis. Average residual urine decreased from 332 ml to 31 ml and urinary infection as well as overflow incontinence disappeared. Urodynamic studies revealed a change from detrusor hyperreflexia with DESD and high detrusor pressure to nearly normal storage and synergic voiding without DESD. Impaired renal function returned to normal. Two patients (13%) who required a skin stimulator to evoke voiding following the VR anastomosis exhibited a partial recovery but had over 100 ml of residual urine. One patient was lost to follow-up and two failed. In summary, an artificial somatic-CNS-autonomic reflex arc can be established surgically to provide a novel method for controlling bladder function for complete suprasacral SCI patients with hyperreflexic bladder and DESD [24].

By the end of 2004, a total of 92 SCI patients with hyper reflexic or acontractile bladder in our hospital have been treated with the somatic and autonomic reflex arc procedure and 81 of them regained bladder control one year postoperatively [25]. A NIH sponsored clinical trial of the somatic-autonomic reflex arc for micturition after SCI at New York University Medical Center has also produced similar satisfactory results for the first two SCI volunteers. Preoperative urodynamic studies in both revealed neurogenic overactivity with urinary incontinence with detrusor sphincter dysynergia (DESD). At six months, a significant decrease in neurogenic overactivity on filling cystometry was observed. Also, L5 stimulation precipated detrusor contractions in both patients (range 5–52 cm H20). At last follow-up (15 months) L5 stimulation caused a detrusor contraction of 59 cm H20, a Q max of 8 cc/sec and no DESD. Voided volume was 150 cc and post-void residual was 200 cc's. Also, at 15 months, the patients have no need for anticholinergics or catheterizations. Bowel function questionnaire revealed significant improvement in one patient and no significant change in the other. The only complication related to this procedure was mild headache for three days postoperatively in one patient [26].

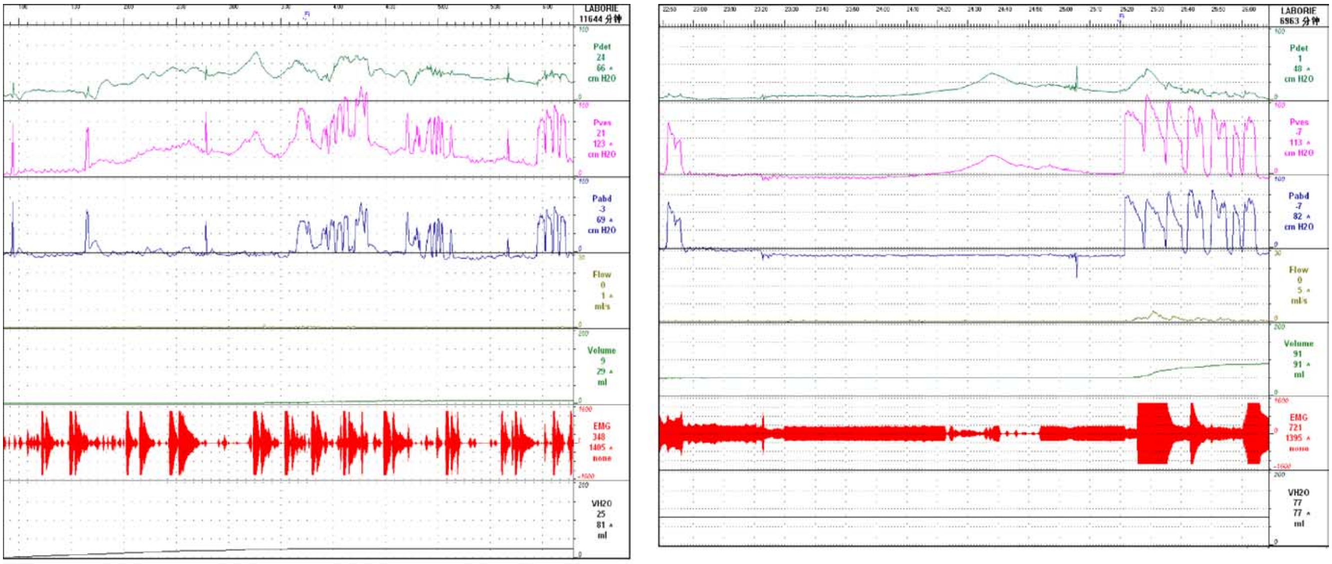
Encouraged by the ability to surgically establish a skin-CNS-bladder reflex pathway in spinal cord injury patients with restoration of bladder storage and emptying, we started trial of this procedure on 20 spina bifida children with neurogenic bladder in 2000 [27]. The neurological principals underlying the procedure were the same as for the SCI patients, though the specific details were different due to the neural abnormalities associated with spina bifida. All of the children underwent limited laminectomy and a lumbar ventral root (VR) to S3 VR micro-anastomosis. The L5 dorsal root (DR) was left intact as the afferent branch of the somatic-autonomic reflex pathway after axonal regeneration. All patients underwent urodynamic evaluation before and after surgery. Preoperative urodynamic studies revealed 2 types of bladder dysfunction: areflexic bladder ($n = 14$) or hyperreflexic bladder with DESD ($n = 6$). All children were incontinent. Seventeen of the 20 patients gained satisfactory bladder control and continence within 8–12 months after VR microanastomosis. Twelve (71.4%) of the 14 patients with areflexic bladder showed improvement. In these cases, the bladder capacity increased from 117.28 to 208.71 ml, and the mean maximal detrusor pressure increased from 18.35 to 32.57cmH20 [Fig. 3A, B]. Five of the 6 patients with hyperreflexic bladder showed improvement with resolution of incontinence. Urodynamic studies in these cases revealed a change from detrusor hyperreflexia with DESD and high detrusor pressure to nearly normal storage and synergic voiding. In these cases, mean bladder capacity increased from 94.33 to 177.83 ml, post void residual urine decreased from 70.17 to 23.67 ml [Fig. 4A, B]. Overall, three cases failed to exhibit any improvement. Like the cases in SCI patients, the children who gained bladder control also gained bowel control. Five patients had signs of partial loss of the left L4 or L5 motor function after surgery, variable from slight muscular weakness to visible foot drop in 2 children. Otherwise, there were no short or long term complications or adverse events. The most fascinating and unexpected result of this trial, however, was that the children who gained bladder storage and emptying functions also gained bladder sensory function. Pre-existing sensory infrastructure may have been activated by stretch as the detrusor tone and bladder storage function improved. Since spinal cord continuity was not interrupted as in SCI, the central nervous system at both spinal and supra-spinal levels may have plasticity to accommodate the artificial somatic-autonomic reflex pathway for micturition. Obviously, the artificial somatic-autonomic reflex arc procedure is an effective and safe treatment for spina bifida patients to restore bladder continence and reverse the bladder dysfunction [27].

Up to date, we have performed the procedure for bladder and bowel control safely on 110 children with spina bifida [25]. The rate of success at the one year follow-up is 87%, compared to the 85% for the first 20 cases reported. Occurrence rate of partial loss of the left L4 or L5 motor function after surgery, the only complication for 25% of the first 20 cases, has



(A) Before the surgery (B) One year after surgery

Fig. 3 – Female, 14 years old. Areflexia neurogenic bladder. A: Pre-operative urodynamic study showed Areflexia detrusor and nonfunctional urethral sphincter. Leaking occurred when infused volume was 60 ml. B: Urodynamic study one year after surgery showed that detrusor became contractile and bladder capacity increased to 294 ml with no leaking. Voluntary voiding and bladder emptying was satisfactory with detrusor contraction and moderate straining. (From Xiao CG et al., J Urol 2005, with permission); Abbreviations: Pdet, detrusor pressure; Pves, total bladder pressure; Pabd, intra-abdominal pressure; Flow, uroflowmetry; Volume, voiding volume; EMG, electromyogram of external urethral sphincter; VH2O, infusion volume.



(A) **Before the surgery** (B) **One year after surgery**

Fig. 4 – Male, 10 years old. Spina bifida cystica with hyperreflexic neurogenic bladder. A: Pre-operative urodynamic study showed small bladder capacity and hyperreflexic detrusor with DESD. Child could not void and depended on catheterization. B: Urodynamic study one year after surgery showed that compliance improved and bladder capacity increased. Detrusor hyperreflxia and DESD disappeared. Detrusor contraction and satisfactory voiding was initiated voluntarily by slight straining. (From Xiao CG et al., J Urol 2005, with permission).

been dramatically reduced to 5% with only slighter and recoverable muscular weakness by using only half of the lumbar ventral root [25].

In summary, bladder reinnervation has been a frequently ignored area of research intending to improve bladder function after spinal cord injuries. Limited animal and clinical investigations showed that cross nerve surgery could play a role in restoring bladder control after SCI. The artificial somatic-autonomic reflex pathway procedure can restore bladder continence and reverse the bladder function for patients with SCI or spina bifida effectively and safely.

Acknowledgments

Supported by grants from: The National Key Basic Research Program of China (2003CB515300); The Ministry of Public Health of China (Major Clinical Trial Grant); Natural Science Foundation of China (NSFC 39925033); and NIH (R01 DK44877 and R01 DK53063).

References

[1] Woolsey RM, Young RR. The clinical diagnosis of disorders of the spinal cord. Neurol Clin 1991;9:573–83.

[2] Wheeler Jr. JS, Walter JW. Acute urologic management of the patient with spinal cord injury. In: Bodner DR, editor. The Urologic clinics of North America: Spinal cord injury. 1993;20:403–11.

[3] Selzman AA, Elder JS, Mapstone TB. Urologic consequences of myelodysplasia and other congenital abnormalities of the spinal cord. Urol Clin North Am 1993;20:485–504, Review.

[4] Stone AR. Neurourologic evaluation and urologic management of spinal dysraphism. Neurosurg Clin N Am 1995;6:269–77, Review.

[5] Jonas U, Heine JP, Tanagho EA. Studies on the feasibility of urinary bladder evacuation by direct spinal cord stimulation I. Parameters of most effective stimulation. Invest Urol 1975;13:142–50.

[6] Hald T, Agrawal G, Kantrowitz A. Studies in stimulation of the bladder and its motor nerves. Surgery 1966;60:848–56.

[7] Brindley GS, Polkey CE, Rushton DN, Cardozo L. Sacral anterior root stimulator for bladder control in paraplegia: the first 50 cases. J Neurol Neurosurgery Psychiatry 1986;49:1004–14.

[8] Tanagho EA, Schmidt RA, Orvis BR. Neural stimulation for control of voiding dysfunction: a preliminary report in 22 patients with serious neuropathic voiding disorders. J Urol 1989;142:340–5.

[9] Bodner DR. How electrical stimulation improves micturition. Contemporary Urol 1990;3:39–45.

[10] Mokhort VA, Makarov VN. Omentovesicopexy with transposition of the bladder into the abdominal cavity in the treatment of neurogenic bladder. Urol Nefrol (Mosk) 1990;4:20–4, Russian.

[11] Hohenfellner M, Gleason CA, Nunes L, Goldsmith PC, Malcamp CA, Schmidt RA, et al. Reinnervation of the rat bladder with a somatic nerve and a striated muscle flap. J Urol 1995;154:2164–9.
[12] Pascual JI, Gudino-Cabrera G, Insausti R, Nieto-Sampedro M. Spinal implants of olfactory ensheathing cells promote axon regeneration and bladder activity after bilateral lumbosacral dorsal rhizotomy in the adult rat. J Urol 2002;167:1522–6.
[13] Stenzl A, Ninkovic M, Kolle D, Knapp R, Anderl H, Bartsch G. Restoration of voluntary emptying of the bladder by transplantation of innervated free skeletal muscle. Lancet 1998;351:1483–5.
[14] Ninkovic M, Stenzl A, Schwabegger A, Bartsch G, Prosser R, Ninkovic M. Free neurovascular transfer of latisstmus dorsi muscle for the treatment of bladder acontractility: II. Clinical results. J Urol 2003;169:1379–83.
[15] Kilvington B. An investigation on the regeneration of nerves with regard to surgical treatment of certain paralysis. Br Med J 1907;1:988.
[16] Trumble HC. Experimental reinnervation of the paralyzed bladder. Med J Aust 1935;1:118.
[17] Vorstman B, Schlossberg S, Kass L. Investigations on urinary bladder reinnervation. Historical perspective and review. Urology 1987;30:89–96.
[18] Chuang DC, Chang PL, Cheng SY. Root reconstruction for bladder reinnervation: an experimental study in rats. Microsurgery 1991;12:237–45.
[19] Carlsson CA, Sundin T. Reconstruction of afferent and efferent nervous pathways to the urinary bladder in two paraplegic patients. Spine 1980;5:37–41.
[20] 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: 211–7.
[21] Xiao CG, Schlossberg SM, Morgan CW, Kodama R. A possible new reflex pathway for micturition after spinal cord injury. J Urol 1990;143:356A.
[22] Xiao CG, Godec CJ. A possible new reflex pathway for micturition after spinal cord injury. Paraplegia 1994; 32:300–7.
[23] 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; 162:936–42.
[24] Xiao CG, Du MX, Dai C, Li B, Nitti VW, de Groat WC. An artificial somatic-central nervous system-autonomic reflex pathway for controllable micturition after spinal cord injury: preliminary results in 15 patients. J Urol 2003;170:1237–41.
[25] Xiao CG. A somatic-autonomic reflex pathway procedure for neurogenic bladder and bowel: results on 92 patients with SCI and 110 children with spina bifida. . In: Proceedings of the International Conference of Urology; Shanghai, July 2–4, Shanghai, China; 2005.
[26] Kelley C, et al. Creation of a somatic-autonomic reflex pathway for treatment of neurogenic bladder in patients with spinal cord injury: preliminary results of the first 2 USA Patients. J Urol 2005;173:1132A.
[27] Xiao CG, et al. An artificial somatic-autonomic reflex pathway procedure for bladder control in children with spina bifida. J Urol 2005;173:2112–6.

Editorial Comment

Karl-Dietrich Sievert, *Tuebingen, Germany*
karl.sievert@med.uni-tuebingen.de

Restored Bladder function by an Intradural Nerve Anastomosis

The presented review of the developed surgical approach for an artificial somatic-autonomic reflex pathway gives a great overview of Xiaos exquisite performance that encompasses basic research to clinical practice. A single anastomosis between the ventral efferent (motor) roots of L5 and S3 seems to restore the ‘‘bladder function’’ up to a certain degree. This seems to be possible up to now with a nerve stimulator with the additional deafferentation [1].

To reestablish the function of the lower urinary tract, specifically storage and the voiding, only presented data can be used to make certain assumptions what this technique causes in regard to normal functioning of the lower urinary tract [2].

The storage and the micturition are controlled through the central nervous system (CNS), the pontine micturition center as the ‘‘switch’’ and the controller to decide for voiding or storage, via the Onuf’s nucleolus [2–4]. With spinal cord injury (SCI), this control function becomes unavailable. Regarding to the level of injury a neurogenic bladder results with an overactive detrusor and urethral sphincter muscle, which are not any longer controlled, because the controller is placed above the SCI [5,6].

With the presented efferent root anastomoses the reflex arc is probably influenced in a different way. Signaling from the urothelium of the bladder and the detrusor concerning filling is no longer the only forwarded information to the detrusor and the sphincter muscle (the kept contralateral intact arc of S3). It can be assumed that after the regeneration and re-innervation of the end organs (lower urinary tract and the rectum with the anus) a stimulus from the skin of the particular dermatome, in this case of L5, is forwarded to the organs and influence their function. With the increased activation of the sensory nerves (strong stimulus, which might be pinching the skin or even electrical impulse) the efferent motor neuron of the former S3 is predominantly activated. By this stimulus the voiding reflex could be imitated with the result of urine flow (increased flow max from 2.4 to 14.8 ml/sec) with a reduced sphincter pressure.

In addition to SCI patients, spina bifida patients can also be treated using this simple surgical approach. The presented intraspinal nerve root anastomosis creates a skin-spine-pelvis-organ reflex. Stimulation of the skin initiates an increase of the bladder pressure and reduces the sphincter pressure with the result of voiding and even further effects to the lower urinary tract, which should to be investigated in the future. For myelomeningocele patients, it must be proven that the pathology of the end organ itself is effectively reversible [7].

Currently, the reports come from one center. In order to confirm the reported success rate, other specialized centers should be capable of performing this surgery. Close follow-up of this procedure is required. In the future it might be even possible to be more selective intraoperatively in respect of the root fibers to preserve available function. With additional higher selectivity of the dorsal root it might open even possible to improve even those lower urinary tract and bowel malfunction with a minimized muscle function loss of the ipsilateral lower leg (L5). Postulating the effect of the reported anastomosis outcome it might be even possible to influence the function of the end organ even more effective by a end to side anastomosis in patients without SCI or incomplete SCI without the need to transect the complete dorsal root of S3, even a bilateral anastomosis or over several levels by preserving leg muscle or other functions.

References

[1] Seif C, Junemann KP, Braun PM. Deafferentation of the urinary bladder and implantation of a sacral anterior root stimulator (SARS) for treatment of the neurogenic bladder in paraplegic patients. Biomed Tech (Berl) 2004 Apr; 49(4):88–92.

[2] de Groat WC, Booth AM, Yoshimura N. Neurophysiolgy of micturation and it's modification in animal models of human diseases. In: Maggi CA., editor. The autonomic nerve system, Vol. 3, Chapter 8, Nervous controle of the urogenital system. London: Harwood Acadamic Publishers, UK; 1993. p. 227.

[3] Wein AJ. Neuromuscular dysfunction of the lower urinary tract. In: Wash PC, Retik AB, Vaughan ED., et al. editors. Campbell's Urology, 8th edition, chapter 26. Philadelphia: Saunders Publishers; 2002. p. 831.

[4] Chancellor MB, Yoshimura N. Physiology and pharmacology of the bladder and the urethra. In: Wash PC, Retik AB, Vaughan ED., et al. editors. Campbell's Urology, 8th edition, chapter 23. Philadelphia: Saunders Publishers; 2002. p. 931.

[5] Corcos J, Schick E. The urethral sphincter. New York: Marcel Dekker; 2001, p. 1–872.

[6] Morrision J, Brinder L, Creggs M, et al. Neural Control. In: Abrams P, Cardozo L, Khoury S, Wein A, editors. Continence Basic and Evaluation, 3rd International Consultation on Incontinence. Health Publication Ltd; 2005.

[7] Shapiro E, Seller MJ, Lepor H, Kalousek DK, Hutchins GM, Perlman EJ, et al. Altered smooth muscle development and innervation in the lower genitourinary and gastrointestinal tract of the male human fetus with myelomeningocele. J Urol 1998 Sep;160(3Pt2):1047.