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ORIGINAL ARTICLE

Recovery of Sensory and Supraspinal Control of Leg Movement in People With Chronic Paraplegia: A Case Series

Marc Possover, MD, PhD

From the Department of Gynecology & Neuropelveology, Hirslanden Clinic, Zurich, Switzerland.

Abstract

Objective: To report on unexpected findings in 4 patients with chronic paraplegia who underwent the laparoscopic implantation of neuroprosthesis procedure in the pelvic lumbosacral nerves.

Design: Observational case series.

Setting: Tertiary referral unit specialized in advanced gynecological surgery and neuropelveology.

Participants: Three patients with incomplete American Spinal Injury Association (ASIA) Impairment Scale (AIS) grade B (n=2) and AIS grade C (n=1) spinal cord injury (SCI) and 1 patient with flaccid complete chronic SCI (AIS grade A) (n=1).

Intervention: Functional electrical stimulation (FES)-assisted locomotor training and continuous low-frequency pelvic-lumbosacral neuromodulation.

Main Outcome Measures: Change in ASIA Lower Extremity Motor Scores, ASIA sensory scores for light touch and pinprick sensation, and Walking Index for Spinal Cord Injury scores.

Results: All 4 patients developed progressive recovery of some sensory and voluntary motor functions below the lesions. Three are currently capable of voluntary weight-bearing standing and walking a few meters with a walker without FES. The first patient with the longest follow-up is even capable of electrically assisted standing/walking with 2 crutches without braces or assistance for a distance of about 900 meters, and of weight-bearing standing and walking for 30 meters with a walker without stimulation.

Conclusions: We report unexpected sensory and locomotor recovery in 4 people with paraplegia with SCI. Our findings suggest that FES-assisted locomotor training with continuous low-frequency pelvic nerve stimulation in patients with SCI may induce changes that affect the central pattern generator and allow supra- and infraspinal inputs to engage residual spinal pathways.

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Spinal cord injury (SCI) dramatically changes the life of the affected person. The loss of skeletal muscle control and the loss of sensation below the level of the injury, together with serious disturbances of autonomic nervous system functions, produce a profound loss of quality of life and autonomy. In view of trends in the epidemiology of an SCI, it is becoming increasingly important to develop treatment strategies that can enhance the recovery of motor functions, particularly walking, after an SCI. In providing treatment to enhance the recovery of walking, rehabilitation specialists must consider factors that may affect walking recovery. Multiple attempts have been made to improve walking ability in patients with SCI. Modalities range from changes in internal constraints using pharmacological or surgical modalities[1] to modalities modifying constraints, such as ambulatory assistive devices[2] or mechanical orthoses. Another approach is the use of active orthoses for functional electrical stimulation (FES)-assisted walking.

There is a long history of the therapeutic use of FES. More than 30 years ago, the procedure was developed as an orthotic system for patients with SCI.[3] The goal of FES is to induce immediate contraction of the skeletal muscles to achieve functional movement. Even though FES-assisted walking has been available for more than 3 decades, it has not been widely used in rehabilitation because the stimulators were bulky, unreliable, prone to breakage, and expensive. Here, we report on an unexpected

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Table 1 Characteristics of patients and evolutions of ASIA motor and sensory scores

Patient No.	Age	Sex	Age at Injury (y)	SCI Level	Follow-Up PostOP (mo)	LEMS PreOP	LEMS PostOP	ASS PreOp	ASS PostOP
1	34	M	30	T7/8	17	**9**	30	67	84
2	26	M	17	T10/L1	10	**0**	18	76	89
3	42	F	30	T4/7	6	**0**	11	66	76
4	37	M	23	T12	9	**0**	1	76	86

Abbreviations: ASS PostOP, ASIA sensory score for both light touch and pinprick sensation at the time of submission of the manuscript; ASS PreOP, ASIA sensory score for both light touch and pinprick sensation direct before the LION procedure; F, female; LEMS PostOP, ASIA Lower Extremity Motor Score at the time of submission of the manuscript; LEMS PreOP, ASIA Lower Extremity Motor Score direct before the LION procedure; LION, Laparoscopic Implantation Of Neuroprosthesis; M, male.

clinical improvement in 4 patients with chronic SCI—and to the best of our knowledge, this is the first report in the literature on such an observation—in whom FES training had obviously led to recovery and voluntary movements without FES.

Methods

Four patients with chronic SCI were included in this study. All 4 patients were presented to our department as candidates for participation in a clinical study focusing on laparoscopic implantation of neuroprostheses on the pelvic/sacral/pudendal nerves for control of bladder dysfunction. The Ethics Committee of the University of Zurich approved this study. The 4 patients explicitly asked for the implantation of neuroprostheses not only on the sciatic and pudendal nerves but also on the femoral nerves for FES-controlled locomotor training. All 4 patients signed informed consent forms before the procedures. They were highly motivated and asking for any kind of procedure that might improve their autonomy and quality of life. Clinical characteristics of patients described in this case series are summarized in table 1.

The first was a 34-year-old man with an incomplete T7/8 SCI (American Spinal Injury Association Impairment Scale [AIS] grade C) incurred in a fall in 2007. He presented with some sensory preservation in lumbar dermatomes on the right side, but complete loss of sensory functions in all lumbosacral dermatomes on the left, and no clinical motor activity in the left lower extremity. Because some active extension of the right leg against gravity and resistance was possible, he was capable of assisted standing and walking with a walker and brace for about 20 meters. The second patient was a 26-year-old man who was hit by a motor vehicle in 2002. Neurological examination revealed AIS grade B status with clinically complete motor paraplegia below T10, incomplete loss of sensory functions below T10, and complete sensory loss below L4. Previous leg nerve conduction studies revealed some deterioration of the left femoral nerve. Despite standard-of-care rehabilitation, he was unable to stand and/or participate in assisted walking. The third patient, a 42-year-old man (AIS grade B), was hit by a motor vehicle in 1999. Neurological examination revealed AIS grade B status with clinically complete motor paraplegia below T7 and some impaired sensory functions in lumbar dermatomes L1-3. Despite standard-of-care rehabilitation, he was also unable to stand and/or participate in assisted walking. The last patient of the series, a 37-year-old man, was also hit by a motor vehicle in 1998. Neurologic examination revealed that he had AIS grade A status with clinically complete, flaccid motor, and sensory paraplegia below T12.

All 4 patients underwent the laparoscopic implantation of neuroprosthesis procedure on the sciatic, pudendal, and femoral nerves. This procedure consists of the laparoscopic implantation of fine wire electrodes (for simulation of the spinal cord or sacral nerve roots) in direct contact with the endopelvic portion of the nerves for electrical stimulation, or "neuromodulation." An epidural spinal cord stimulation unit[a] and four 4-array fine wire electrodes were implanted on the sciatic, pudendal, and femoral nerves, as described previously.[4] The procedures were performed under general anesthesia. Laparoscopic exposure of the endopelvic portion of both the sciatic and pudendal nerves was obtained by passing lateral to the external iliac vessels, through the lumbosacral space, and by gently detaching the interiliac lymph and fatty tissue from the pelvic side wall to prevent lymphocele formation.[5] The use of multichannel electrodes enabled stimulation of both the nerves with only 1 lead electrode. Exposure of the femoral nerves was achieved from a transperitoneal approach from behind the psoas major muscle. Before implantation, electrical stimulability of the nerves was tested by direct intraoperative laparoscopic electrical stimulation. Four lead electrodes were implanted and secured by suturing them to perineural tissues; they were passed though the pelvic wall and finally connected to a pulse generator implanted subcutaneously into the anterior abdominal wall.

List of abbreviations:

AIS **American Spinal Injury Association Impairment Scale**
FES **functional electrical stimulation**
SCI **spinal cord injury**

Results

The mean duration of the procedures was 181 minutes. No pre- or postoperative complications occurred. Patients were discharged after recovery of bowel motion between the second and third postoperative day.

Continuous bilateral sciatic and femoral nerve stimulation was started on the first postoperative day with a current at a frequency of 10Hz and a pulse width at 60μs. The intensity of stimulation was modified from 0.1 to 3V to determine the lowest level needed for the first minimal visible skeletal muscle contraction and was then maintained at that level. This low-frequency/low-voltage stimulation was used primarily for muscle training and also as additional possible benefits of the procedures for the control of spasticity of the lower extremities and induction of peripheral vasodilatation for decubitus prophylaxis.

In parallel, 3 further programs were installed to train the quadriceps muscles: one for each leg separately and one for both legs together. Stimulation parameters were fixed at a pulse width of 60μs, a frequency of 300Hz, and variable intensities to ensure harmonious and stabile extension of the knees. After the patient became familiar with the use of the electric stimulation unit, training was started with concomitant sciatic (gluteal muscle