Journal of Neurorestoratology

Volume 7 | Number 3 Article 2

2019

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Recommended Citation

Wenbin Ding, Shaocheng Zhang, Dajiang Wu et al. Hand function recovery using nerve segment insert grafting in patients with chronic incomplete lower cervical spinal cord injury: a preliminary clinical report. Journal of Neurorestoratology 2019, 7(3): 129-135.

Journal of Neurorestoratology 2019, 7(3): 129–135
DOI 10.26599/JNR.2019.9040013 ISSN 2324-2426
RESEARCH ARTICLE

Hand function recovery using nerve segment insert grafting in patients with chronic incomplete lower cervical spinal cord injury: a preliminary clinical report

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ARTICLE INFO

Received: 19 March 2019
Revised: 2 June 2019
Accepted: 10 July 2019

KEYWORDS

chronic lower cervical spinal cord injury;
functional recovery;
nerve segment insert grafting

ABSTRACT

Objective: The objective of this study was to show that hand functions could be recovered using nerve segment insert grafting in quadriplegic patients with chronic incomplete lower cervical spinal cord injury (CSCI) (C5/6/7/8).

Methods: A retrospective analysis was performed in 18 quadriplegic patients (12 male and 6 female patients; mean age, 27 years; age range, 17–55 years) with chronic incomplete lower CSCI who had undergone nerve segment insert grafting from January 2001 to June 2015. Among the 18 patients, the right upper limb was involved in 7, left upper limb in 4, and bilateral upper limbs in 7 patients.

Results: The mean follow-up period was 16 months (range, 3 months–3 years), and all patients exhibited obvious relief of limb spasm. Among all patients, 15 patients experienced no obvious spasm attacks and exhibited recovery of living abilities, i.e., recovery of the hand functions of grasping, holding, and pinching, and recovery of pain and temperature sensation in the fingers and palms; furthermore, they were able to steer an ordinary wheelchair independently postoperatively. The remaining three patients exhibited a significant and continuous improvement in hand functions over time, without any significant donor nerve dysfunction.

Conclusions: Nerve segment insert grafting is an effective method that helps recover hand functions in quadriplegic patients with chronic incomplete lower CSCI. Moreover, spasticity can be relieved and partial normal innervation can be obtained in the spastic muscles postoperatively.

1 Introduction

Most quadriplegic patients with cervical spinal cord injury (CSCI) are young adults; three-quarters of these young quadriplegic patients desire recovery of hand and upper limb functions, with most patients expecting a significant improvement in their quality of life after functional recovery [1, 2]. With improvements in the management of emergencies and the quality of subsequent long-term nursing for road traffic and sports injuries, increasing attention is being

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paid to the rehabilitation of quadriplegic patients. In 1999, Zhang et al. [3–7] performed peripheral nerve grafting to treat spasmodic paralysis of the limbs following central nervous system injury and obtained good results including relief of spasticity and partial recovery of nerve functions.

The objective of this study was to show that hand functions could be recovered using nerve segment insert grafting in quadriplegic patients with chronic incomplete lower CSCI (C5/6/7/8).

2 Patients and methods

2.1 Patients

The study included 18 quadriplegic patients (12 male and 6 female patients; mean age, 27 years; age range, 17–55 years) with chronic incomplete lower CSCI who had undergone nerve segment insert grafting from January 2001 to June 2015. Among the 18 patients, the right upper limb was involved in 7, left upper limb in 4, and bilateral upper limbs in 7 patients. Furthermore, 4 patients had injury at C5, 3 at C6, 5 at C7, and 6 at C8. The SCI levels of the patients according to the American Spinal Injury Association Impairment Scale (AIS) classification were recorded (Table 1); the levels were as follows: AIS-B in 6 patients, AIS-C in 9 patients, and AIS-D in 3 patients. The mean time from CSCI to nerve segment insert grafting was 13 months (range, 6 months–5 years).

Table 1 Demographic and clinical features of study patients.

Age (years ± SD)	27 ± 10.2
Sex, *n* (%)	
Male	12 (66.7)
Female	6 (33.3)
AIS classification, *n* (%)	
AIS-A	0
AIS-B	6 (33.3)
AIS-C	9 (50.0)
AIS-D	3 (16.7)
AIS-E	0
Injury level, *n* (%)	
C5	4 (22.2)
C6	3 (16.7)
C7	5 (27.8)
C8	6 (33.3)

AIS, American Spinal Injury Association Impairment Scale.

2.2 Technique

2.2.1 *Inclusion and exclusion criteria*

The inclusion criteria were as follows: patients in whom injury had occurred ≥ 6 months ago; patients in whom surgical decompression and internal fixation had been performed, with nuclear magnetic resonance and electromyography evidence; patients in whom clinical examination showed the presence of shoulder and elbow joint functions, with the key muscle strength > grade 3, but without hand functions of grasping, gripping, and pinching; and patients and their families showing willingness to undergo surgery in case of patients aged < 55 years.

All other forms of quadriplegic patients were excluded.

2.2.2 *Preoperative preparation*

Repeated and detailed preoperative examinations were performed to determine the nerve branches around the cervical plexus; the accessory nerve peripheral branches and the upper as well as middle trunks of the brachial plexus, which could be displaced during the procedure; and the nerves to be grafted.

2.2.3 *Operative methods*

This study was approved by the relevant research ethics committee of the Shanghai Changhai Hospital and was conducted in accordance with the Declaration of Helsinki. All patients provided written informed consent for the study.

Supraclavicular and axillary incisions can be used for grafting the upper trunk with the middle and low trunks (Fig. 1) and for grafting the lateralis bundle with the fasciculus posterior and fasciculus medialis, respectively. As the

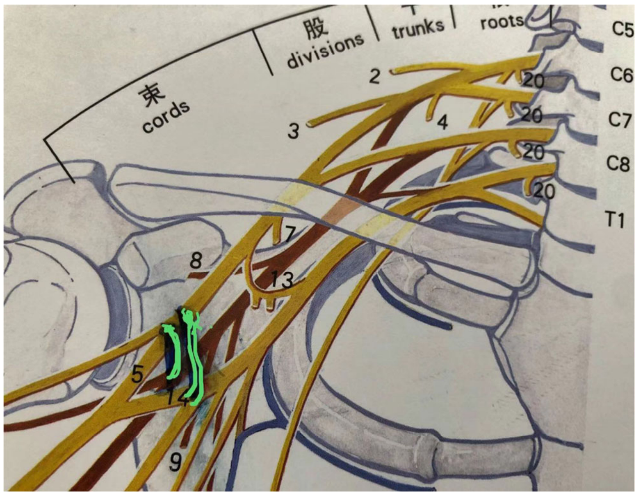

Fig. 1 Illustration of nerve transfer: a part of the posterior bundle/radial nerve or medial bundle/ulnar nerve from the original site is grafted at the original site of the lateral bundle/musculocutaneous nerve.

axillary incision provides the advantages of minimal trauma and simultaneous release of the pectoralis major and shoulder joint, it has been preferred in recent years, particularly for patients who have undergone anterior cervical decompression and internal fixation. The surgical procedure is as follows. First, the donor nerve is selected. Normal or near-normal adjacent peripheral nerve roots, trunks (the target organ's function can reach M4, Medical Research Council scale, or S4, British Medical Research Council scale), and nerve fiber reserve can be selected; the general perimeter should be > 3 mm. Second, the receptor nerve is determined; one, two, or even three nerve roots innervating the major spastic paralytic muscle group can be considered. Third, nerve segments for bridging are selected and prepared. The upper arm medial cutaneous nerve (Fig. 2), forearm medial cutaneous nerve, or cervical plexus cutaneous branch can be considered. For example, for patients with the spastic paralysis of forearm, wrist, and hand, the C5, C6, or upper trunk can be selected as the donor and C7, C8, or lower trunk can be selected as the acceptor, respectively. The donor can be

Fig. 2 The medial cutaneous nerve of the arm.

cut into multiple nerve segments in accordance with the required length of the graft for 30%~50% bridging, with the proximal and distal ends having a 30°~45° bevel (Fig. 3 and 4). Fourth, donor and receptor incisions are planned. This is a key step; therefore, it is important for the surgeon to be familiar with the microscopic anatomy of the nerve trunk and achieve accurate

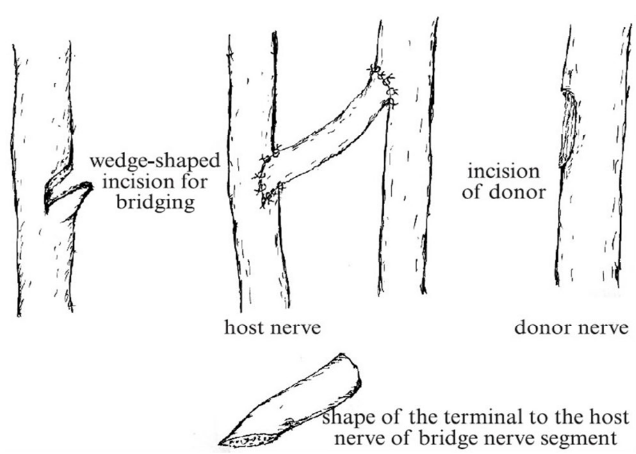

Fig. 3 Nerve grafting.

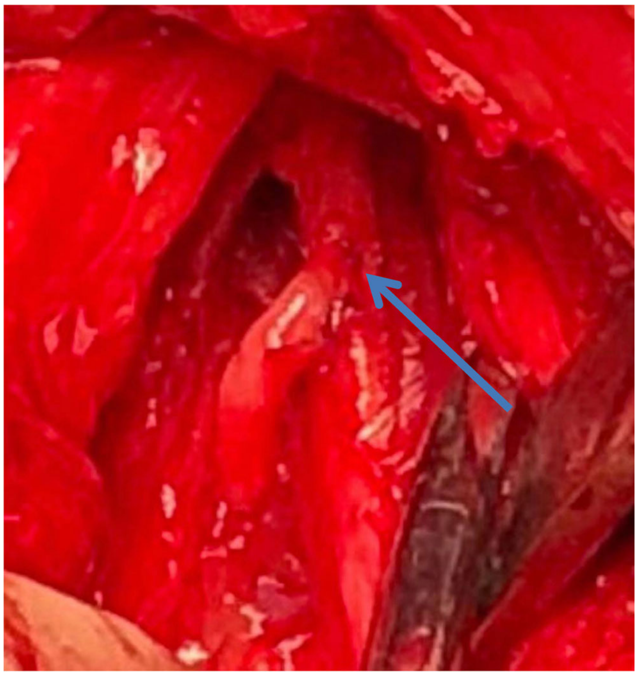

Fig. 4 Grafted nerve segment.

positioning using an electric stimulator. Depending on the severity of the receptor's neural spasm, 15%~30% or even 40% (in severe conditions) of the volume of the nerve fiber innervating the target muscle group can be removed. Regarding the donor nerve, 10%~15% or even 20% (in certain cases) of the total nerve fiber volume can be removed. Fifth, appropriate bridging is performed. The distal tip of the nerve segment is inserted into the recipient nerve incision; the distal nerve fiber cross-section is matched and joined obliquely with the cross-section of the trimmed and open cut end of the receptor nerve fiber, and nerve bundle and epineurium suturing is performed using 9-0 or 10-0 nylon non-destructive microsurgical instruments. The proximal end of the donor nerve segment is placed opposite to the recipient nerve in the matching direction, i.e., the bevel of the cut end of the donor nerve segment faces the proximal end of the cut section of the receptor nerve fiber; furthermore, the tip portion is aligned with the lateral side of the nerve fiber denuded in the incision, with the suture method being the same as that mentioned above.

2.2.4 *Postoperative management*

Postoperatively, the involved limb was immobilized in a plaster or frame for 3 weeks.

2.2.5 *Main observation indicators*

The main observation indicators included the degree of spasm in the affected limb and the recovery of functions of the affected limb.

3 Results

The mean follow-up period was 16 months (range, 3 months–3 years), and all patients exhibited obvious relief of limb spasm. Additionally, partial sensation and motor function recovery in the regions innervated by the anastomosed nerves were observed among all patients within 18 months–2 years postoperatively. Muscle strength recovered to grade 3~4 in 15 of the 18 patients, with sensation (pain and temperature) improving to grade S3. Living abilities improved in 15 patients, and these patients exhibited recovery of hand functions of grasping, holding, and pinching as well as recovery of pain and temperature sensation in the fingers and palms postoperatively. Additionally, these 15 patients could steer an ordinary wheelchair independently postoperatively. The remaining three patients exhibited a significant and continuous improvement in hand functions over time, without any significant donor nerve dysfunction. In these patients, muscle tone was preserved because only part of the nerve bundle was cut off to use for the grafting. Although all of the patients' postoperative muscle strength was < grade 3, effective motor functions (such as elbow flexion) could be performed when active contraction synchronized with spasticity. Hand and upper limb functions can be further improved with tendon transposition and nerve side anastomosis after nerve grafting.

4 Discussion

Chronic incomplete lower CSCI is often responsible for spastic paralysis of the limbs. Muscle spasticity, a type of resistance to passive limb movement, is caused by decreased inhibition of the ascending as well as descending pathways and nerve endings, thereby resulting in increased activation of the muscle stretch reflex [8]. Muscle spasticity is characterized by involuntary muscle contraction reactions and velocity-dependent stretch hyperreflexia, and it is one of the clinical signs of upper motor neuron injury. Clinically, patients present with increased muscle tension, active or even hyperactive deep tendon reflexes, and relatively mild muscle atrophy.

Regarding surgical approach described above, a part of the nerve innervating the spastic muscle (the receptor nerve) was selectively removed as muscle spasm can be alleviated when a part of the receptor nerve is cut off. Moreover, cutting even half of the functional reserve of the peripheral nerves does not markedly influence the original function. We grafted the receptor nerve via transplanting an autogenous segment of the adjacent normal nerve associated with the normal cerebral cortex, thereby providing the receptor nerve with a normal nerve fiber and possibly altering cerebral cortex localization. Furthermore, the highly selective severance of nerve fibers partially blocks gamma loop afferent fibers and establishes new nerve pathways through the nerve graft. Thus, the conduction imbalance in the original gamma loop is corrected and connections are made with higher central conducting pathways, thereby partially providing effective normal nerve fibers associated with normal brain regions [7, 9]. Therefore, a new conduction balance is established, which lowers muscle tension and alleviates muscle spasm symptoms in patients.

Our findings are merely a preliminary clinical observation on the application of nerve segment insert grafting for the recovery of hand functions in quadriplegic patients with chronic incomplete lower CSCI. Considering the insufficient number of appropriate facilities and the difficulty faced by the patients in revisiting the hospital, as all enrolled patients lived outside the city, detailed examinations and investigations in strict accordance with international standards could not be performed. Additionally, two-thirds of the follow-ups were performed via telephone calls and video chat, with the patients having poor comprehension of professional terminology and knowledge. Thus, only the following could be assessed: whether their functions of grasping and pinching were restored and whether they could wear a top; lift trousers; grasp a spoon; put food in the mouth; lift a small water bottle; use a cup to drink water; and grasp bread, steamed bread, and other food items to eat. Further improvements in the procedure are essential and urgent to achieve better results. The procedure presented in this study involves only peripheral nerve grafting and cannot be used for treating SCI; furthermore, the purpose of grafting was partial recovery of the peripheral nerve functions associated with motor innervation of the hand. Thus, this procedure can only improve hand functions in certain patients and does not provide any improvement in defecation or lower limb functions.

We believe that this work may provide an effective method that helps recover hand functions in quadriplegic patients with chronic incomplete lower CSCI.

Acknowledgement

This study was supported by the Shanghai Science and Technology Project (No. 10411953800).

Conflict of interests

The authors have no conflicts of interest to declare.

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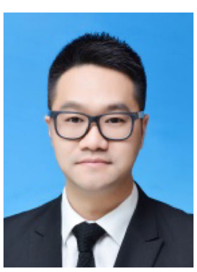

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