Two Cases of Traumatic Brachial Plexus Injury With Complete Spinal Cord Injury

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Abstract

Background: Traumatic brachial plexus injury (BPI) in patients with complete spinal cord injury (SCI) such as paraplegia or tetraplegia is a very rare and debilitating combined injury that can occur in high-energy traumas. Management of a BPI should be aimed at regaining strength for self-transfers and activities of daily living to restore independence. However, brachial plexus reconstruction (BPR) in this unique patient population requires considerable planning due to the combined elements of upper and lower motor neuron injuries. **Methods:** We present 2 cases of traumatic complete SCI with concomitant BPI with mean follow-up of 42 months after BPR. The first patient had a left C5–7 BPI with a T2 complete SCI. The second patient sustained a left C5–8 BPI with complete SCI at C8. **Results:** The first patient underwent BPR including free functioning muscle, intra- and extraplexal nerve transfers, and tendon transfers resulting in active elbow flexion and active elbow, finger, and thumb extension, but no recovery of shoulder function. While the second patient underwent extraplexal nerve transfer to restore elbow flexion yet did not recover any function in the left upper extremity. **Conclusions:** Because extensive upper and lower motor neuron injuries are present in these combined injuries, treatment strategies are limited. Expectations should be tempered in these patients as traditional methods to reconstruct the brachial plexus may result in less than ideal functional outcomes due to the associated upper motor neuron injury.

Keywords: brachial plexus reconstruction, brachial plexus injury, spinal cord injury, traumatic cord injury, complete spinal cord injury

Introduction

Usually the result of high-energy mechanisms of injury, complete spinal cord injuries (SCI) are very debilitating for patients and frequently result in paraplegia or tetraplegia, as well as many other associated syndromes, such as neurogenic bladder and neurogenic bowel.¹ In addition, the magnitude of energy and trauma that can result in an SCI often causes a number of other related injuries such as fractures to the extremities, pulmonary contusions, and brachial plexus injuries (BPIs).⁹ Traumatic BPI in paralyzed patients is rare, with a reported incidence of 0.6% to 0.7%.^{1,10} A concomitant BPI can restrict independent functionality even more, as some patients consider it a greater disability than the SCI, particularly in patients with paraplegia, because the upper extremity dysfunction leaves them dependent on others for activities of daily living (ADLs).¹⁰ Thus in the complete SCI patient, restoring the ability to accomplish ADLs is of the highest priority.⁵

Brachial plexus reconstruction (BPR) in patients without SCI is usually aimed at restoring elbow flexion and shoulder abduction, often utilizing intact intraplexal donor nerves in cases of nerve ruptures and relying upon extraplexal

nerves when root avulsions are present with the best results obtained the sooner the repair occurs after the injury.² However, because of the high-energy mechanisms required to sustain a combined SCI and BPI, there are often associated life-threatening injuries that must be addressed first, or the upper extremity deficits are erroneously attributed to the SCI which ultimately can result in delayed detection and treatment of the BPI.² These delays in diagnosis and treatment can affect functional outcome of treatment, as BPR delayed greater than 9 to 12 months can result in poor outcomes.² However, in patients with combined BPI and SCI, traditional methods of BPR may be inappropriate due to the superimposed upper motor neuron injuries that may render commonly utilized donor nerves inadequate for nerve transfer, nerve grafting, or free functioning muscle transfer.

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This case series reports on 2 BPI patients with a concomitant, complete SCI (American Spinal Injury Association [ASIA] Classification A) due to high-energy mechanisms (Table 1). At the time of BPR, one patient was a paraplegic and the other a tetraplegic.

Case Report 1

A 43-year-old man (patient 1) sustained a C5-7 BPI in the dominant left upper extremity with a concomitant complete SCI (T2 ASIA A) due to a motorcycle accident. His associated injuries consisted of a left vertebral artery dissection and fractures to the right coracoid process, left tibia/fibula, and the left C6 facet. He underwent C5-C6 discectomy with instrumented fusion and external fixation of the left tibia. Upon initial evaluation, he had no motor or sensory function below T2 with absent deltoid, shoulder rotator, elbow flexor, or any radial nerve innervated function in the left upper extremity. Based on the Medical Research Council scale for muscle strength, there was grade 5 strength in the trapezius, grade 4 or higher in the hand intrinsic muscles, and grade 3 or higher in the flexor/pronator mass (Table 1).

At 9 months from injury, he underwent BPR and tendon transfers to restore active shoulder abduction/external rotation, elbow flexion, elbow extension, wrist extension, finger extension, and thumb extension (Table 1). Notably, 2 procedures were performed to reconstruct elbow flexion: (1) ulnar nerve fascicle transfer to the biceps motor branch; and (2) gracilis free functioning muscle transfer with the spinal accessory nerve as a donor. Although the lower motor neurons to the gracilis muscle should be uninjured, there was concern that the upper motor neuron injury to the obturator nerve may result in poor outcomes after transfer to the upper limb. Therefore, the distal nerve transfer was performed to augment elbow flexion and also given the patient's time from injury to BPR, nerve regeneration would likely occur before irreversible degeneration of the motor end plates. At 25-month follow-up, he exhibited recovery of elbow flexion and elbow/fingers/thumb extension with no clinical recovery of shoulder function (Table 1). He had a "limb with very limited usefulness" based on the Sedel Classification for Usefulness of the Brachial Plexus Injured extremity (Table 2).¹⁷ However, electromyography/nerve conduction studies (EMG/NCV) noted ongoing reinnervation in the deltoid and supraspinatus.

Case Report 2

A 28-year-old man (patient 2) presented with C5-8 BPI in the left upper extremity in the setting of a complete SCI (C8 ASIA A) after a motor vehicle accident in which he was ejected from the vehicle. He also sustained a mandible fracture, multiple lacerations of the face and neck, transected left carotid and left vertebral arteries, crushed/significantly

damaged C7 and T1, fractured T2, and a right posterior hip dislocation. The patient exhibited grade 5 strength in the right deltoid, biceps, and triceps function, with grade 2 strength in hand intrinsic function. His left upper extremity and bilateral lower extremities were flaccid. He had a sensory level to pinprick at T3 on the right and C3 on the left.

The patient was initially treated with plate fixation of the mandible, left carotid repair and left vertebral artery ligation, and closed hip reduction. He then underwent a C4-T5 posterior cervicthoracic fusion and transcanal anterior strut placement for stabilization of the spine. He continued to have neuropathic pain distal to his left elbow and had no improvement in his left upper extremity motor function.

Three months after his injury, he underwent a brachial plexus exploration which revealed a C5-8 root avulsion. Given his short time from injury to BPR, with adequate time for successful reinnervation, he underwent spinal accessory to biceps nerve transfer with a superficial radial nerve autograft. Postoperative, he noted significant relief from the neuropathic pain shortly following the BPR. At 27-month follow-up, his neuropathic pain continued to be minimal, and he exhibited no evidence of reinnervation in the biceps muscle (Table 1). The patient had also developed ulnar clawing in the right upper extremity.

Discussion

Combined BPI and complete SCI is a relatively rare entity that can result in significant functional impairment. In spinal cord injured patients, BPIs have been reported to occur at an incidence of 0.6% to 0.7%.^{1,10} Tetraplegics are mostly dependent on others for ADLs due to the loss of function in all extremities. However, paraplegics without associated injuries can be expected to be fully independent for most tasks. In a series by Grundy and Silver, the BPI was considered a greater disability than the SCI in 4 out of 9 paraplegics who were completely dependent on others for ADLs.¹⁰ Similarly, even after operative intervention for the brachial plexus lesion, Akita et al noted a residual useless upper extremity in 3 of 6 patients with a complete SCI.¹ Treatment priorities of a BPI in patients with an SCI differ than those with a solitary BPI. As opposed to BPIs where restoration of elbow flexion and shoulder abduction takes precedence, in patients with an SCI, elbow extension and lateral thumb pinch (key pinch) are integral to performing self-transfers and rudimentary ADLs.⁵

Brachial plexus reconstructive options are limited in the setting of a complete SCI. Difficulty arises from the lack of available intraplexal reconstructive options in cases of tetraplegia where donor nerves from within the injured metamere will have upper and motor neuron deficits while donor nerves that are infralesional will have loss of upper motor neuron connection. If the spinal accessory nerve is intact, nerve transfer to the musculocutaneous

Table 1. Surgical Outcomes for Patients With Combined Complete Spinal Cord Injury and Traumatic Brachial Plexus Injury.

Case	Age/Sex	Level of complete SCI	Time from injury to brachial plexus reconstruction	Brachial plexus lesion by operative findings	Nerve surgery for brachial plexus lesion	Musculotendinous transfer for brachial plexus lesion	MRC grade ^a	Pain (VAS) ^a	DASH ^a	Sedel grade	Follow-up after nerve surgery (mo)
1	43/Male	T2-ASIA A	9	Stretch C5/C6 Avulsion C7	C5 → SSN and AN [SN] ^b C6 → triceps motor branch ^c SAN → Gracilis FMT UN fascicle → biceps motor branch	FCR → EDC Long finger FDS → EPL PT → ECRB	SA: 0 → 2 EF: 0 → 4 EE: 0 → 3 WF: 4 → 4 WE: 0 → 0 FF: 4 → 4 FE: 0 → 3	4.9 → 6	59.2 → 66.7	3	58
2	28/Male	C8-ASIA A	3	Avulsion C5-C8	SAN → biceps motor branch [SPRN] ^d	—	SA: 0 → 0 EF: 0 → 0 EE: 0 → 0 WF: 0 → 0 WE: 0 → 0 FF: 0 → 0 FE: 0 → 0	10 → 6.5	82.5 → 63.3	5	26

Note. SCI = spinal cord injury; MRC = Medical Research Council; VAS = visual analog scale; DASH = Disabilities of the Arm, Shoulder and Hand; ASIA = American Spinal Injury Association. **Nerves:** SSN = suprascapular nerve; AN = axillary nerve; SAN = spinal accessory nerve (cranial nerve XI); UN = ulnar nerve; SPN = superficial radial nerve graft. **Muscles:** FMT = free muscle transfer; FCR = flexor carpi radialis; EDC = extensor digitorum communis; FDS = flexor digitorum superficialis; EPL = extensor pollicis longus; PT = pronator teres; ECRB = extensor carpi radialis brevis. **Motor function:** SA = shoulder abduction; EF = elbow flexion; EE = elbow extension; WF = wrist dorsiflexion; WE = wrist extension; FF = finger flexion; FE = finger extension.

^aPreoperative to postoperative.

^bSural nerve autograft = 2 cables (12 cm) from C5 to AN, 1 cable (9 cm) from C5 to SSN.

^cSural nerve autograft (25 cm) and superficial radial nerve (25 cm) = 2 cables (25 cm) from C6 to triceps motor branch.

^dSuperficial radial nerve = 1 cable (18 cm) from SAN to the biceps motor branch.

Table 2. Sedel Classification for Usefulness of the Brachial Plexus Injured Extremity.

Grade	Usefulness of the arm
1	Manual work can be performed with normal strength
2	The limb can perform or assist everyday activities, but not strong enough for manual work (cutting meat or tying shoe laces)
3	The limb has very limited usefulness The forearm can be held against the chest The flexed wrist can be used as a hook The whole arm can be used as a paperweight
4	The limb is virtually useless and serves as an aesthetic animated arm (some movement of the elbow and fingers)
5	No recovery has occurred and serves as an aesthetic unanimated arm (occasionally, trophic changes can lead to an unaesthetic arm)

nerve has resulted in antigravity elbow flexion in 50% to 100% of cases.^{7,15} Spinal accessory nerve transfer to the axillary and suprascapular nerve has resulted in antigravity shoulder abduction in 23 of 24 (95.8%) and 26 of 26 (100%) of reported cases, respectively.^{8,11,14} Other extra-plexal donor nerves that may be available in lower cervical level SCI, including the phrenic nerve (C3-5), hypoglossal nerve (cranial nerve XII), or the cervical plexus, have been used but with poor motor recovery.⁶ In our series, the use of spinal accessory nerve to the biceps motor branch resulted in no recovery of elbow flexion for patient 2 (Table 1).

Conversely, difficulty may arise with utilizing lower motor neurons from caudal, or infralesional, to the level of SCI. Upper motor neuron injuries have been shown to result in conversion from type 1 (slow-twitch) to type 2 (fast-twitch) muscle fibers in rat and human studies after cord transection.^{12,16} Although denervated muscle is susceptible to fibrosis, atrophy, and loss of volitional control, the neural elements caudal to the level of SCI remain anatomically intact.^{4,5} Thus, the preserved neural architecture serves as a nerve conduit allowing for reinnervation and restoration of volitional control.⁵ For example, Mackinnon et al transferred the brachialis motor branch to an anterior interosseous nerve motor fascicle to restore grade 3 flexor pollicis longus and flexor digitorum profundus function in a C7 complete SCI at 23 months after injury.¹³ In contrast, patient 1 (T2 ASIA A) in the current study underwent Oberlin transfer and free functioning gracilis transfer utilizing supralesional donor nerve at 9 months from SCI with recovery to grade 4 elbow flexion strength,³ in contrast to utilizing the infralesional intercostal nerves, with injured upper motor neurons, as donor nerves for the gracilis free functioning muscle transfer.

In the SCI patient with a concomitant BPI, it is important to structure treatment strategy and goals around the patient's specific injury. Care must be taken to avoid the use of injured upper motor neurons for reconstruction, which would limit recovery, though lower motor neurons

remain intact. Outcomes should be aimed at restoring ADLs and the ability to self-transfer, and expectations should be tempered with the extent of the SCI in these patients, as many do not achieve a functional extremity.

Ethical Approval

Each author certifies that his or her institution approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.

Statement of Human and Animal Rights

Procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000 and 2008.

Statement of Informed Consent

Informed consent for research purposes was obtained per institutional protocol. Each author certifies that all patients gave proper informed consent for this study.

Declaration of Conflicting Interests

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References

1. Akita S, Wada E, Kawai H. Combined injuries of the brachial plexus and spinal cord. *J Bone Joint Surg Br.* 2006;88: 637-641.
2. Birch R. Surgery for brachial plexus injuries. *J Bone Joint Surg Br.* 1993;75:346-348.

3. Bishop AT. Functioning free-muscle transfer for brachial plexus injury. *Hand Clin.* 2005;21:91-102.
4. Brown JM. Nerve transfers in tetraplegia I: background and technique. *Surg Neurol Int.* 2011;2:121.
5. Brown JM, Dimitrijevic M, Kakulas B, et al. The reconstructive neurosurgery of spinal cord injury. In: Dimitrijevic MR, Kakulas BA, McKay WB, Vrbova G, eds. *Restorative Neurology of Spinal Cord Injury*. New York, NY: Oxford University Press; 2012:134-168.
6. Chuang DC. Neurotization procedures for brachial plexus injuries. *Hand Clin.* 1995;11:633-645.
7. Chuang DC, Epstein MD, Yeh MC, et al. Functional restoration of elbow flexion in brachial plexus injuries: results in 167 patients (excluding obstetric brachial plexus injury). *J Hand Surg Am.* 1993;18:285-291.
8. Chuang DC, Lee GW, Hashem F, et al. Restoration of shoulder abduction by nerve transfer in avulsed brachial plexus injury: evaluation of 99 patients with various nerve transfers. *Plastic Reconstr Surg.* 1995;96:122-128.
9. Eckert MJ, Martin MJ. Trauma: spinal cord injury. *Surg Clin North Am.* 2017;97:1031-1045.
10. Grundy DJ, Silver JR. Combined brachial plexus and spinal cord trauma. *Injury.* 1983;15:57-61.
11. Kline D, Hudson A. Stretch injuries to the brachial plexus. In: Murovic JA, Spinner R, Robert T, eds. *Nerve Injuries: Operative Results for Major Nerve Injuries, Entrapment, and Tumors*. Philadelphia, PA: WB Sanders; 1995:415-416.
12. Lieber RL, Friden JO, Hargens AR, et al. Long-term effects of spinal cord transection on fast and slow rat skeletal muscle. II. Morphometric properties. *Exp Neurol.* 1986;91:435-448.
13. Mackinnon SE, Yee A, Ray WZ. Nerve transfers for the restoration of hand function after spinal cord injury. *J Neurosurg.* 2012;117:176-185.
14. Oberlin C, Beal D, Leechavengvongs S, et al. Nerve transfer to biceps muscle using a part of ulnar nerve for C5-C6 avulsion of the brachial plexus: anatomical study and report of four cases. *J Hand Surg Am.* 1994;19:232-237.
15. Richardson PM. Recovery of biceps function after delayed repair for brachial plexus injury. *J Trauma.* 1997;42:791-792.
16. Round JM, Barr FM, Moffat B, et al. Fibre areas and histochemical fibre types in the quadriceps muscle of paraplegic subjects. *J Neurol Sci.* 1993;116:207-211.
17. Sedel L. The results of surgical repair of brachial plexus injuries. *J Bone Joint Surg Br.* 1982;64:54-66.