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ORIGINAL ARTICLE

Identification of patients with cervical SCI suitable for early nerve transfer to achieve hand opening

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Study design: Retrospective audit.
Objectives: The objective of this study was to identify the proportion of patients with cervical spinal cord injury who would potentially benefit from nerve transfer surgery to gain active hand opening, and to determine when a safe nerve transfer decision can be made.
Setting: Christchurch, New Zealand.
Methods: Case note review of the first 12 months following acute cervical spinal cord injury (2007–2012). Neurological assessment at 6 weeks, 12 weeks and 1 year following injury.
Results: Fifty-three patients had complete assessments and showed changes in the level of injury and severity of neurological injury between assessments. Forty-two percent of patients had motor complete C5–7 level injuries 12 weeks following injury and would benefit from consideration for nerve transfer to improve hand opening. Fewer (26%) would benefit 1 year following injury owing to a change in the neurological level of injury.
Conclusions: Twelve-week neurological assessment identifies patients who may benefit from nerve transfer surgery. This enables referral for comprehensive upper limb assessment and reassessment of motor function to determine suitability for surgical intervention. Nerve transfer within the window of opportunity provides active hand opening for patients following cervical spinal cord injury.
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INTRODUCTION

Following cervical spinal cord injury (SCI), the upper limb function is a key determinant of quality of life. Rehabilitation and subsequent tendon transfer surgery has been the mainstay of gaining improvement in the upper limb function for many years.[1,2] Very often, cervical SCI results in poor upper limb function, which can be improved with tendon transfer surgery to provide elbow extension, and basic pinch and grasp. However, results of tendon transfer to achieve active hand opening have been disappointing. Hand opening by thumb abduction and finger extension occurs with the tenodesis effect driven by gravity-assisted wrist flexion. Nerve transfer surgery has improved outcomes for many patients following brachial plexus and other upper limb nerve injuries. More recently, nerve transfer surgery has been introduced following cervical SCI.[3–5] The first and most successful nerve transfer in SCI has been the transfer of the nerve to supinator (C5–6) to the posterior interosseus nerve (PIN) (C7–8).[3] PIN function enables active hand opening in all wrist positions as well as correcting the radially deviated wrist. This improves function in a wide range of activities requiring hand opening such as hand shaking and reaching for objects. In addition, correcting wrist radial deviation improves hand positioning for tasks such as handwriting. Promising results have been reported when surgery is performed within 12 months of SCI. Nerve transfer requires the division of both the donor and recipient nerves. As supinator does not functionally add to the powerful supination function of the retained functioning biceps, it is considered expendable. The PIN should only be divided when there is confidence that it will not recover spontaneously.

The International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI)[6] is routinely used in spinal injury trauma and rehabilitation services to assess severity and monitor change in function following traumatic SCI. The ASIA Impairment Scale (AIS) has five grades: from A (complete motor and sensory loss below the level of injury) to E (normal sensory and motor function), with varying degrees of incompleteness in between.[6]

The aim of this study was to identify the proportion of patients with cervical SCI who would potentially benefit from nerve transfer surgery to gain hand opening by comparing their ISNCSCI scores at various time points during their first year following SCI. For these patients, we aimed to analyze changes in the motor level and severity to determine when a safe nerve transfer decision can be made.

MATERIALS AND METHODS

We performed a retrospective in-patient notes audit of people admitted to the Burwood Spinal Unit (BSU), Christchurch, New Zealand between 1 January 2007 and 31 December 2012. Cases were included if the clinical records showed a cervical SCI injury at the motor level C2–8 with AIS A–D and were aged between 15 and 80 years of age. Further analyses were performed on those with AIS D and only those with hand impairment were included. Demographic data were collected from the clinical records and the International Upper Limb Surgery Registry.[7] ISCNSCI assessment information performed at 6 weeks, 12 weeks and 1 year were also recorded.

RESULTS

Between January 2007 and December 2012, a total of 600 people were acutely admitted to the BSU for management and rehabilitation following SCI (approximate incidence of 5/1 00 000 per year).

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Of these 600 people, 55 people met the inclusion criteria for the audit. The demographics of the study population are shown in Table 1. Eighty two percent of the study population was under the age of 55 years. Two patients did not have a 12-week assessment and have therefore been excluded from the analysis ($n=53$).

Changes in severity

Changes in AIS between 6 and 12 weeks. At 6 weeks, there were 40 (75%) patients classified as motor complete (AIS A or B). Eight (20%) of these improved to become motor incomplete between 6 and 12 weeks. At 6 weeks, there were 13 (25%) patients classified as motor incomplete (AIS C or D). None of these patients deteriorated to motor complete between 6 and 12 weeks (Table 2).

Changes in AIS between 12 weeks and 1 year. Twenty-nine out of the 32 (90%) patients who were classified as motor complete (AIS A or B) at 12 weeks remained motor complete at 1 year. Half of the patients with AIS C at 12 weeks remained AIS C, whereas the other half converted to AIS D. All those with AIS D at 12 weeks remained AIS D at 1 year (Table 3).

Changes in the motor level

Fifty-three patients had ISCNSCI assessments performed at both 12 weeks and 1 year. The distribution at 12 weeks and 1 year is shown in Tables 4 and 5, respectively. Twenty-four patients (45%) had a changed motor level in this time (15/29 motor complete, 9/24 motor incomplete).

Motor complete C5–7 SCI may benefit from supinator to PIN transfer. At 12 weeks, 22 patients (42%) appeared suitable for nerve transfer, this decreased to 14 out of the 53 (26%) at their 1-year assessment. Patients whose change in level from 12 weeks to 1 year that would have changed their suitability for nerve transfer included those who were no longer suitable (four moved up to C4 and three moved down to C8) and those who became suitable (two moved down to C5). All three patients who changed from motor complete to motor incomplete between 12 weeks and 1 year were also no longer suitable. Ten out of the 22 patients (45%) who appeared suitable for nerve transfer at 12 weeks were no longer suitable at 1 year. Two out of the 31 patients (6%) who appeared unsuitable for nerve transfer at 12 weeks became suitable at 1 year.

Table 1 Population demographics ($n=55$)

Demographic	*Number (%)*
Age at the time of injury (years)	
15–24	16 (29%)
25–34	11 (20%)
35–44	8 (15%)
45–54	10 (18%)
55–64	4 (7%)
65–79	6 (11%)
Sex	
Male	50 (91%)
Female	5 (9%)

DISCUSSION

Nerve transfer allows the nerve from one 'spare' muscle to innervate a group of muscles. This is in contradistinction to tendon transfer surgery in which one tendon can only power one musculotendinous unit. The challenge for nerve transfer surgery is that it must be performed early enough to allow muscle reinnervation before irreversible motor endplate degeneration occurring at ~18 months following injury for the lower motor neuron component of the SCI. This means that ideally nerve transfer surgery should be performed before 12 months[3,4] and preferably earlier. However, many clinicians and patients are wary of proceeding with irreversible surgical intervention if there is potential for further recovery following SCI. Similar to other studies,[8] the findings from this study have shown that those assessed as motor complete by the ISCNSCI assessment at 12 weeks remained motor complete at 1 year, although 15/29 had a recorded change of motor level.[9,10] Thus, the ISCNSCI reliably identifies patients who would benefit from further assessment for nerve transfer surgery without affecting potential recovery. This allows timely referral to an upper limb team for assessment, education and reassessment before surgery, which can occur in the 6–12-month window of opportunity.

Severity assessment in SCI can be challenging across time, with a range of ability and training of assessors. In this study, changes were seen in the motor level between 12 weeks and 1 year, with some patients improving levels of function and some deteriorating. It is difficult to determine whether this is the expertise of the assessor performing the examination or true neurological deterioration/improvement. Burns *et al.*[8] found that those with AIS A had negligible chance of meaningful motor recovery, but 60% of AIS B at 48 h developed some meaningful motor recovery by 1 year.

In this study, the proportion of cervical SCI patients who should be referred for consideration of nerve transfers has been analyzed in two different ways, first in regard to severity scale and second motor level at 12 weeks and 1 year. In addition, we have determined the proportion of patients who have motor complete C5–7 SCI (based on the fact that patients with a C7 motor level of injury (triceps Medical Research Council grade $\geqslant 3$) may not have active hand opening). At 12-week and 1-year assessments, this comprised of 42% and 26% of the group, respectively. Based on this 5-year period, we would expect every second or third patient to benefit from a hand assessment within 6 months of injury.

Based on our observation that a fifth of initially motor complete patients improved between 6 and 12 weeks, we do not recommend hand referral until after the 12-week assessment as the 6-week

Table 2 Comparison of 6- with 12-week AIS ($n=53$)

AIS	*12-week AIS A*	*12-week AIS B*	*12-week AIS C*	*12-week AIS D*
6-week AIS A ($n=21$)	19 (90%)	2 (10%)	0	0
6-week AIS B ($n=19$)	1 (5%)	10 (53%)	4 (21%)	4 (21%)
6-week AIS C ($n=8$)	0	0	6 (75%)	2 (15%)
6-week AIS D ($n=5$)	0	0	0	5 (100%)

Abbreviation: AIS, ASIA Impairment Scale.

Table 3 Comparison of 12-week and 1-year AIS ($n=53$)

AIS	*1-year AIS A*	*1-year AIS B*	*1-year AIS C*	*1-year AIS D*
12-week AIS A ($n=20$)	19 (95%)	1 (5%)	0	0
12-week AIS B ($n=12$)	2 (17%)	7 (58%)	3 (15%)	0
12-week AIS C ($n=10$)	0	0	5 (50%)	5 (50%)
12-week AIS D ($n=11$)	0	0	0	11 (100%)

Abbreviation: AIS, ASIA Impairment Scale.

Table 4 Severity and level of injury at 12 weeks ($n=53$)

Level	*AIS A*	*AIS B*	*AIS C*	*AIS D*
C2	1	0	0	0
C3	0	0	0	0
C4	6	3	2	3
C5	**9**	**4**	6	3
C6	**3**	**1**	1	3
C7	**1**	**4**	1	2
C8	0	0	0	0

Abbreviation: AIS, ASIA Impairment Scale.
Bold numbers indicate potential suitability for supinator to PIN transfer ($n=22$).

Table 5 Severity and level of injury at 1 year ($n=53$)

Level	*AIS A*	*AIS B*	*AIS C*	*AIS D*
C2	0	0	0	0
C3	2	0	0	0
C4	6	4	0	1
C5	**6**	**0**	3	4
C6	**4**	**2**	4	8
C7	**1**	**1**	0	3
C8	2	1	1	0

Abbreviation: AIS, ASIA Impairment Scale.
Bold numbers indicate potential suitability for supinator to PIN transfer ($n=14$).

assessment was not reliable. In contrast, the 12-week ISCNSCI assessment was reliable with regard to severity of injury, although the level of motor injury changed over the subsequent period in 45% of patients. We recommend that a comprehensive upper limb assessment be performed on patients who are motor complete C4–7 at 12 weeks owing to the lack of sensitivity of the ISCNSCI. This assessment will determine the strength of specific muscle groups. Repeated examination over the following 6-month period (up to 9 months following injury) will identify any upper limb neurological change. Our retrospective data does not identify when in the 3–12-month window neurological improvement occurred. We are performing prospective, sequential upper limb assessments to determine this. We recognize that undertaking surgery earlier than 12 months following injury is controversial as the full benefit of natural recovery may not be apparent. However, sequential upper limb assessment will identify any specific neurological recovery that would make nerve transfer surgery inappropriate. For example, nerve to supinator to PIN transfer is only suitable when there is confidence that there is no prospect of natural PIN recovery. Given that a nerve transfer can only improve the lower motor neurone component of the spinal injury if performed in a timely manner, specific upper limb assessment and reassessment should occur within the window of opportunity.

More 'spare' but functional muscles have been identified for nerve transfer. As well as supinator providing a donor nerve, the nerve to brachialis has also been used, mainly to innervate the anterior interosseous nerve.[4] In addition, it has been proposed that nerve transfers that replicate tendon transfers should be considered because of the reduced rehabilitation period required. For example, nerve to deltoid to nerve to triceps transfer instead of the posterior deltoid to triceps tendon transfer.[11] The reliability of this approach will have to be confirmed before jeopardizing these established techniques that reliably improve function. In the meantime, we suggest focusing on the nerve transfers to muscles that are not suitable for active tendon transfer and for which denervation causes no reduction in function.

Nerve regeneration following any nerve surgery is poorer with advancing age and this is likely to be the case with nerve transfers in SCI, although there have not been enough reported cases to confirm this. However, SCI is most prevalent in young males as seen in our population in which 82% are under the age of 55 years.

Nerve to supinator to PIN transfer has little downside for the patient. Our experience is consistent with reported cases showing few complications or new neurological deficits.[5] Specifically, this transfer can be reliably performed without weakening wrist extension. Importantly, unlike tendon transfer surgery, there is little interruption to overall rehabilitation. Splinting has been used for up to 3 weeks and reduced upper limb activities such as transferring for 2–4 weeks following surgery.[4,5] Thus, nerve transfer can be performed either within the early acute hospitalization of people with SCI without impeding overall rehabilitation or during a brief readmission for those patients with shorter initial in-patient rehabilitation

CONCLUSION

Nerve transfers offer improved function for patients with cervical SCI. Potential candidates for comprehensive assessment for nerve transfer surgery in people with tetraplegia can be identified using the 12-week ISCNSCI assessment. Those with motor complete SCI are highly unlikely to demonstrate improvement to motor incomplete between 12 weeks and 1 year. Early referral allows for comprehensive upper limb assessment and reassessment of motor function to determine suitability for surgical intervention. There is a window of opportunity in which patients may benefit from nerve transfer surgery if they are seen between 3 and 12 months.

DATA ARCHIVING

There were no data to deposit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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