Nerve transfers to restore upper limb function in tetraplegia

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"For those who have nothing, a little is a lot."[1] As Sterling Bunnell, a pioneer of tetraplegic extremity reconstruction observed, small gains in function for people with spinal cord injury can equate to enormous gains in independence. People with mid-cervical spinal cord injury usually retain volitional movement at the shoulder and some control of their elbows and wrists. Hand opening and closing, a capacity that patients rate as more important to regain than walking or sexual function, is often lost.[2] Reconstruction with tendon transfers can restore motion within the upper limbs,[3] yet few undergo such procedures.[4,5] Nerve transfers, in which expendable donor nerves are rerouted to non-functional recipient nerves, were developed to treat peripheral nerve and brachial plexus injuries. Donor nerve fibres grow from the transfer site along the path of the recipient nerve to reach the muscle and restore volitional motor control.[6]

Injuries to the spinal cord are neurologically complex; both upper and lower motor neurons can be damaged.[7] In lower motor neuron paralysis, because the nerve degeneration that occurs leads to irreversible muscular atrophy, muscle reinnervation must be done within 12–18 months of injury if any function is to be restored.[6] Conversely, in upper motor neuron paralysis, the intact lower motor neuron preserves the muscle; thus, transfers to restore volitional control in this context have no discernible time limit.[8] Many nerve transfer options exist for spinal cord injury.[8–11]

In Natasha van Zyl and colleagues' prospective case series[12] in *The Lancet*, participants with upper limb paralysis due to motor level C5–C7 spinal cord injury underwent single or multiple nerve transfers in one or both upper limbs for restoration of elbow extension, grasp, pinch, and hand opening. 59 nerve transfers were completed in 16 participants (13 men and three women; 27 limbs). In ten participants (12 limbs), nerve transfers were combined with tendon transfers. In the 13 participants (22 limbs) who completed follow-up, improvements at 24 months versus baseline were recorded for all primary outcomes: action research arm test total score (median 34·0 [IQR 24·0–38·3] *vs* 16·5 [12·0–22·0], p<0·0001), grasp release test total score (125·2 [65·1–154·4] *vs* 35·0 [21·0–52·3], p<0·0001), and spinal cord independence measure total score (mean 39·3 [SD 13·8] *vs* 31·2 [7·9], greater than minimal clinically important difference). Three participants had four failed nerve transfers (Medical Research Council grade 0–1), two had a permanent decrease in sensation, and two had a temporary decrease in wrist strength that resolved by 1 year post surgery. These findings show that tendon and nerve transfers improve upper limb movement in cervical spinal cord injury, as is portrayed in the patient testimonial video for this study.[12]

As van Zyl and colleagues suggest, nerve transfers seem to restore more natural movement and finer motor control than are achieved by tendon transfers.[6,12] Nerve transfers also harness existing anatomy and physiology,[7] which circumvents risky spine-level surgery, foreign cells, complex special equipment, and implantation of devices.[8] A single donor nerve can reinnervate multiple muscles,[6,12] which is especially important in spinal cord injuries with few available donor nerves. Additionally, patients can resume light activity immediately after the procedure, avoiding the prolonged immobilisation and non-weightbearing necessary following tendon transfer.[6] Furthermore, whereas tendon transfers can stretch out over time, results from nerve transfers improve over time through cortical plasticity.[6]

The disadvantages of nerve transfers include the months before new motion is seen and the years until full strength is achieved.[6,8,10] van Zyl and colleagues maximised results in their patients by using the most

Washington University School of Medicine distal donor nerves available. However, nerve transfers sometimes fail,[8,10,12,13] and patient satisfaction does not always correlate directly with measurable gains in strength or function.

An individualised approach to surgical assessment and management is vital in this heterogeneous population. In our experience, each person with spinal cord injury responds uniquely, and injury patterns, clinical examinations, electrodiagnostic testing, social situations, and functional goals are diverse. Shared physician–patient decision making is imperative to develop a plan that meets an individual's expectations and biopsychosocial situation. In van Zyl and colleagues' practice setting, both nerve and tendon transfers are possible.[12] We envisage a role for nerve transfers in settings where the intensive therapy and immobilisation required to optimise complementary tendon transfers are unavailable.

Stem cells and neuroprostheses could change the landscape of regenerative medicine in the future. For now, nerve transfers are a cost-effective way to harness the body's innate capability to restore movement in a paralysed limb. As nerve transfers are adopted and their uses adapted, careful ongoing outcomes research is paramount to advancing the field. This research should include efforts to compare nerve transfer with tendon transfer; find the optimal timing of such surgeries; and determine which approach produces the greatest functional improvement. Detailed study of the reasons for nerve transfer failure is also required, as is improving our understanding of the effects of biopsychosocial factors, including access to information and care, psychological readiness, and social support, on patient decision making and outcomes.

Nerve transfers represent a huge advance in reconstruction to restore hand function following spinal cord injury.[12] Expanding surgical options enables more choice for those with such injuries. Given the time sensitivity of nerve transfers in combined upper motor neuron and lower motor neuron injury,[7,8] referral to an extremity surgeon well versed in both nerve and tendon transfer surgery at 6 months post injury is important, as almost half of those who present later are no longer candidates for nerve surgery.[13] Surgeons who integrate nerve transfers into their spinal cord injury practice should take a careful and measured approach, and rigorously study and disseminate their outcomes to advance this growing field. We hope that increased awareness of nerve transfer surgery will stimulate early referral, wide discussion, and appropriate use of this treatment option throughout the world.

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