Tetraplegia Management Update

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Tetraplegia is a profound impairment of mobility manifesting as a paralysis of all 4 extremities owing to cervical spinal cord injury. The purpose of this article is to provide an update and analyze current management, treatment options, and outcomes of surgical reconstruction of arm and hand function. Surgical restoration of elbow and wrist extension or hand grip has tremendous potential to improve autonomy, mobility, and critical abilities, for example, eating, personal care, and self-catheterization and productive work in at least 70% of tetraplegic patients. Tendon and nerve transfers, tenodeses, and joint stabilizations reliably enable improved arm and hand usability, reduce muscle imbalance and pain in spasticity, and prevent joint contractures. One-stage combined procedures have proven considerable benefits in any form have been received or will be received related directly or indirectly to the subject of this article.
Advantages over traditional multistage approaches. Immediate activation of transferred muscles reduces the risk of adhesions, facilitates relearning, avoids adverse effects of immobilization, and enhances functional recovery. Transfer of axillary, musculocutaneous, and radial nerve fascicles from above the spinal cord injury are effective and promising options to enhance motor outcome and sensory protection, especially in groups with limited resources. Improved communication between medical disciplines, therapists, patients, and their relatives should help that more individuals can benefit from these advances and could empower many thousands tetraplegic individuals “to take life into their own hands” and live more independently. (J Hand Surg Am. 2015;40(12):2489–2500. Copyright © 2015 by the American Society for Surgery of the Hand. All rights reserved.)

**Key words** Combined procedures, early activation, nerve transfer, tendon transfer, tetraplegia.

**GLOBAL INCIDENCE OF SPINAL CORD INJURY (SCI) has been estimated as 10–80 new cases per million annually, which means that approximately 12,000 in the USA alone and 250,000–500,000 people worldwide become paralyzed every year. This population often represents otherwise healthy and active individuals aged between 20 and 40 years. In approximately 50%, SCI occurs at the cervical level, which leads to tetraplegia.**

The causes of SCI differ among countries but worldwide most commonly occur because of motor vehicle accidents, falls, violence (crime), sports, and leisure activities. Nontraumatic causes include tumors, infection, degenerative, or vascular disorders—it can happen to anyone of us any day.1–4

Upper extremity functional surgery has an important role in the management of patients with SCI. As SCI remains incurable, upper extremity function, aside from the brain, is the most important functional resource of tetraplegic patients and judged to be most desirable to regain, before bowel, bladder, sexual function, or walking ability. Anderson reports that 49% of surveyed tetraplegic patients ranked rehabilitation of arm and hand function as first priority, with no other goal surpassing 13%.2 Similarly, another study reports that 77% of 565 tetraplegic patients expected important or very important improvement in quality of life if their hand function improved.5

Surgical rehabilitation is a powerful tool to restore upper extremity function, for example, restored elbow extension improves reach and stabilizes the elbow, allowing further reconstruction of grasp, and the ability to swim and drive.3,6,7 Regaining grip by reconstructive surgery eliminates the need for adaptive equipment; allows patients to groom, self-feed, self-catheterize, manipulate objects, write, and perform productive work; and markedly improves autonomy and spontaneity, thus enhancing self-esteem for tetraplegic people.8 Regrettably, despite highly positive results, tetraplegia surgery is profoundly underutilized. In the USA with more than 100,000 tetraplegic citizens, fewer than 400 receive upper extremity functional surgery annually—less than 10% of appropriate candidates. The reasons for explaining this paradox are complex, with inadequate information causing skepticism among patients, therapists, and rehabilitation physicians. Inadequate referral networks also play a role.9

The objective of this article is to provide an update on surgical management of tetraplegia upper extremity surgery from the experience of the authors.

**CLINICAL PICTURE**

Remaining upper extremity function in tetraplegia depends on the injury level. Patients with C2-4 tetraplegia generally have no arm and hand muscle function, except shoulder elevation (trapezius muscle innervated by the spinal accessory nerve), some neck muscle control, and may be ventilatory support dependent. Individuals with intact C5 myotome usually retain elbow flexion and shoulder abduction and may be able to perform simple activities such as eating, using devices attached to their wrists and hands. Wrist extension is the key function of the C6 level that usually produces only weak grip, as active thumb and finger flexion is paralyzed. At the C7 level, extension of the elbow is present that is crucial for transfer and may enable patients to live in an adapted environment with some caregiver assistance. Although this categorization is simplified, it clearly shows that any treatment improving the functional level, for example, from C5 to C6 or 7, produces a marked enhancement in both function and independence.

**Muscle testing**

Planning treatment depends on muscle strength testing of the upper extremity according to the Medical Research Council system and International Classification of Surgery of the Hand in Tetraplegia10.
TABLE 1. Muscle Function According to Medical Research Council System

<table>
<thead>
<tr>
<th>Muscle Strength Grade</th>
<th>Muscle Function</th>
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<tr>
<td>M0</td>
<td>No active range of motion, no palpable muscle contraction</td>
</tr>
<tr>
<td>M1</td>
<td>No active range of motion, palpable muscle contraction only</td>
</tr>
<tr>
<td>M2</td>
<td>Reduced active range of motion—not against gravity, no muscle resistance</td>
</tr>
<tr>
<td>M3</td>
<td>Full active range of motion, no muscle resistance</td>
</tr>
<tr>
<td>M4</td>
<td>Full active range of motion, reduced muscle resistance</td>
</tr>
<tr>
<td>M5</td>
<td>Full active range of motion, normal muscle resistance</td>
</tr>
</tbody>
</table>

(Tables 1, 2). Donor muscles must be healthy, of adequate strength (M4), preferably not injured or reinnervated, yet with limited available donors weaker muscles (M3) may be used. Donors ideally should be similar in architecture, synergistic, and have an adequate soft tissue bed along their transfer route.3,8,11

**Joint range of motion**

Passive joint motion, particularly in shoulder, elbow, forearm, wrist, and metacarpophalangeal (MCP) and proximal interphalangeal (PIP) joints, is a prerequisite for reconstruction. The tenodesis effect during wrist extension (hand closure), flexion (hand opening), and joint stability (primarily thumb trapeziometacarpal) is preferable but not a prerequisite for reconstruction.

**Sensibility testing**

Sensory examination focuses on cutaneous afferents with a 2-point discrimination of 10 mm or less in the thumb for cutaneous control; otherwise ocular control is required.10

**Special aspects**

Neuromuscular examination should also rule out brachial plexus lesions, entrapment neuropathies, spine deformity, thoracoscapular instability, spasticity, and contractures. Pain and swelling in the arm and hand are relative contraindications and need to be treated before surgery.3,12 A stable emotional and psychological situation and good social support networks for the patients are especially critical for successful rehabilitation among other factors (Table 3).

**TREATMENT**

**Nonoperative treatment**

Dedicated physiotherapy and occupational therapy, including orthosis fabrication, optimize the preoperative situation and postoperative function. They provide the “other half” of rehabilitation with patient motivation, training of transferred muscles, edema control, and contracture prevention pre- and postoperatively. They also bring input from rehabilitation specialists and the patients themselves, which is essential for successful outcomes.3,13,14

**Surgical treatment**

Several operations aimed at better daily-life performance are listed in Table 4 and based on the International Classification of Surgery of the Hand in Tetraplegia. Surgical algorithms according to International Classification (IC) are listed in Table 5.

**Time management**

The above-mentioned conditions are usually achieved after completing the first period of rehabilitation. Strict time rules (eg, no operations before 1 year after injury) are not appropriate; early operations may be possible if the patient is psychologically stable and ready for surgery. Neurological stability may be achieved after 6 months in complete tetraplegia. Early surgery in psychologically stable patients has many advantages, such as faster reintegration. Often however, financial, family, or work-related problems must be solved first. Notably, a tendon transfer reconstruction remains feasible even decades after SCI. In incomplete SCI, functional recovery takes longer, so treatment plans should be developed only after complete nerve regeneration and spasticity control.12 Regarding nerve transfers, muscles in SCI can be categorized into (1) functional muscles innervated by the supraspinal segment, (2) muscles with damaged anterior horn cells and lower motor neuron denervation, and (3) muscles innervated from the infra- spinal segment without connection to the upper motoneuron but with intact lower motoneuron. The first group represents potential donor nerves; the nerves to the latter 2 groups are potential recipients. Early surgery (within 1 year) is critical, as neuromuscular end-plate degeneration makes the denervated muscle refractory to eventual reanimation (after approximately 2 years). In upper motoneuron lesions, neuromuscular degeneration is slower that may extend the time window for successful nerve transfers.15,16
Reconstruction of elbow extension

Elbow extension is critical for overhead activities, weight shifting, and transfers, greatly increasing wheelchair propulsion and workspace of the hand by 800%. Elbow extension restoration should precede grip reconstruction because

- use of a hand that cannot reach out is limited,
- elbow extension stabilizes the trunk in the wheelchair,
- stability enables more controlled hand use, and
- tendon transfer to restore wrist or hand function using the brachioradialis improves with previously restored antagonistic elbow extension.

Procedures to restore triceps function include

(a) Tendon transfer in the form of posterior deltoid-to-triceps muscle transfer or biceps-to-triceps muscle transfer.

(b) Nerve transfer in the form of axillary or musculocutaneous nerve fascicles to the radial nerve.\(^{15,16}\)

Posterior deltoid muscle transfer reliably restores triceps function in C5/6 tetraplegia.\(^3,7,8,14\) Candidates for biceps transfer require intact and functional brachialis and supinator muscles; the transfer may also improve elbow flexion contracture. Both techniques are time proven and provide improved arm control, useful for many daily activities (Fig. 1). Alternatively, triceps reanimation is possible by transferring motor branches from the posterior portion of the deltoid or teres minor muscle (axillary nerve) or the brachialis branch (musculocutaneous nerve) to a triceps motor branch of the radial nerve.\(^{15,16}\)

Reconstruction of forearm pronation

Supination contracture due to imbalance between the functional biceps brachii and supinator muscles and weak or paralyzed pronators seriously impairs hand function and increases the risk of gravity-induced wrist extension contracture. Restoration of forearm pronation re-enabling key pinch is possible by

(a) Distal biceps tendon rerouting, with interosseous membrane release if necessary.\(^7\)

(b) Dorsal transfer of brachioradialis (BR) during transfer onto the flexor pollicis longus (FPL).\(^3\)

The BR muscle is transferred through the interosseous membrane from dorsal to the palmar aspect of the distal forearm and inserted into the FPL.
tendon, which creates simultaneous forearm pronation and thumb flexion.

(c) Derotation osteotomy of the radius, ulna, or one-bone forearm.18

Reconstruction of wrist extension

Brachioradialis-to-extensor carpi radialis brevis tendon transfer:

Reconstruction of active wrist extension is highly important to enable the wrist-driven tenodesis effect. If wrist extension is absent (IC groups 0 and 1), the BR (only IC group 1) can be transferred onto the extensor carpi radialis brevis for passive key pinch during wrist extension after additional FPL-to-radius tenodesis (Moberg procedure).7

Nerve transfer from above the elbow: If antigravity wrist extension is absent and cannot be restored by tendon transfer because of a lack of donors below the elbow (group 0) in C5 tetraplegia, tenodesis pinch can be restored by brachialis motor nerve transfer to the extensor carpi radialis longus (ECRL)
TABLE 5. Surgical Algorithms According to International Classification

<table>
<thead>
<tr>
<th>IC Group</th>
<th>Recommended Surgical Procedure</th>
</tr>
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</table>
| 0        | • Abducted shoulder (anterior deltoide muscle transfer)  
          | • Flexion contracture of the elbow (biceps tendon Z-tendonotomy)  
          | • Supinated but not contracted forearm (Zancoli biceps rerouting—check the presence of supinator muscle)  
          | • Fixed supination contracture—osseotomy of radius  |
| 1        | • BR-to-ECRB for active wrist extension  
          | • Moberg’s key pinch procedure  
          | • ELK procedure  
          | • EPL tenodesis to dorsal forearm fascia  |
| 2        | • BR-to-FPL  
          | • ECRL-to-FDP 2-4  
          | • ELK procedure  
          | • House intrinsic procedure  
          | • CMC 1 fusion  
          | • EPL-tenodesis  |
| 3        | • BR-to-FPL  
          | • ECRL-to-FDP 2-4  
          | • ELK procedure  
          | • House intrinsic procedure  
          | • CMC 1 fusion  
          | • EPL-tenodesis  |
| 4        | • BR-to-FPL  
          | • ECRL-to-FDP 2-4  
          | • ELK procedure  
          | • House intrinsic procedure  
          | • CMC 1 fusion  
          | • EPL-tenodesis  |
| 5        | • BR-to-FPL  
          | • ECRL-to-FDP 2-4  
          | • ELK procedure  
          | • House intrinsic procedure  
          | • CMC 1 fusion  
          | • EPL-tenodesis  |
| 6        | • BR-to-FPL  
          | • ECRL-to-FDP 2-4  
          | • ELK procedure  
          | • House intrinsic procedure  
          | • EDM-to-APB transfer  
          | • EDC-to-EPL  |
| 7        | • BR-to-FPL  
          | • ECRL-to-FDP II-IV  
          | • ELK procedure (if required)  
          | • House intrinsic procedure  
          | • EDM-to-APB or EIP-to-APB  |
| 8        | • BR-to-FPL  
          | • ECRLB activated ADDP  
          | • Opponensplasty (EIP, EDM, FCU)  
          | • Active Zancoli lasso procedure (ECU)  
          | • House intrinsic procedure  |
| 9        | • House intrinsic procedure  

(Continued)

TABLE 5. Surgical Algorithms According to International Classification (Continued)

<table>
<thead>
<tr>
<th>IC Group</th>
<th>Recommended Surgical Procedure</th>
</tr>
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</table>
| 10       | • Pathological postures (MP joints fixed in hyperextension, lack of any functioning intrinsic muscles, wrist fixed either in flexion or extension, etc.)  
          | • Release of contracted muscles, joint capsules, tendon lengthenings  |

ADDP, adductor pollicis; BR, brachioradialis; CMC, carpometacarpal; ECRB, extensor carpi radialis brevis; ECRL, extensor carpi radialis longus; ECU, extensor carpi ulnaris; EDM, extensor digiti mini; EIP, extensor indicis proprius; ELK, extensor pollicis longus loop knot; EPL, extensor pollicis longus; FCU, flexor carpi ulnaris; FDP, flexor digitorum profundus; FPL, flexor pollicis longus; IC, international classification.

Positioning and stabilization of the thumb

**Thumb trapeziometacarpal (TM) joint fusion**: Arthrodesis of the TM joint in approximately 30° of palmar and radial abduction as well as pronation, using T-plate osteosynthesis, positions the thumb in an ideal position to meet the lateral index at the PIP joint level.

**Thumb interphalangeal (IP) joint stabilization**: Hyperflexion of the thumb IP joint disturbs thumb function by missing index during pinch, because of the risk of missing the index during pinch, if extrinsic flexor function is preserved or reconstructed (eg, by FPL reanimation) but intrinsic or extrinsic thumb extensors are paralyzed. The EPL (extensor pollicis longus) loop knot (ELK) and the FPL split tenodesis maximize the thumb-to-index contact area and prevent the drawbacks of arthrodesis (rigidity, nonunion, hardware problems). The EPL tendon is duplicated by forming a tendon loop and suturing it onto itself, which limits interphalangeal flexion to 20°—30°.

Reconstruction of grip function

Tetraplegic patients have only a spontaneous weak pinch depending on wrist extension (tenodesis pinch). To produce a useful grip, preoperative planning considers the patient’s goals, hand muscle function, sensibility, and spasticity. In IC group 2, ECRL is the only reliable wrist extensor and is unavailable for transfer. In IC 3 and higher groups, with 2 strong radial wrist extensors, ECRL is expendable and the donor of choice for active transfers because of its superior architectural properties. In our opinion, the only reliable way of confidently determining sufficient strength of the 2 radial wrist extensors is to elicit
the M4 strength of wrist extension and the concomitant pronator teres muscle strength of at least M3.

**Reconstruction of thumb-to-lateral-index key pinch:** Lateral key pinch grip depends on hand opening by wrist flexion and closing by wrist extension whereby the thumb pulp ideally meets the index middle phalanx radially. The prerequisites are M3 wrist extension, forearm pronation, and an acceptable relationship between the thumb and the fingers. Stabilizing procedures are IP thumb joint tenodesis and TM arthrodesis. Active key pinch is preferably achieved by BR-FPL tendon transfer.\(^3,8\)

**Reconstruction of finger flexion—ECRL-to-\(\phi\)xor digitorum profundus tendon transfer:** Active whole hand closure is powered by ECRL tendon transfer on the deep finger flexors of the index, middle, and ring fingers that may exclude the little finger to prevent hyperflexion.\(^3,8\) It is difficult to distinguish if only the ECRL is present with M4 wrist extension or if both radial wrist extensors have M4 strength and the ECRL can be transferred. In our practice, we recommend to use the ECRL only if there is concomitant pronator teres strength of at least M3; otherwise we favor passive key pinch leaving the ECRL in place and use of the BR for finger flexion.

**Nerve transfer to restore anterior interosseous nerve function:** Transferring the expendable brachialis motor branch (musculocutaneous nerve) to the anterior interosseous nerve (median nerve) can reanimate finger and thumb flexion.\(^15\)

**Reconstruction of intrinsics**

Interossei and/or lumbrical muscle reconstruction can secure MCP joint flexion as well as PIP and distal interphalangeal extension, thereby optimizing index position and flexion to meet the thumb, and also creating support from the middle, ring, and little fingers. Furthermore, extension of the PIP joints is essential for capture and release providing a more normal hand opening compared with extensor digitorum communis reconstruction that gives an intrinsic minus type of opening. The Zancolli lasso and House procedures have been successfully used, yet recent kinematic studies have shown advantages of the lumbrical tenodesis.\(^21,22\)

(a) Restoring passive interosseous muscle function using tenodesis with tendon grafts into lumbrical canals (House procedure).\(^23\)

(b) Reconstruction of active interosseous muscle function by tendon transfer, for example, FDS 4 with 4 tendon slips into lumbrical canals (Brand procedure).

(c) Restoration of palmar abduction of the thumb.

Transferring extensor digiti minimi to the insertion of abductor pollicis brevis restores thumb palmar abduction. Notably, M3 power of the extensor digiti minimi is usually sufficient to increase first web space opening and alter the position of the thumb along the radial border of the index finger.\(^11\)

**Reconstruction of hand opening (extensor phase)**

Reconstruction of hand opening facilitates coming around objects during capture that is frequently impossible due to adhesions of flexors and insufficient finger straightening, even with good passive wrist flexion. Improved hand opening is particularly necessary when gravity or remaining finger extension strength cannot overpower the finger flexion spasticity.\(^12\)

(a) **Passive opening of the first web space** by EPL tenodesis to forearm fascia, powered by active or passive wrist flexion.

(b) **Active opening by tendon transfer,** for example, by transferring pronator teres to EPL, abductor pollicis longus, and extensor digitorum communis (to create global hand opening).

(c) **Nerve transfer of the supinator motor branches (C6) to the posterior interosseous nerve (C7-\(\phi\)l).** Supinatus muscle is always C6-innervated and redundant when biceps is intact. Finger and thumb extension as well as extensor carpi ulnaris (ECU) function is innervated by the posterior interosseous nerve (C7-\(\phi\)) and can be restored by transferring the expendable supinator motor branches.\(^16,17\)

**ECU tenorrhaphy for wrist alignment**

Wrist radial deviation often occurs because of lack of ulnar deviating muscle action, especially in groups

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**FIGURE 1:** A woman with C6 tetraplegic who has regained the ability to shake hand after posterior deltoid to triceps reconstruction and subsequent single-stage grip reconstruction—a good example for enhanced independence and communication.
0 and 1, where only ECRL is strong. The tendon is shortened by suturing a tendon loop onto the ECU itself; the grip strength may increase because of more ergonomic hand function compared with unbalanced hands. The shoulder does not compensate by externally rotating as in the radially deviated wrist.24

Additional procedures to reduce spasticity
As the incidence of incomplete tetraplegia has increased, patients demonstrate more complex functional loss with spastic muscle-joint deformities. These can frequently be corrected by muscle release and/or tendon lengthening and release (Table 6). Lengthening of flexor tendons is performed approximately 5 cm proximal to the carpal canal using a stair-step incision of 6–8 cm in length that achieves a parallel sliding of both tendon stumps and subsequent prolongation of 2–3 cm.12

Combined procedures: active flexor and passive extensor phase with intrinsic reconstruction (alphabet operation)
Traditionally, operations for flexors and extensors were performed separately, yet we developed a reliable one-stage combination of active key pinch and finger flexion together with passive hand opening in C6 tetraplegia (Table 7). To reduce adhesions after extensive surgery and facilitate relearning, activation of transferred muscles with new functions requires early active postoperative training. This simultaneous reconstruction saves time and limits the need for immobilization compared with standard 2-stage reconstructions without increased complications.22,24

Early active mobilization of transferred tendons
Immediate postoperative activation of transferred muscles means a removable orthosis replaces the cast the day after surgery and intermittent exercises start by activating the donor muscles with slight external resistance. Early activation not only prevents adhesions but also facilitates voluntary recruitment of motors before swelling and immobilization-induced stiffness restrain muscle contraction. In addition, the patient is motivated by their early experiences, which gains momentum during the demanding initial postoperative period.13 This approach requires strong tendon-to-tendon attachments using a side-to-side technique with a minimum of 5 cm of crossed sutures along both sides (Fig. 2). This technique is extremely safe as the maximum passive tension in a cadaver model was approximately 20 N, whereas the failure strength of this specific repair exceeded 200 N.25

Nerve transfers
Nerve transfers have been rarely applied in tetraplegia. Extra-anatomical short circuits between expendable donor nerve fascicles from above the SCI and the motor branch of a paralyzed muscle below are effective. Muscles with injured upper but intact lower motoneuron have preserved reflex arcs. They should not become refractory to reinnervation and external stimulation after 18–24 months, like lower motoneuron injured muscles. Intraoperative fascicle stimulation of the recipient nerve may allow highly selective neurotization by axon transfer from the intact donor nerve and thus minimize the distance between donor and recipient and regeneration time. Furthermore, natural biomechanics, force, and excursion of the original muscle are preserved, and adhesion-induced motion restriction is prevented. Extended immobilization is not required—a primary factor why appropriate candidates refuse tendon transfers. Nerve transfers also provide options for patients not amenable to conventional tendon transfers, including IC group 0,3,15,16

Further research should be directed at combining traditional algorithms with these new approaches like Bertelli et al, restoring elbow extension, finger extension (MCP joint), thumb extension, and pinch.26

| TABLE 6. Surgical Management of Spasticity in the Tetraplegic Upper Extremity |
|----------------------------------|-----------------|-----------------|-----------------|
| Spasticity | Affected Muscles | Surgical Procedure | Function |
| Forearm  | Pronator teres | Release | Supination possible |
| Wrist    | FCR, FCU | Tendon lengthening | Wrist extension possible |
| Thumb    | FPL, ADDP | Tendon lengthening | Thumb extension and opening of 1st web space possible |
| Fingers  | FDS/FDP | Tendon lengthening | Hand opening |
| Fingers  | Interossei | Release | Reduction of intrinsic tightness, better grip |

ADDL, adductor pollicis; FCR, flexor carpi radialis; FCU, flexor carpi ulnaris; FDP, flexor digitorum profundus; FDS, flexor digitorum superficialis; FPL, flexor pollicis longus.
Complications

Complications are related to candidate selection, surgery, and rehabilitation (Table 8). Tendon rupture with sudden loss or reduced function during the rehabilitation phase should be carefully evaluated. On the suspicion of transfer and/or tenodesis failure, the patient should be brought back to the operating room for revision and the surgeon should be prepared to augment the revised transfer and/or tenodesis with tendon graft. Transfers and tenodeses may also stretch over time, mostly because of overuse. Thumb and/or index positioning during reconstruction is important for effective pinch. Problems arise if the TM joint is fused in excessive flexion or extension. There are times when the index finger fails to adequately flex to meet the pulp of the thumb at the level of the middle phalanx/distal interphalangeal joint. We have attempted flexor digitorum profundus tenodesis, Zancolli lasso, and even MCP capsulodesis to improve index finger posturing; however, none are truly satisfactory, yet individuals ultimately learn to adjust using a surface to help flex their fingers during the acquisition phase of pinch.

Strict adherence to postoperative therapy is critical. Surgeons and therapists should watch for signs indicating stretch of the transfer and modify postoperative treatment or use protective orthosis fabrication. Finally, dissatisfaction may occur despite good objective results because of poor candidate selection, inadequate information, and thus unrealistic expectations. Preoperative patient-to-patient contact as well as good documentation, with written and video documentation of the functional status and goals, may minimize this risk.

Outcomes

Historically, results have been measured in terms of grasp and pinch strength and activity of daily living performance. A meta-analysis of the literature from more than 500 cases in 14 studies revealed a mean
increase of the Medical Research Council score for elbow extension from 0 to 3.3 after reconstruction and a mean postoperative pinch strength of 2 kg, which markedly improved upper extremity usability. More recently, reconstructive procedures have been evaluated with regard to improved independence, as evidenced by patient-perceived satisfaction and performance of preoperatively prioritized daily-activity goals. Upper extremity surgery affects body function, activity, participation, and personal and environmental factors, and improvements are not just seen in basic activities of daily life such as eating, but also in more complex activities such as domestic life and leisure activities. In a recent interview study by Wangdell et al,
patients summarized their gains as “enhanced independence,” which meant autonomy, freedom from control, self-reliance, and acting for oneself and more active participation in social situations. Psychological aspects included feelings of greater management in daily life, less dependence on people and environment, and greater self-efficacy in hand control (Fig. 3). Mohammed et al presented their results of surgical restoration in a large patient series reporting improved quality of life in 84%. Individuals with stable non-traumatic tetraplegia benefitted similarly from surgical rehabilitation of their upper extremities compared with traumatic cohorts. The sustainability of these benefits has been established.

Studies on neuroprostheses have reported improved ability to perform functional tasks, and allowed patients to perform many activities without adaptive equipment. No longer commercially available but still studied in academic centers, the functional benefits of implanted neuroprostheses may serve selected subpopulations in the future.

Nerve transfers have been used for elbow, wrist, and finger extension as well as digital grasp with more than 70 published procedures including double and triple transfers (Fig. 4). The overall rate of postoperative M3 and 4 functions exceeded 80%, mostly in young patients (younger than 25 years) who were operated on early (6–12 months after their accident). Notably, results in patients older than 40 years, or operated on beyond 12 months after injury, were substantially worse.

In conclusion, the main goals of patients with tetraplegia are more mobility and independence from others’ aid. This can be realistically achieved by surgical rehabilitation of arm and hand function. Every person with tetraplegia should be assessed and informed of possible reconstructive options. This form of hand surgery is extremely reliable, and results are rewarding from the perspective of patients and surgeons, possibly more than in any other field of hand surgery. Combining traditional muscle with innovative nerve transfer will expand the indications in the future. Reconstruction remains possible, even decades after cervical spinal cord paralysis. Improved communication between the medical disciplines who care for spinal injury, therapists, patients, and their relatives should contribute to ensuring that more patients benefit from these options in the future, to at least partially allow them to “take their lives into their own hands” again.
REFERENCES

JOURNAL CME QUESTIONS

Tetraplegia Management Update

Muscle transfer for restoring elbow extension increases the workspace of the hand by what percentage?

- a. 400%
- b. 500%
- c. 600%
- d. 700%
- e. 800%

Which of the following procedures is most applicable for stage 1 International Classification of tetraplegia?

- a. Zancolli lasso
- b. House intrinsic procedure
- c. Extensor carpi radialis-to-flexor digitorum profundus transfer
- d. Extensor digiti minimi-to-abductor pollicis brevis transfer
- e. Moberg key pinch procedure

To take the online test and receive CME credit, go to http://www.jhandsurg.org/CME/home.

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