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SPECIAL COMMUNICATION

Understanding and Overcoming Barriers to Upper Limb Surgical Reconstruction After Tetraplegia: The Need for Interdisciplinary Collaboration

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Abstract

There are approximately 300,000 persons with spinal cord injury living in the United States, and nearly 60% of these persons have suffered tetraplegia with resultant alterations in body function, activity, and therefore participation. Restoring hand function can improve independence, and various studies have shown that persons with tetraplegia rate restoration of arm and hand function higher than bowel and bladder control, walking, or sexuality. There are conservative options to improve upper limb function in this population (eg, orthoses, neuroprostheses). Surgical interventions are also available, and 70% of surgical patients report satisfaction and improvement in various activities of daily living after surgery to restore arm and hand function. Despite these positive surgical outcomes, <10% of the eligible population of 60% to 70% undergo tendon transfer surgery to restore function. Underutilization of surgical interventions can be explained by population-, provider-, and health care systems−specific barriers. With further education of providers and patients and team building across disciplines these barriers can be overcome, ultimately leading to reduced disability and improved quality of life for persons with tetraplegia.

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This article is part of a proposed series of articles aimed at physicians and therapists who treat individuals with complete and incomplete cervical spinal cord injuries (SCIs) who undergo surgical restoration to improve upper limb function. This article provides a basic overview of classification systems for SCI and surgery for the hand and understanding of prevalent barriers and possible solutions.

The entire upper extremity including the hand can be impaired to varying degrees by tetraplegia. The degree of disability depends on the neurologic level of injury as determined by the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) (appendix 1),[1] which guides expected functional outcomes for the patient. The higher the level of injury, the greater the associated loss of function. However, each limb is unique in every patient with tetraplegia; other limb injuries, contractures, and spasticity can all affect the function of the upper limb.

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Surgery to improve function of the upper limb in people with tetraplegia uses standard hand surgical techniques to optimize the residual upper limb function. These surgeries often use a combination of joint fusions, tenodesis, and tendon transfer. Tendon transfer is the most common technique used in this population. Tendon transfer surgery redeploys a functioning muscle by detaching its normative insertion and rerouting it into a different (nonfunctioning) tendon that performs a more desirable function. A contraction of the donor muscle then pulls on the new tendon providing the desired function. This procedure is commonplace after peripheral nerve injuries and has a long track record in tetraplegia. Although a tendon transfer surgery does not change the neurologic level of injury, it is equivalent to a caudal shift in level in terms of improving function. Tendon transfer surgery can therefore be a determining factor in the degree of dependence or independence for a person with tetraplegia.

There are approximately 300,000 persons with SCI living in the United States; of these, nearly 60% have suffered tetraplegia with resultant alterations in body function, activity, and participation.[2] The incidence of SCI in the United States is estimated to

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be 40 cases per million with a global variation of 15 to 29 per million, with tetraplegia varying from 22% in Estonia to 75% in Japan.[3] Because of the lack of proper registries and variability in the incidence and prevalence of tetraplegia, it is difficult to approximate the percentage of persons with tetraplegia who are surgical candidates.[4] Various studies have shown that persons with tetraplegia highly value hand function[5] and even have prioritized hand function over other functions (eg, bowel and bladder control, sexual function, walking).[6,7] Therefore, restoration of hand function is of great importance in improving independence for activities of daily living (ADL) and productivity to persons with tetraplegia and reducing caregiver burden and cost, thereby benefiting the patient, their family, and society as a whole.

Brief history

Care of the upper limb for people with tetraplegia began after World War II when these patients began to survive past their acute injury. Initial attempts included multiple joint fusions, but the results were unacceptable. There were early reports of using tendon transfers in tetraplegia— Freehafer and Mast in the United States in 1967 and Lamb and Landry in Scotland in 1971—but major contributions by Zancolli, Moberg, and colleagues in the early 1970s revolutionized the approach to surgical management in this population.[8-11] Moberg[12] noted that persons with tetraplegia preferred soft supple hands similar to able-bodied individuals and spurned orthotics and functional hinged splints so as to not draw attention to themselves. Shortly thereafter in 1978, surgical restoration of hand and arm function in tetraplegia became a clinical discipline with an international conference attended by surgeons and therapists dedicated to this field. This international group delineated a classification system for the upper limb, the International Classification of Tetraplegia, created in 1984 in Giens, France.[12]

Classification

Innervation of the hand and upper extremity comes from spinal roots C4-T1 and proceeds in a fairly reliable, segmental manner, proximal to distal (table 1). Once the level of injury is known, prediction of function retained and lost is easily defined. The ISNCSCI (see appendix 1), the classification system commonly used in traumatic SCI, focuses on the functional level of injury. The latest revision permits the use of nonkey muscles in addition to key muscles in the 5 cervical myotomes, and it includes the ASIA Impairment Scale (AIS) that distinguishes the completeness of the injury and the sensory integrity of the extremities. In this system, the most distal myotome with a strength grade of 3 in a muscle with the one rostral to it being graded as normative is the motor level. Although this scale is useful in standardizing examination and classification of individuals with SCI, it is not fully able to characterize remaining motor function at each myotome level as is required for surgical planning (see table 1). For example, a patient with C6 level of SCI with strong wrist extension may or may not have 2 wrist strong extensors carpi radialis brevis or extensor carpi radialis longus. It is crucial to be able to define what an individual lacks in function and what muscles are functioning to allow the formulation of a plan using principles of reconstructive surgery. This classification has undergone revisions and is presented in its current form—the International Classification for Surgery of the Hand in Tetraplegia (ICSHT)—in table 1. The ICSHT has sensory and motor components. The presence of intact sensation defined as 2-point discrimination <10mm in the index and thumb is labeled as cutaneous and the absence is called ocular, implying that the individual has to visually monitor their function. For the motor component, a muscle grade of 4, not 3 as in the ISNCSCI standards, is considered functional. A donor muscle must have a muscle grade strength of 4 because after transfer there is a loss of some strength, and therefore a weaker muscle would not produce a functionally useful result.[13,14] After tendon transfer, the muscle is in a different position and the force length curve is never quite the same as it was in its native state. A comparison of the ICSHT and ISNCSCI systems is shown in table 1.[15] Details regarding principles of surgical restoration are provided in other articles in this supplement.

List of abbreviations:

ADL	**activities of daily living**
ICSHT	**International Classification for Surgery of the Hand in Tetraplegia**
ISNCSCI	**International Standards for Neurological Classification of Spinal Cord Injury**
SCI	**spinal cord injury**

Functional outcomes and goals of reconstruction

To understand and treat the upper limb, it is important to recognize the different roles of each part of the anatomy. The hand is a universal tool for manipulation, whereas the shoulder, upper arm, elbow, and forearm provide proximal stability and the ability to move the hand in space for function. Both functions of moving the arm in space and using the hand for manipulation are severely impaired in persons with tetraplegia.

The level of injury directly determines what residual upper limb function remains after a cervical SCI. Persons with high tetraplegia, at levels C2-4, do not have voluntary elbow movement and retain only shoulder shrug and neck movement. Depending on other factors, including the completeness of the injury, they may or may not require ventilator support. Current surgical techniques do not allow reliable restoration of shoulder function; therefore, an individual with SCI above the C5 level is rarely a candidate for surgery.[16]

Injury at C5 is the most common level in SCI (14.9%). Patients with voluntary control of C5 myotome can flex their elbows and retain functional control of the deltoid. They can feed and partially groom themselves with assistance and the aid of adaptive devices. With an injury at the C6 level, patients can extend their wrist and with adaptive equipment can be considered modified independent in grooming, bathing, driving, and simple meal preparation.

The patient with C5/6 level of injury lacks elbow extension strength and the ability to pinch and grasp with the hand. Restoring these functions are the 2 primary reconstructive goals for this group (detailed in other articles in this supplement). Persons sustaining SCI at C5/6 levels usually require a caregiver daily to assist with ADL and mobility.

Use of triceps is retained at the C7 level along with wrist flexion and possible finger extension. These patients can usually perform most ADL and live alone with adaptive devices for the hand and their environment. In those with injury at C7, more donor muscles are available, therefore making it possible to perform more elegant procedures for restoration of pinch and grasp.