General indications for functional surgery of the hand in tetraplegic patients

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Functional surgery of the upper limb is a recent, specialized surgery. In 1987, Möberg [1] wrote, "A totally new way of thinking was needed to overcome strong resistance against surgery." Today, functional surgery of the upper limb plays an important role in the rehabilitation of tetraplegic patients. During the past 30 years, this surgical concept has developed continuously, having been shaped by the experience of a small number of specialized teams throughout the world who meet regularly for international conferences [2–4]. An almost unlimited number of variations are now possible in this rapidly expanding field of hand surgery [5]. In this article, the author presents his experiences and stresses his current point of view, which is still evolving.

Functional surgery of the upper limb in tetraplegic patients is not only a reconstructive operation but also a surgical rehabilitation. One must forget the classic concepts of surgical reconstruction and turn toward the patient's personal desires to lead better tetraplegic life with its myriad problems. The surgical rehabilitation of the tetraplegic patient is always a challenge, because each one is unique, with his or her own remaining physical abilities, wishes, and expectations. Thus, establishing surgical indications based solely on the level of the anatomic lesions and the possibilities of the remaining muscles is a course of action that indicates only what can be done, not what should be done. The surgeon must take into account the individual patient's requirements.

Additionally, this surgery cannot be based only on experience. The number of cases performed by any surgeon will not be high. Because each case is different, experience is acquired only after several years of surgical practice during which the knowledge of the surgeon was challenged repeatedly. Furthermore, several years are necessary to arrange a team of surgical and other professionals to treat the patient. This type of surgery can be practiced only in a specialized environment with a panel of physiotherapists and ergotherapists in highly specialized centers.

Finally, when dealing with the general indications for hand surgery in tetraplegic patients, one must answer three main questions: When?, Who?, and What?

When?
As early as possible

The author has learned from his experience that operating on the patient before he or she adapts to the injury is essential [6]. If a tetraplegic patient is treated too late, the surgery still will provide him or her with new functional possibilities, but the patient will not be able to take advantage because of the new adjustments that would have to be developed. There would be academic results, of course, but they may not be of any practical use to the patient. Tetraplegia that dates back several years is more often a contraindication to surgery; however, even in these cases, there is no general rule against surgery, so long as the patient desires
a precise functional improvement and has understood clearly the aims and risks of a specific surgery.

**When it becomes feasible**

Generally, functional surgery of the upper limb should be considered only 12 to 18 months after the injury (Table 1). According to Ejeskär [7], this can be shortened to 6 or 7 months, a time period with which the author's personal experience concurs. The surgery must be performed as early as possible but should be considered only if the tetraplegia has stabilized (i.e., only after motor improvement has ceased and when there is no risk of posttraumatic myelopathy). Important spasticity and neurovegetative complications must have been treated already, and pressure sores and problems with urinating and defecating must have been remedied as well. Furthermore, the patient must be able to sit in a wheelchair so that he or she can move the upper limb against gravity.

Consideration of the patient’s psychological condition is important. The dramatic change in the patient’s life requires an arduous psychological adjustment that is a prerequisite of surgery. Follow-up by a psychologist is necessary.

In a specialized center, the patient is in contact with others in similar situations who may have undergone surgery already, thus demonstrating the surgical possibilities. The roles of not only a physiotherapist and a medical team but also a para-medical team composed of nurses and medical assistants who have close contact with the patient are of prime importance.

One must operate only on patients who are psychologically ready and who understand the surgical planning, aims, and possible outcomes.

**Who?**

A motivated, well-informed patient who is in sound psychological condition and who has a precise and realistic need for rehabilitation is a good candidate for this type of hand surgery. Individual factors such as age, profession, hobbies, education, family support, and social background must be taken into account. Most of the unsatisfactory outcomes of functional upper limb surgery result from an error in patient selection. Improving hand function in tetraplegic patients is an individual problem, the solution to which depends on the surgeon’s experience and on

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Surgical classification of the upper limb in tetraplegia</th>
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<tbody>
<tr>
<td><strong>Group</strong></td>
<td><strong>M4 (BMRC) muscles</strong></td>
</tr>
<tr>
<td>IC 0</td>
<td>No muscle below the elbow</td>
</tr>
<tr>
<td><strong>High-level tetraplegia</strong></td>
<td></td>
</tr>
<tr>
<td>IC 1</td>
<td>Brachioradialis</td>
</tr>
<tr>
<td>IC 2</td>
<td>ECRL</td>
</tr>
<tr>
<td><strong>Mid-level tetraplegia</strong></td>
<td></td>
</tr>
<tr>
<td>IC 3</td>
<td>ECRB</td>
</tr>
<tr>
<td>IC 4</td>
<td>Pronator teres</td>
</tr>
<tr>
<td>IC 5</td>
<td>Flexor carpi radialis</td>
</tr>
<tr>
<td><strong>Low-level tetraplegia</strong></td>
<td></td>
</tr>
<tr>
<td>IC 6</td>
<td>ECRB, Pronator teres, +/- others</td>
</tr>
<tr>
<td>IC 7</td>
<td>ECRB, Pronator teres, +/- others</td>
</tr>
<tr>
<td>IC 8</td>
<td>ECRB, Pronator teres, +/- others</td>
</tr>
<tr>
<td>IC 9</td>
<td>ECRB, Pronator teres, +/- others</td>
</tr>
<tr>
<td>IC 10</td>
<td>Triceps (+/-)</td>
</tr>
<tr>
<td><strong>Sensation:</strong> Weber = 12 mm (+/-)</td>
<td>Spasticity (+/-)</td>
</tr>
<tr>
<td>+</td>
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</tr>
</tbody>
</table>

**Abbreviations:** ECRB, extensor carpi radialis brevis; ECRL, extensor carpi radialis longus; IC, International Classification.
Spasticity, if present and important, is a classic surgical contraindication but must be differentiated between its harmful and useful types [11]. In some cases of high-level tetraplegia, the activity of the sublesional segment can induce a useful spastic tone that facilitates hand grasp and grip. Harmful spasticity that does not respond to tendon transfers is the only surgical option for patients with the highest levels of tetraplegia who have no transferable muscle below the elbow (International Classification [IC] group 0). FES can improve the results in IC group 1. The author believes that FES is not indicated when there is a strong wrist extension (IC group 3). FES is a technique used only in specialized centers, and it requires precise conditions: anatomic medullary state (ie, presence of a sublesional segment), social adjustment of the patient, and so forth. These indications are rare, and high-level tetraplegic patients who do not fulfill these requirements must not be deceived with false hopes.

Selective sensation in the hand can influence the results but is not as important as Möberg believes; its absence should not be a contraindication to surgery.

Spasticity, if present and important, is a classic surgical contraindication, but must be differentiated between its harmful and useful types [11]. In some cases of high-level tetraplegia, the activity of the sublesional segment can induce a useful spastic tone that facilitates hand grasp and grip. Harmful spasticity that does not respond to medical or surgical treatment is a contraindication.

The shoulder muscles, particularly the pectoralis major, of patients with high-level tetraplegia must be evaluated as being paralyzed or not, which the author has included in his classification. The latissimus dorsi muscle also should be evaluated [11]. The shoulder affects the orientation of the upper limb in space, permitting numerous tricks to compensate for elbow extension deficit. The shoulder must have not only good motor condition but also good proprioceptive control. Because the pectoralis major stabilizes the shoulder anteriorly, the author does not use the posterior deltoid to reconstruct the elbow extension when (1) it is paralyzed in patients with the highest tetraplegia level, and (2) the shoulder is not anteriorly stabilized by the anterior deltoid. The reason for this is this procedure has a retro pulsion parasitic effect during elbow extension. In these cases, the author prefers to use the biceps brachii according to the method described by Zancolli [12] even though (1) this technique reduces the strength of elbow flexion by 30%, and (2) the author generally prefers to use the posterior deltoid.

The trophicity and articular condition of the upper limb also must be considered. A poor condition necessitates a preoperative rehabilitation program.

- Passive flexion of the metacarpo-phalangeal joint must be sufficient.
- Avoid and treat early hyperflexion of the proximal interphalangeal joint caused by hypertony of the flexor digitorum superficialis. A prolonged hyperflexion results in a weakening of the central band of the extensors at the dorsum of the proximal interphalangeal joint.
- The thumb and the index must be well positioned early in the key-grip situation.
- Stiffness of the wrist in flexion must be overcome to allow thumb and finger opening via passive flexion due to gravity.
- Passive elbow extension must be complete to allow elbow locking in extension.
- Supination contracture must be prevented by rehabilitation from the first day of tetraplegia. When established, this attitude is severely debilitating and must be treated surgically with (1) a biceps pronator transfer (according to Zancolli [12]) when it is reducible, or (2) pronation osteotomy of the radius, which the author is using with more frequency. The latter procedure is simple, remarkable operation that considerably improves the condition of the patient and boosts his or her confidence and that of the other patients in the same center who witness the immediate and spectacular
results. Correcting supination contracture avoids stiffness of the wrist in extension due to gravity and the remaining wrist extensors. Correcting supination contracture and replacing the hand in pronation allow the action of the wrist extensors. Sometimes the patient is then able to perform a key grip (Fig. 1); alternatively, rehabilitation can be of use.

What?
The aims of this type of surgery is whatever the well-informed patient desires, not just what can be done (ie, surgical tools).

Surgical tools
The type of functional surgery depends on the level of tetraplegia. The author has adopted the IC, which, despite being overly analytical in defining the number of remaining transferable muscles, is still useful with some modification. For example, the three different types of tetraplegia must be distinguished according to the possibilities of functional surgery. All of these are not necessarily indicated; rather, the choice among these tools depends on the patient and his covenant with the surgeon.

High-level tetraplegia
Functional surgery in high-level tetraplegia is a rather specific operation whose fundamental principles were established by Möberg. The number of high-level tetraplegic patients has been increasing because of the progress made in intensive care. There are two types of high-level tetraplegia according to the extent of the medullary lesion (Fig. 2). (See article on the injured metamere later in this issue.) In high-level tetraplegia, the extent of the medullary lesion predicts the presence or absence of an active sublesional segment. There are two types of paralyzed muscles: those with and those without lower motor neuron damage. The conservation of a sublesional medullary segment without lower motor neuron damage allows FES to be performed in patients with the highest tetraplegia level, which is the only possibility in group 0 when there is no transferable muscle below the elbow.

Clinical examination, electrophysiologic studies and MR imaging permit muscular mapping, which demonstrates the indications for tendon transfer associated with FES. Functional surgery in patients with high-level tetraplegia (G1 or G2) is characterized by only one transferable muscle, the brachioradialis, and by the necessity to reconstruct an active elbow extension and a key-grip prehension.

Reconstruction of active elbow extension
According to Möberg, active elbow extension is of prime importance. Generally, reconstruction of active elbow extension must be performed first, not only to stabilize the elbow and allow the trans-

![Fig. 1. Bilateral supination contracture (high-level tetraplegia; IC group 2). Extensive lesionsal medullary segment. This severely debilitating deformity must be corrected surgically.](image)
In track racing, as in table tennis, the status of the triceps defines only two classes. In archery competition, there is only one class for all tetraplegic athletes because the elbow can be stabilized with a splint. In swimming competitions, all tetraplegic patients are grouped in a single class; there is no competition for tetraplegic athletes without triceps.

In tetraplegic patients who excel at a particular sport, postoperative improvement in the quality of daily life can become secondary to their athletic achievements. For example, a patient without triceps, who became a champion table tennis player by using shoulder movements to adapt to his handicap, feared that he might lose his standing because he would have to change his classification after triceps reconstruction. This case demonstrates the importance of operating before adaptation occurs.

Key-grip construction

Key-grip construction allows for the recovery of prehension. The surgery can be passive according to Möberg [1] or active via the transfer of the brachioradialis to the flexor pollicis longus if the strength of wrist extension is sufficient. The surgeon must consider several factors before performing a key-grip construction:

- The articular status and stability of the thumb ray
- The posture of the thumb, which depends on the presence or absence of a sublesional segment
- The wishes of the patient

The strength of the key pinch
- The amplitude of the opening

Key-pinching strength is better after performing arthrodesis on the carpometacarpal joint and after transferring the brachioradialis to the flexor pollicis longus. The amplitude of the opening is better after a passive key-grip construction without carpometacarpal arthrodesis.

The Simplicity of the key grip construction according to Möberg is in fact very relative. Key grip construction has evolved in time [12,16,17], remains a challenge for the surgeon, and must be custom made.

Mid-level tetraplegia

According to Zancolli [12], mid-level tetraplegia is defined by the presence of a strong wrist extension; however, this classification is too simplistic. A strong wrist extension may be caused by the combined action of the two radial wrist extensors and a weak extensor carpi radialis brevis, which does not allow the transfer of the extensor carpi radialis longus (ECRL). Accurately evaluating the two radial wrist extensors is always a problem; thus, one must be cautious before transferring an ECRL.

Several surgical options exist for mid-level tetraplegia (IC groups 3–5). When there are two transferable muscles (as in IC group 3; brachioradialis and ECRL) or three transferable muscles (as in IC groups 4 and 5; brachioradialis, ECRL, and pronator teres) constructing not only a key pinch but also a grasp is possible. Numerous surgi-
surgeon should inform the patient only of the functional benefits he or she can gain.

The Baltimore Therapeutic Equipment (BTE) Work Simulator [13,14] is useful for assessing and rehabilitating the upper limb. With the BTE Work Simulator, the author has analyzed the role of the triceps during the act of driving a car and has discovered that driving without the triceps but with active elbow extension allows better adjustment of the trajectory and improves driving ability. The BTE also lets the patient evaluate his movements depending on the situation. Driving a car is particularly important for these patients; if it is taught during the rehabilitation program, the patient may wish to undergo surgery more readily (Fig. 3).

The author also has analyzed the role of active elbow extension and found that it increases the possibility of participating in certain sports [15]; however, its importance varies. Ironically, tetraplegia and sports are closely related. Not only are 33% of tetraplegia cases caused by sports injuries, but tetraplegic patients are participating in sports more than ever, as demonstrated in the International Paralympic Games for the handicapped. In the author’s experience, practicing a sport during the acute phase of hospitalization seems to improve the health and well-being of these patients.

Swimming shows a benefit in these patients, but it requires bilateral elbow extension. After bilateral reconstruction of elbow extension, even high-level tetraplegic patients can practice deep-sea diving with a specialized team. Below the water’s surface, they can discover a new universe in which their handicap is far less of a hindrance. Additionally, active elbow extension improves the practice of table tennis, although this can be possible without surgery owing to the mobility of the shoulder. Similarly, in archery, elbow extension reconstruction is not absolutely necessary because a splint that the patient will need to use after reconstruction anyway can stabilize the elbow.

Surgeons must keep in mind that some tetraplegic patients (usually the younger ones) may desire to compete, not merely participate, in a particular sport and that these competitions require a classification system. The original Stoke Mandeville classification system [15] was based on anatomic criteria defined by the level of the tetraplegia and the presence or absence of triceps. The current functional classification system for each sport is defined in terms of the sport and tends to reduce the number of classes in sports for the disabled.

Fig. 2. Cervical MRI of posttraumatic tetraplegia. This patient has useful spasticity and good thumb positioning. Classifications: C6 useful tetraplegia, American Spinal Injury Association (ASIA) motor score of 20/100, ASIA sensitivity score of 40/112, IC group 3 on both upper limbs (symmetrical lesion), mid-level tetraplegia, short lesion segment, sublesional segment without motor neuron damage.
tential programs have two stages: active key pinch and
grasp with active or passive release. Classically,
these programs have been based on the number
of remaining muscles; however, just because they
are available does not mean that the surgeon must
perform them. One must try to forget the classical
surgical procedures for the paralytic hand and, in
most cases, not use any remaining muscles. Resto-
rative of finger extension primarily should be pas-
sive with extensor tenodesis and passive flexion of
the wrist in patients classified as high as IC group 5
who possess strong active flexion of the wrist via
the flexor carpi radialis. In some cases, one may
choose to perform a key-grip construction without
a digitopalmar prehension procedure.

The author's experience has verified an impor-
tant concept stressed by Möberg [1,18]: “The hand
is an organ used not only for gripping but also for
human contact.” The latter function is more
important to young people and may conflict with
the gripping function in tetraplegics. The
author cautiously considers, therefore, the restora-
tion of a grasp in cases of mid-level tetraplegia. If
there is a risk for the development of a rigidly
flexed hand, the author performs only a termino-
lateral pollicidigital pinch.

Low-level tetraplegia

Functional surgery in low-level tetraplegia is
not specific but rather follows the classical princi-
pies of surgery for peripheral hand palsies. Per-
forming classic reconstructive surgery is possible,
but the author has observed a low demand for it
due to good adaptation and other problems that
are prevalent in this patient population.

Using the surgical tools

The results of the different techniques and
tools must be evaluated functionally rather than
analytically. The author has used Lamb's Test to
evaluate the functional results of 76 high-level tetra-
plegic patients who underwent surgery [19]. Fig. 4
shows the important functional improvement after
a complete rehabilitation program of one upper
limb (reconstruction of elbow extension and key
grip). Rehabilitation of both upper limbs does
not improve the results much more, which is a con-
sideration when establishing a surgical program
that should not span too long a period of time.
In mid-level tetraplegia, however, improving the
function of both hands is useful in some cases to
allow intermittent urinary self-catheterization,
which considerably improves self-care and quality
of life. Furthermore, as suggested by House et al
[17], constructing a different type of prehension
on each hand is possible in mid-level tetraplegia,
depending on the patient's wishes.

The use of the surgical tools requires planning a
precise treatment that is compatible with the
patient. This planning stage must not last too long

![Graph](image)

Fig. 4. Pre- and postoperative Lamb's test (mean values) in 76 high-level tetraplegic patients. Comparative results after
surgical rehabilitation of one or two upper limbs.
eral rules. Each case is different, and a successful outcome depends on the experience acquired by a specialized surgeon, the team that surrounds the patient, and the customization of treatment to the personality and wishes of the patient. In addition, direct and caring human contact between the surgeon and his patient are fundamental. Today, many tetraplegic patients who are confined to their wheelchairs spend much of their time on the computer, eager to obtain as much information as possible about their condition from the Internet. One must stress, however, the risks of the false and partial information they might find. Surgical indications should be assessed only after a clinical evaluation and a long and personal discussion between the surgeon and the patient, who in this way establish a covenant between them.

In the 21st century, patients will continue to become better informed, but the surgeon will maintain his role as mediator between the patient and surgery.

Summary

General indications for surgery of the upper limb cannot be codified and do not follow any general rules. Each case is different, and a successful outcome depends on the experience acquired by a specialized surgeon, the team that surrounds the patient, and the customization of treatment to the personality and wishes of the patient. In addition, direct and caring human contact between the surgeon and his patient are fundamental. Today, many tetraplegic patients who are confined to their wheelchairs spend much of their time on the computer, eager to obtain as much information as possible about their condition from the Internet. One must stress, however, the risks of the false and partial information they might find. Surgical indications should be assessed only after a clinical evaluation and a long and personal discussion between the surgeon and the patient, who in this way establish a covenant between them.

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References


