Protection of the Deltoid to Triceps Tendon Transfer Repair Sites

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The posterior deltoid muscle was used to replace lost elbow extension in 11 patients with C5 or C6 level tetraplegia. During surgery stainless steel sutures were inserted into the donor muscle, graft, and tendon insertion sites. Over the succeeding time periods (1 month to 2 years) the distances between the various markers were measured. Significant tendon elongation of 23.1 ± 4.8 mm (mean ± SEM; n = 6) was observed in patients receiving traditional postoperative care. To reduce the tendon elongation observed, a specially designed armrest was developed and applied the first postoperative day. The armrest was designed to maintain the elbow in 20° flexion and to prevent shoulder adduction. The addition of this armrest to the traditional postoperative protocol resulted in a dramatic decrease of tendon elongation to only 8.4 ± 3.0 mm (n = 5). Elongation occurred within the first 6 postoperative weeks in the armrest group; in the nonprotected group, elongation continued for several additional months. The majority of the elongation in both groups occurred in the proximal portion of the tendon–graft–tendon unit. Although this study did not explicitly measure strength, we conclude that preventing excessive muscle length change is required to protect repair sites in posterior deltoid to triceps transfer. (J Hand Surg 2000;25A:144–149. Copyright © 2000 by the American Society for Surgery of the Hand.)

Key words: Tendon transfer, spinal cord injury, muscle, tendon mechanics.

The posterior deltoid muscle may be transferred to the triceps insertion to replace lost elbow extension in patients with C5 and C6 level tetraplegia. The outcome of this procedure has been reported to be acceptable with both tibialis anterior or extensor digitorum longus interpositional grafts.1–4 Considering the large range of motion of the elbow and shoulder joints, a risk exists for overstretching the repair sites, thereby jeopardizing the torque-producing capability of the new motor due to active insufficiency.5 Previous studies have suggested the importance of considering the length-tension relationship,6 not only during surgery but also after surgery, to maintain optimal length that maximizes strength. A particular threat to the structural integrity of the tendon graft attachment site is distraction of posterior deltoid caused by adduction of the shoulder joint.7 Because the muscle passive length–tension curve increases approximately exponentially with length,8 minimal changes in muscle length result in large passive force changes that could rupture muscle, tendon grafts, and repair sites. For more than 15 years we have placed stainless steel markers into the tendons proximally and distally to the attachments during tendon transfer surgery. The distance between...
markers has been radiologically measured at various time intervals after surgery.

Based on our previous experience of deltoid to triceps transfer with tendon elongation frequently exceeding 20 mm (mean, 12.5 ± 4.7 mm; n = 10, years 1984–1994; unpublished data), we wanted to reduce the elongation and thus improve the elbow extension range of motion and strength. The purpose of this study was to describe and test the effect of rigorous postoperative deltoid–triceps protection on tendon elongation as measured by the stainless steel marker technique.

**Materials and Methods**

**Patient Population**

Eleven patients (mean age, 24 years; age range, 20–35 years; 9 men and 2 women) had 13 tendon transfers of the posterior deltoid to triceps brachii muscle secondary to spinal cord injury. The average interval from the time of injury to the procedure was 3.5 ± 1.0 years. The mechanisms of injury were motor vehicle, fall, diving, and sports-related accidents (Table 1). Preoperative evaluation included sensibility testing, joint range of motion tests, and muscle strength tests. Muscle testing was performed according to the British Medical Research Council grading system.9

**Surgical Procedure**

Surgery was performed under brachial plexus anesthesia combined with an axillary nerve block. The patient was placed in the supine position with the arm slightly abducted. An S-shaped incision was made over the posterior aspect of the deltoid and extended approximately 5 cm distal to include the deltoid tuberosity. The posterior deltoid border was then mobilized and the interval between middle and posterior deltoid identified. Care was taken to identify the posterior deltoid insertion that was subsequently detached along with the associated periosseum.

In the second portion of the procedure, tendon was harvested from the tibialis anterior muscle according to the method described by Lacey et al.5 A subcutaneous tunnel was created from the level of deltoid insertion to the distal triceps tendon via a dorsal incision to the level of olecranon. The distal deltoid tendon and the tendon graft were placed with an overlap of 5 cm and sutured to each other using 5–0 Ethibond running sutures (Ethicon, Inc, Somerville, NJ) along the sides of the graft and host tendons. The distal graft insertion was created by threading the tendon graft through several holes made in the flat triceps tendon. The muscle–tendon unit passive tension was set to a moderate level when the arm was positioned along the body with the elbow extended. The tendons were sutured securely using the technique described above. Stainless steel sutures (3–0) were placed in 4 positions: the deltoid tendon (marker1), proximal tendon graft (marker 2), distal tendon graft (marker 3), and triceps tendon (marker 4) at a spacing of 3 cm (Fig. 1). After meticulous cauteration, skin closure, and wound draping, a

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Cervical Level of Injury</th>
<th>Age at Time of Accident (y)</th>
<th>Gender</th>
<th>International Classification</th>
<th>Triceps Grade 4*</th>
<th>Type of Injury</th>
<th>Time Between Injury and Reconstruction (mo)</th>
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<td>1</td>
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<tr>
<td>3</td>
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<td>–</td>
<td>Fall</td>
<td>18</td>
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<tr>
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<td>OCu:3</td>
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<td>–</td>
<td>Dive</td>
<td>18</td>
</tr>
</tbody>
</table>

* Triceps Grade 4 (+ or −) according to the Sixth International Congress on Tetraplegia, Cleveland, OH, 1998.
† Ice hockey.
‡ Horseback riding.
Circumferential plaster cast was applied with the elbow flexed 10° to 15°.

Postoperative Care and Evaluation

Plaster cast immobilization was maintained for 4 weeks to permit adequate strength recovery of the tenorrhaphy sites. After plaster removal, an adjustable elbow angle orthosis was applied for an additional 8 weeks. The elbow was gradually flexed 10° every 2 weeks. The first 6 patients in this study were not provided with any further protection of the transfer; all patients undergoing the procedure after 1993 (n = 5) were provided with a specially designed armrest (Fig. 2) on the first postoperative day that was maintained for approximately 4 months. The armrest consisted of a semicircular and partially constrained padded splint support mounted onto a wheelchair and aligned along the side of the trunk. Thus, shoulder joint adduction was effectively prevented. In addition, the use of an electrical wheelchair was required. During sleep, a rigid splint was used and the arm was positioned slightly abducted. During turning, special attention was paid to keep the arm abducted.

Upper extremity x-rays were obtained 4 to 6 weeks, 3 months, and 6 months after surgery. In

Figure 1. Conventional lateral x-ray view of the upper arm. Four stainless steel markers are indicated. The distances are denoted as proximal (#1 and #2) and distal (#3 and #4) as described in the text. A calibration ruler is shown at the left of the figure.

Figure 2. The arm support attached to the electric wheelchair. Not only is the elbow motion restricted, the shoulder is also restricted from being adducted.
certain cases, measurements were obtained up to 2 years after surgery. The distances between markers 1 and 2 (defined as the proximal interval) and 3 and 4 (defined as the distal interval) were measured after adjusting for x-ray magnification using a calibration ruler (Fig. 1). The stable intratendinous position and orientation of markers relative to bony landmarks have been previously reported.\textsuperscript{11}

After surgery elbow extension was measured using a goniometer with the arm maximally elevated while sitting in a wheelchair. The difference between maximal active and maximal passive extension was measured and reported as elbow extension deficit (in degrees).

### Statistical Analysis

Muscle–tendon unit elongation parameters (proximal, intermediate, distal, and total tendon elongation) were compared by 1-way ANOVA between patients who received and did not receive the armrest support. A 2-way ANOVA was used to test for interaction between postoperative time periods and the effect of the armrest. The significance level ($\alpha$) was chosen as .05 and statistical power (1-$\beta$) was calculated as 71% using the equation of Sokal and Rohlf.\textsuperscript{12}

### Results

#### Tendon Elongation Measurements

The total distance between markers measured approximately 6 months after surgery was 23.1 ± 4.8 mm for patients undergoing the procedure before 1993 (ie, patients without armrests); the corresponding value measured after the change of the postoperative regimen was significantly lower (8.4 ± 3.0 mm; $p < .05$) (Fig. 3). While all of the elongation in the arm rest group occurred within the first 6 weeks, only 60% of the elongation occurred within the first 6 weeks in the nonrestricted group. Four to 6 weeks after surgery there was no significant difference between groups for any marker intervals measured ($p > .4$; Fig. 3). The majority of the elongation in both groups occurred in the proximal interval. The elongations in the distal attachments were essentially the same in both groups (4.0 ± 4.0 mm compared with 3.2 ± 3.2 mm in patients treated with and without armrest, respectively; $p > .8$). Elbow extension deficits of more than 20° occurred in 3 of 7 patients in the nonrestricted group but in only one patient in the restricted group. This latter patient, however, was unable to comply with the standards that were required in terms of immobilization, care, and the use of an electric wheelchair. Elbow extension deficit was decreased, although not significantly, compared with the extension deficit measured before the use of the armrest (7° ± 2° vs 15° ± 5°; $p > .1$).

#### Discussion

The purpose of this study was to quantify the effect of rigorous postoperative repair site protection following transfer of the posterior deltoid to the triceps distal tendon. The present data suggest that elongation of the deltoid–triceps transfer occurs secondary to overstretch of the muscle–tendon unit during recovery. Recently, Kirsch et al\textsuperscript{6} demonstrated that the elbow extension moment produced by the transferred posterior deltoid in the C5 tetraplegia patients was strongly dependent on both shoulder and elbow joint angles. We believe that the most important effect of the armrest in our study is that it prevented shoulder adduction and therefore spared the tendon graft from excessive passive tension. It is, of course, possible to correct for the overstretch of the deltoid by simply resetting the transferred deltoid to a shorter sarcomere length, but slack in this system may jeopardize the final function.\textsuperscript{13}

Lacey et al\textsuperscript{5} presented an attractive technique for
determining the necessary deltoid donor muscle excursion and the deltoid–triceps length–tension relationship during surgery. Excursion was determined by passively lengthening the muscle to its maximal physiologic length and recording the length change from a reference position. Length–tension measurements were performed by attaching the deltoid tendon to a force transducer and applying an electrical stimulus. This may be an effective method for quantification of the passive tension that the repair sites can withstand. Ultimately, however, it would be highly beneficial to correlate sarcomere length and passive tension in the reconstructed elbow extensor as a function of shoulder and elbow positions to enable precise predictions of muscle function.

Recent data from a cadaveric study of the posterior deltoid muscle revealed that muscle fiber length averaged 116 ± 8 mm (mean ± SEM; n = 10; unpublished data). This finding indicates that the 23-mm tendon elongation observed at the repair site would cause approximately 20% shortening of the muscle fibers. If the deltoid normally operates on its descending limb, 20% shortening would increase muscle force by approximately 15%. Alternatively, if the deltoid normally operates on its ascending limb, 20% shortening would decrease muscle force by approximately 10%. Distinguishing between these two possibilities is currently impossible because there are no estimates of the deltoid muscle in vivo operating range in the literature.

The most pronounced elongation took place in the proximal portion of the graft–tendon unit. This likely reflects the comparatively poor tendon structure in the deltoid insertion tendon which was present in spite of the meticulous detachment of the distal tendon insertion that was performed. Further support provided by interweaving a synthetic mesh may strengthen this proximal repair site, as it has been shown in flexor tendon repair. We believe that elongation in the proximal portion takes place early (within days) and prevents the more solid attachment resulting in the greater healing observed during complete immobilization. Distally, on the other hand, it appears that elongation is limited and comparable between the two postoperative protocols. It may imply that the flat but well-defined distal triceps tendon is a structurally acceptable recipient for the graft and that because there are fewer degrees of freedom associated with elbow rotation compared with shoulder movement, distal stresses may be lower. It is also easily accessible and exposed and therefore the risk for technical mistakes is small. The intermediate portion was significantly distended in the unprotected group. This finding may indicate the existence of necrotic portions with mechanically weaker tendon within the graft. This contention remains to be proven, for example, by postoperatively monitoring the graft physiological condition using magnetic resonance imaging.

Significant tendon elongation was found within the first 4 to 6 weeks after surgery, but even more intriguing is the fact that the elongation continued over the next months. This could be due to the fact that the plaster was removed after 4 weeks allowing increased mobility (although restricted by orthosis) in many directions and thereby risk for slippage of the components in the repair site.

It is unclear whether the patients with the armrest were stronger than they would have been without the extra postoperative protection. The elbow extension deficit demonstrated a trend toward reduction, although more measurements are required to unequivocally prove a difference. Comparison of strength between the patients who received the armrest and those who did not is difficult because of the high degree of variability in remaining function, even among patients with identical cervical injury levels. The data clearly support the importance of developing relatively simple and obvious rehabilitative protocols as an adjunct to sophisticated surgical procedures to maximize the effectiveness of the surgery performed.

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References


