Electrical activation of triceps brachii using the Freehand System: A case report

SG Carroll¹, CA Cooper, DJ Brown & GW Sormann
Victorian Spinal Cord Service, Austin and Repatriation Medical Centre and
¹ School of Physiotherapy, The University of Melbourne, Victoria, Australia.

Abstract- The provision of electrically activated elbow extension was studied in recipient of the Freehand system who was deemed too weak to undergo a posterior deltoid to triceps transfer. To achieve eight channels of motor stimulation, the feedback electrode was not utilised in this individual. Two methods of integrating elbow extension into the grasping patterns were trialled. Method 1 involved activation of triceps during the preliminary grasp states when the hand was being positioned for acquisition. Method 2, which was preferred by the subject, involved constant triceps activation throughout the entire grasping task. Careful study of upper extremity function revealed that the subject was unable to maintain forearm position when lifting heavy items unless the triceps stimulation was included in the grasp pattern. There were no difficulties encountered by the loss of the sensory electrode or through muscle fatigue. Our experience in a single individual indicates that electrical activation of triceps brachii should be considered for recipients of the Freehand system who may not be suitable for an alternative tendon transfer.

I. Introduction
The posterior deltoid to triceps transfer for improving elbow extension in people with C6 quadriplegia was first described in 1975 [1]. Although there are now several versions of the original technique, the basis of this procedure has been retained. In this procedure, the posterior part of the deltoid muscle is detached from its insertion on the humerus and attached, via a synthetic graft or lower leg tendon, to the triceps muscle. Contraction of the posterior deltoid in this way produces extension of the elbow.

In order to achieve a functional result, it is important that the elbow be immobilised in extension in plaster of paris or a splint for up to six weeks. Gradual controlled flexion of the elbow is then permitted with the aim being to avoid overstretching of the triceps muscle. This process of gradual mobilisation can take 12 to 16 weeks [2].

The posterior deltoid-triceps transfer is used widely in C6 quadriplegia patients undergoing tendon transfer surgery for augmentation of hand function. In addition to providing elbow extension, this transfer increases stability at the elbow joint by providing opposition to the strong elbow flexors. It also maximises benefits gained from the transfer of the brachioradialis muscle to augment wrist extension or thumb flexion. Without some extensor control at the elbow joint, contraction of the brachioradialis muscle would lead to elbow flexion rather than wrist or thumb movement.

The developers of the Freehand system™, an implanted 8 channel neuroprosthesis designed to restore grasp following quadriplegia [3] have also recognised the value of elbow control in order to maximise hand function. Sites evaluating this technology have been encouraged to incorporate the posterior deltoid triceps transfer into their surgical protocols. Of the first 38 Freehand system recipients, 29 have received a posterior deltoid to triceps transfer either prior to or during their implant surgery [unpublished results].

The Austin and Repatriation Medical Centre, Melbourne, Australia, commenced trialling the Freehand System in patients with C5 quadriplegia in 1993/4. To date, five patients have received this device. Of these, the first two subjects underwent the posterior deltoid to triceps transfer prior to their implant surgery while the third subject had both surgeries on the one occasion. Good results have been achieved for the Posterior deltoid to triceps transfers in the first and third subjects where elbow extension has improved in each case from grade 2 preoperatively to grade 4 [4] postoperatively. In the second subject, the posterior deltoid muscle was quite weak pre operatively (Grade 2) and the transfer only produced a Grade 2 elbow extensor.

The fourth candidate was not a candidate for a posterior deltoid triceps transfer as he had previously undergone a transfer of biceps to triceps. The fifth subject, however, was found to have marked weakness in the posterior deltoid muscle preoperatively (Grade 2) and thus it was decided to trial the use of an electrode to activate triceps brachii. It was hoped the application of an electrode to the triceps muscle would produce stronger elbow extension and avoid the prolonged rehabilitation time associated with the posterior deltoid to triceps transfer.

II. Method
The subject was a 28 year old farmer who had suffered quadriplegia 14 months prior to his Freehand surgery. His injury was classified as C5 on the left and C4 on the right (see Table 1).

Typically the Freehand system provides seven channels for muscle stimulation and one channel for system-state feedback. It was this eighth channel that was used to provide triceps stimulation. The epimysial electrode was positioned at the junction of the proximal and middle thirds of the muscle. The other seven epimysial electrodes were placed on the following muscles: extensor digitorum communis, flexor digitorum sublimis, flexor digitorum communis, extensor pollicis longus, flexor pollicis longus, abductor pollicis brevis and adductor pollicis. This is the standard arrangement for the Freehand system. Other reconstructive procedures performed included tenodesis of the flexor pollicis longus tendon, brachioradialis to extensor carpi radialis brevis.
After three weeks of immobilisation, an exercise program was commenced. After six weeks of up to six hours a day of exercise, the subject returned for grasp and control, set up and rehabilitation. All implanted electrodes were found to produce strong contractions of target muscles, including the triceps electrode which produced antigravity elbow extension, graded as 4- on the MRC scale [4].

<table>
<thead>
<tr>
<th>Voluntary Strength</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper trapezius</td>
<td>4+</td>
<td>5</td>
</tr>
<tr>
<td>Middle deltoid</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Biceps brachii</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Brachioradialis</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Supination</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Wrist extension</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pronation</td>
<td>2-</td>
<td>0</td>
</tr>
<tr>
<td>Triceps brachii</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>All distal muscles</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 1: Pre-operative voluntary muscle strength based on the MRC scale [4].

III. Results

To avoid the need for a separate control system for the triceps electrode, a simple system for incorporating elbow extension into the grasp pattern was planned. It had been intended that the triceps electrode would be just used to extend the elbow during acquisition of objects such as a pen, or a cup. This was considered important for this subject who was not able to use his other hand to assist in this phase of grasping. The pulsewidth of the triceps electrode was to be progressively reduced so that the subject could bend his elbow and bring the cup, for example, to his mouth.

However, after preliminary trials, the subject requested that the output of the triceps electrode be maintained throughout the entire grasping process as he found that it stabilised his elbow and improved his control of the object in his hand. To investigate this further, a series of activities of daily living were studied both with the triceps electrode on through out the grasp and with it turned off at all times. These studies revealed that while the absence of an active triceps had no effect on the ability of the subject to lift light objects, it did impair performance on tasks such as drinking from a full cup or lifting a video cassette. In these latter tasks, the subject appeared unable to overcome the effects of gravity on the object being held without co-contraction of flexors and extensors at the elbow. Furthermore, despite continuous stimulation during grasping tasks, there was no evidence of triceps muscle fatigue.

IV. Discussion

The need for an electrically activated triceps has not been ignored by developers of functional electrical stimulation (FES) systems. For example, Miller et al [5], Hoshimiya et al [6] and Nathan et al[7] each describe sophisticated FES systems which incorporate elbow extension as well as grasp and release function. These systems have been designed for people with quadriplegia at C4 or C5 level but unlike the scenario described above, each has required a complex and separate mechanism for controlling stimulation to the triceps electrode. Our experiences with this subject indicate that such complex control systems may not be necessary if the subject has a strong excitable triceps brachii muscle and sufficient voluntary strength of the biceps brachii muscle to counter the effect of the triceps electrode.

There are definite advantages of the posterior deltoid to triceps transfer over the triceps electrode. The key advantage of the tendon transfer procedure is that the voluntary elbow extension and the stability of the elbow to facilitate the action of a transferred brachioradialis muscle are not dependent upon the operation of a neuroprosthesis but are available to the user at any time. Additionally anecdotal studies in our Spinal Injuries Unit have revealed that partial denervation of the triceps is quite common in people with C6 quadriplegia. Such people are, however, also likely to have sufficient strength in their posterior deltoid and brachioradialis muscles for tendon transfer.

Based on the limited findings of this case study, the use of an electrically activated triceps muscle is recommended for individuals whose posterior deltoid muscle is considered too weak for transfer into the triceps brachii muscle. The precise level of strength required pre and postoperatively for a successful tendon transfer has yet to be determined. Further studies to clearly identify the kinematics of grasp during the presence and absence of triceps activation and the presence or otherwise of muscle fatigue are also required.

V. References