Introduction

The reconstruction of the upper limb often requires functioning muscle units to be transferred. In severe injuries such as crushed forearms, Volkmann's ischaemia, brachial plexus lesions and tetraplegia, there is often a paucity of available muscle units for reconstruction. One avenue, which is relatively unexplored, is the use of split pedicled muscle transfers. The prerequisite for a split muscle to work is the presence of two or more sub-division or compartments, each with its own neuro-vascular supply. The flexor carpi ulnaris has been found to have two neuromuscular compartments, each compartment having with its own nerve entry point (motor point) and blood supply. This paper looks at the independent isometric function and muscle architecture of neuromuscular compartments of the split flexor carpi ulnaris (FCU) in the adult macaca fascicularis.

Material and Methods

In four adult macaca fascicularis (2.5 -3.5 kg) under general anaesthesia, the forearm was exposed and the FCU tendons released, leaving the muscle belly still attached to its ulna border and the humeral attachment. The nerve entering the muscle supplied from the ulnar nerve was identified and then electrically stimulated with mono-polar electrodes at their motor points (5 V, 25 ms pulse width, 20 Hz, for 5 seconds). Five-minute intervals were respected between stimulation to avoid fatigue and creep of the muscle. The isometric force at the tendon end was measured using a force transducer (DFG, Lloyds, London UK) recorded at a sampling rate of 100Hz (CODAS, Dataq Instruments and a Personal Computer). At all times the in-situ muscle resting length was maintained and the forearm and wrist secured in neutral. The intact muscles were stimulated at both motor points. The muscles were then split along its tendon, up to the distal third of the muscle belly leaving the humeral and ulna attachments intact. The isometric force at the split tendon ends were then measured after stimulating the motor points of each compartment separately. The muscles were then harvested and the muscle architecture and muscle fiber type of each compartment determined.

Results

The mean isometric force of the intact muscle was 2.50-kg, when the main nerve supplying the muscle was stimulated. After splitting the muscle, the isometric force measured for each compartment when stimulated separately was 2.02-kg (SD, 0.69) for the humeral compartment and 2.22-kg (SD 0.82) for the ulnar compartment (Fig. 1). Stimulating one compartment did not result in any contraction at the other compartment. The PCSA and the fiber length for each compartment respectively, were 2.18 cm² and 1.66-cm for the humeral compartment and 1.47 cm² and 1.29-cm for the ulnar compartment (Table 1).

Discussion

The electrical stimulation studies confirmed that the split muscle could be stimulated to elicit individual independent muscle contraction of each of the humeral and ulnar compartment bellies. This has great potential of using either bellies for tendon transfer, each with its own neuro-vascular pedicle. It also has the potential of using one belly, while leaving the other belly in-situ, thus reducing the donor morbidity in tendon transfers.
The force generated when stimulating the ulna component of the FCU was marginally higher (p=0.08) than the humeral compartment, although the PCSA was smaller and the fiber length shorter in the ulna compartment. It was noted that the fiber types in the ulna compartment were more type I fibers at the distal third of the muscle belly of the ulna compartment (40%) than the humeral compartment (25%), while at the middle compartment the distribution was not significantly different in both compartments (humeral = 33.3%, ulna 34.3%). The proximal attachment of the humeral compartment was noted to be 100% type II fibers. This wide distribution of muscle fiber types throughout both compartments probably also has some bearing to the type of isometric contraction and force generated rather than predicting it from just the PSCA of each compartment. This reflects a need to re-look at how the PCSA is used as a predictor of muscle force potential in split muscle compartments.

Splitting the muscle disrupts the relationship between the two compartments, yet creating a new design for possible use as independent motor units. The next step is to, of course, question whether there is plasticity in a muscle relevant enough to adapt to its new mode of operation and mechanical environment when used in a pedicled tendon transfer.

Table 1. Mean Muscle Architecture and Compositions for the two compartment of the FCU.

<table>
<thead>
<tr>
<th></th>
<th>FCU, humeral compartment</th>
<th>FCU, ulna compartment</th>
<th>FCU, whole muscle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample, n</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Weight, g</td>
<td>3.80 (0.28)</td>
<td>2.39 (0.33)</td>
<td>6.19</td>
</tr>
<tr>
<td>Fiber length, cm</td>
<td>1.66 (0.59)</td>
<td>1.29 (1.84)</td>
<td>1.48 *</td>
</tr>
<tr>
<td>Pennation angle, deg.</td>
<td>8.67 (2.14)</td>
<td>20.00 (0.01)</td>
<td>14.33 *</td>
</tr>
<tr>
<td>PCSA, cm²</td>
<td>2.18 (0.33)</td>
<td>1.47 (0.33)</td>
<td>3.65</td>
</tr>
<tr>
<td>Type I Muscle Fibers (% of total fibers))</td>
<td>32.3 %</td>
<td>38.0%</td>
<td>35.2%*</td>
</tr>
</tbody>
</table>

* - average between the ulna and humeral compartment

Fig. 1. Isometric Muscle Force (N) versus stimulation time (sec.) curves of the a) humeral compartment and b) ulna compartment from one specimen, after stimulating the either compartments independently after splitting the muscle up to the proximal third of the muscle belly.
References


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