The involvement of the triceps brachii muscle is frequently observed in patients who have sustained partial injuries to the brachial plexus. Extending along the posterior surface of the arm, the triceps acts as the most powerful muscle for extension of the elbow. Elbow extension is an action frequently required for opposing gravity, as when the patient aims to reach some overhead objects reliably. The control of the triceps brachii may increase the patient’s ability for properly positioning the hand, dramatically improving the quality of life of patients who have sustained injury to the upper and middle trunks of the brachial plexus.

To date, there is no standardized protocol determining the best operative planning for patients sustaining traumatic brachial plexus lesions. However, most experienced peripheral nerve surgeons agree that restoration of elbow flexion and shoulder abduction are the primary goals of the procedure. The most recent advancements in operative treatment of the brachial plexus, such as improvement in microsurgical technique and the use of alternative donor nerves (such as contralateral donor nerves or distal nerve transfer techniques) have allowed for more extensive repairs; therefore, hand flexion and especially elbow extension can currently be included in the rank of desirable functions to be restored.

The purpose of this study is to describe the author’s experience with restoration of elbow extension for adults who have suffered nerve root injuries.

Object. Recent advancements in operative treatment of the brachial plexus authorized more extensive repairs and, currently, elbow extension can be included in the rank of desirable functions to be restored. This study aims to describe the author’s experience in using the medial pectoral nerve for reinnervation of the triceps brachii in patients sustaining C5–7 palsies of the brachial plexus.

Methods. This is a retrospective study of the outcomes regarding recovery of elbow extension in 12 patients who underwent transfer of the medial pectoral nerve to the radial nerve or to the branch of the long head of the triceps.

Results. The radial nerve was targeted in 3 patients, and the branch to the long head of the triceps was targeted in 9. Grafts were used in 6 patients. Outcomes assessed as Medical Research Council Grades M4 and M3 for elbow extension were noted in 7 (58%) and 5 (42%) patients, respectively.

Conclusions. The medial pectoral nerve is a reliable donor for elbow extension recovery in patients who have sustained C5–7 nerve root injuries.

Key Words: • elbow extension • medial pectoral nerve • nerve transfer • shoulder adduction • triceps brachii • peripheral nerve

Reanimation of elbow extension with medial pectoral nerve transfer in partial injuries to the brachial plexus

Clinical article

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Object. Recent advancements in operative treatment of the brachial plexus authorized more extensive repairs and, currently, elbow extension can be included in the rank of desirable functions to be restored. This study aims to describe the author’s experience in using the medial pectoral nerve for reinnervation of the triceps brachii in patients sustaining C5–7 palsies of the brachial plexus.

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Key Words: • elbow extension • medial pectoral nerve • nerve transfer • shoulder adduction • triceps brachii • peripheral nerve

Abbreviations used in this paper: BLHT = branch of the long head of the triceps; MPN = medial pectoral nerve; MRC = Medical Research Council.
Medial pectoral nerve transfer to triceps
cord injury or other neuromuscular disorders affecting the limbs were excluded. Written informed consent was obtained from each participant, and the study was carried out in accordance with the Declaration of Helsinki II and was approved by the local ethics committee.

Preoperative assessment included nerve conduction studies, electromyography, and CT myelography. The latter examination was indicated for cases of closed traction injuries, and 2-mm-thick axial sections of the cervical spine (C-1 to T-1) were obtained. Root integrity was considered if the root imprint was identified, and pseudodemocele was considered a criterion for avulsion only if the root imprint was not visualized. The British MRC grading system (Grades 0–5) was used to score the strength of the triceps brachii.4 The muscle was tested against gravity and resistance, with the shoulder positioned in 90° of anterior flexion and the patient lying supine.

The surgical planning for these cases included reanimation of shoulder abduction and elbow flexion motions as the primary goals for all cases. Grafts from C-5 to the posterior division of the upper trunk and the accessory nerve to suprascapular nerve transfer were the most frequent techniques used for reinnervation of the shoulder. Grafts from C-5 or C-6 to the anterior division of the upper trunk or to the musculocutaneous nerve, and the Oberlin procedure (transfer of a motor fascicle from the ulnar nerve to the nerve of the biceps18) were the most frequently used techniques for elbow flexion recovery.

Surgical Technique

The surgical approach was made via a deltopectoral incision. The pectoralis major muscle was identified and carefully separated from the fibers of the deltoid muscle. The pectoralis minor muscle was sectioned laterally to the neurovascular bundle. Following mobilization of the musculocutaneous nerve, the lateral cord and axillary artery were medially retracted, and the radial nerve was isolated at the point at which it runs superficial to the lower border of the subscapularis muscle. The position of the axillary nerve was checked superiorly and, following distal mobilization, the branch destined to the long head of the triceps muscle was identified running medial and somewhat obliquely to the radial nerve. The MPN was isolated and dissected from the level of the ansa pectoralis to the point at which it pierces the fascia of the pectoralis minor muscle (Fig. 1 upper). Intraoperative electrical stimulation (Aesculap) was used to check the function of the MPN, which was finally transected and rerouted to the target nerve via a terminoterminal tension-free cooperation (Fig. 1 lower), or by using a single short interpositional sural nerve graft (3–5 cm).

The affected upper extremity was immobilized in a sling for 3 weeks, with the elbow flexed at 90°. Intense physiotherapy training followed this process; initially, passive exercises were encouraged to prevent joint contractures. As soon as the first contraction of the triceps brachii muscle was seen, nerve stimulation was undertaken by asking the patient to perform a forceful shoulder adduction while attempting to actively extend the elbow.

Fig. 1. Infraclavicular surgical exposure of the brachial plexus on the left side. Upper: The pectoral minor muscle is sectioned, revealing the MPN and BLHT. Lower: The medial pectoral nerve is sectioned and sutured to the BLHT.

Results

This retrospective study included 12 adult patients who met the criteria for inclusion specified earlier. There were 9 men and 3 women with a mean age of 31.5 years (range 18–50 years). All patients demonstrated complete palsy of the triceps brachii muscle before the surgery. The mean time interval from injury to surgery was 5.5 months (range 3–11 months), and the mean postoperative follow-up time was 25.5 months (range 18–45 months).

Table 1 summarizes the data regarding preoperative parameters and the outcomes of each case. The radial nerve was targeted in 3 patients (those who sustained an extended Erb-Duchenne syndrome associated with preoperative palsy of the finger and wrist extension), and the BLHT muscle was chosen as the recipient in 9 patients (those in whom the hand and finger extension functions were considered normal or near normal preoperatively). All patients exhibited reinnervation of the triceps (Fig. 2). An MRC Grade M4 for elbow extension was noted in 7 patients (58%), and Grade M3 was noted in 5 patients (42%). In patients in whom the radial nerve was targeted, 2 had Grade M3 outcomes and 1 had a Grade M4 outcome; in the group in which the BLHT was targeted, 3 attained...
Grade M3 (33%) and 6 attained Grade M4 (66%). Six patients required interpositional grafts; outcomes graded as MRC M4 were noted in half of these patients. However, of the 6 patients in whom direct cooptation between donor and target nerve was possible, 4 patients (66%) attained Grade M4. Good surgical results were also noted for elbow flexion (Grade M2 in 1 patient, Grade M3 in 4 patients, and Grade M4 in 7 patients); conversely, the outcomes regarding shoulder abduction were considered fair (Grade M0 in 2 patients, Grade M2 in 1, Grade M3 in 7, and Grade M4 in 2 patients with at least 60° of abduction in the coronal plane).

The average time for the first triceps contraction was 9 months (range 6–12 months). The average time required to achieve extension against gravity was 13 months (range 9–18 months). Simultaneous biceps and triceps co-contraction was not noted in any case, and the power for elbow flexion was not considered downgraded due to the triceps reinnervation in any case. The postoperative power for shoulder adduction and internal rotation was considered diminished by all patients; however, it was noted that the patients were still able to perform these actions by activating the latissimus dorsi muscle in particular.

Discussion

The radial nerve innervates the triceps brachii muscle via some motor branches destined specifically for the 3 heads of this muscle. Anatomical studies demonstrated that a single branch innervates the long head of the triceps, whereas double innervation is usually observed in the lateral and medial heads.6 Hence, the BLHT was chosen as the recipient nerve (instead of other motor branches to the lateral or medial heads) because it is the easiest branch to identify via an infraclavicular approach (as it is the first motor nerve to branch off from the radial nerve), and as the long head of the triceps also acts as a weak shoulder adductor,7 its reanimation could improve the final stability of the shoulder joint. This secondary gain might partially compensate for the loss of function of the pectoralis major muscle.

Elbow extension is required to oppose gravity, and, without active extension, the arm and hand may fall onto the face of the patient when he or she lies supine. In ad-

TABLE 1: Outcomes of 12 patients who sustained C5–7 nerve root injuries in which the medial pectoral nerve was used as a donor for restoration of elbow extension*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Type of Injury</th>
<th>Target</th>
<th>Associated Technique</th>
<th>FU (mos)</th>
<th>Elbow Ext</th>
<th>Elbow Flex</th>
<th>SA (ROM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24</td>
<td>C-5 RR, C-6–7 RA</td>
<td>radial (graft)</td>
<td>XI-SN, Phr-MC</td>
<td>38</td>
<td>M3</td>
<td>M3</td>
<td>M3 (30°)</td>
</tr>
<tr>
<td>2</td>
<td>41</td>
<td>C5–7 RA</td>
<td>radial</td>
<td>XI-SN, Phr-MC</td>
<td>40</td>
<td>M3</td>
<td>M3</td>
<td>M3 (30°)</td>
</tr>
<tr>
<td>3</td>
<td>27</td>
<td>C-5 RR, C-6–7 RA</td>
<td>radial</td>
<td>XI-SN, Oberlin, C5-Ax</td>
<td>33</td>
<td>M4</td>
<td>M4</td>
<td>M4 (60°)</td>
</tr>
<tr>
<td>4</td>
<td>34</td>
<td>C-5 RR, C-6–7 RA</td>
<td>BLHT</td>
<td>XI-SN, C5-MC</td>
<td>45</td>
<td>M4</td>
<td>M4</td>
<td>M3 (45°)</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>C5–7 RA</td>
<td>BLHT (graft)</td>
<td>XI-SN, Oberlin</td>
<td>30</td>
<td>M4</td>
<td>M4</td>
<td>M0</td>
</tr>
<tr>
<td>6</td>
<td>24</td>
<td>C5–6 RR, C-7 RA</td>
<td>BLHT (graft)</td>
<td>C5-PDUT &amp; SN, C6-ADUT</td>
<td>40</td>
<td>M3</td>
<td>M4</td>
<td>M3 (50°)</td>
</tr>
<tr>
<td>7</td>
<td>27</td>
<td>C5–7 RA</td>
<td>BLHT</td>
<td>XI-SN, Phr-MC</td>
<td>36</td>
<td>M3</td>
<td>M2</td>
<td>M0</td>
</tr>
<tr>
<td>8</td>
<td>18</td>
<td>C 5–7 RA</td>
<td>BLHT (graft)</td>
<td>XI-SN, Oberlin</td>
<td>24</td>
<td>M4</td>
<td>M4</td>
<td>M3 (30°)</td>
</tr>
<tr>
<td>9</td>
<td>37</td>
<td>C-5 RR, C-6–7 RA</td>
<td>BLHT</td>
<td>C5-ADUT &amp; PDUT</td>
<td>28</td>
<td>M4</td>
<td>M3</td>
<td>M2 (30°)</td>
</tr>
<tr>
<td>10</td>
<td>43</td>
<td>C–7 RR, C-5–6 RA</td>
<td>BLHT (graft)</td>
<td>XI-SN, C7-PDUT, Oberlin</td>
<td>20</td>
<td>M4</td>
<td>M4</td>
<td>M4 (70°)</td>
</tr>
<tr>
<td>11</td>
<td>22</td>
<td>C5–7 RA</td>
<td>BLHT</td>
<td>XI-SN, Oberlin, Phr-Ax</td>
<td>18</td>
<td>M4</td>
<td>M4</td>
<td>M3 (50°)</td>
</tr>
<tr>
<td>12</td>
<td>31</td>
<td>C5–6 RR, C-7 RA</td>
<td>BLHT (graft)</td>
<td>C5-SN &amp; PDUT, C6-ADUT</td>
<td>24</td>
<td>M3</td>
<td>M3</td>
<td>M3 (60°)</td>
</tr>
</tbody>
</table>

* ADUT = anterior division of the upper trunk; Ax = axillary nerve; Ext = extension; Flex = flexion; FU = follow-up; MC = musculocutaneous nerve; Oberlin = transfer of a motor fascicle from the ulnar nerve to the nerve of the biceps; PDUT = posterior division of the upper trunk; Phr = phrenic nerve; RA = root avulsion; ROM = range of motion of the joint on the coronal plane; RR = root rupture; SA = shoulder abduction; SN = suprascapular nerve; XI = accessory nerve.

Fig. 2. This female patient sustained an avulsion of the C-5 nerve root and postganglionic injury of the C-6 and C-7 spinal nerves. A transfer of the medial pectoral nerve to the BLHT was performed, and the patient recovered strength (MRC Grade M4) for elbow extension 14 months after the surgery.
dition, the need for extension of the forearm typically includes exercises such as swimming or throwing a ball, and it is especially useful when the patient needs to reach some overhead objects reliably. Triceps reinnervation has not been considered of much importance regarding functional outcomes in brachial plexus injuries because gravity usually helps to extend the elbow in determined positions of the upper limb. However, selective reinnervation of only the biceps/brachialis muscles (associated with a paralyzed elbow extension) results in an unstable elbow flexion motion, and frequently the patient needs to use the contralateral hand to lock the elbow and to keep the forearm in the desired position.

The MPN arises from the medial cord or the anterior division of the lower trunk, receiving output from the C-8 and T-1 spinal nerves. Initially, it travels in a right angle around the lateral thoracic artery. At this point it forms a plexus with a deep branch of the lateral pectoral nerve, forming a loop around the axillary artery, termed the ansa pectoralis. Next, the nerve pierces the pectoralis minor muscle, to finally end in distal terminal branches that innervate the pectoralis major muscle. In one-third of cases, the MPN may travel along the inferior border of the pectoralis minor muscle, instead of piercing it. During our surgeries, we usually identified the nerve at a site distally to the ansa pectoralis and proximally to the point at which it pierced the pectoralis minor muscle. Considering that the plexiform arrangement of the pectoral nerves around the axillary artery may sometimes make it difficult to differentiate the medial and the lateral pectoral nerves, routine use of electrical stimulation of each nerve is strongly recommended to ensure the proper donor for the transfer. The selected nerve must be followed to the level at which it began to divide in its distal muscular branches, and finally sectioned. A length for rerouting of 4–5 cm is usually possible to obtain by using this technique (Fig. 3).

The transfer of the MPN to other recipient nerves has already been documented in the literature, especially for reanimation of the musculocutaneous and axillary nerves. Samardzic et al. described 85.7% of useful functional recovery of elbow flexion in adult patients in whom the MPN was transferred to the musculocutaneous nerve and 81.6% for transfers targeting the axillary nerve. In infants, Wellons et al. noted that 80% of patients regained functional recovery of elbow flexion by transferring the MPN to the musculocutaneous nerve. The MPN is a good option as a donor for elbow extension reanimation only in cases in which elbow flexion and shoulder abduction have already been reinnervated by other powerful donors; otherwise, it should be reserved as a source of axons for restoration to one of these functions. A preference for elbow flexion and shoulder abduction reinnervation for patients sustaining partial injuries of the brachial plexus is adjusted on a case-by-case basis; however, the use of proximal roots is always considered when the C-5 and C-6 roots are not avulsed, and distal nerve transfer techniques (such as the Oberlin procedure) have been used with increased frequency.

There are some advantages to using the MPN as donor for triceps recovery. 1) The MPN, the BLHT, or the radial nerve can be approached via the same route (the infraclavicular approach). However, occasionally we noted a lack of adequate distance for direct coaptation between the MPN and the BLHT. In these situations, a short single interpositional graft was used, and the analysis of the results suggested that the use of grafts did not demonstrate a significant impact on the final outcome of these patients. 2) In the particular case of the BLHT, its cross-sectional area matches adequately the area of the MPN. Although in this study satisfactory results by transferring the MPN to both the radial nerve and the BLHT were obtained, currently I consider one of the motor branches to the triceps as the ideal target instead of the radial nerve itself. Targeting the donor nerve directly to one of the motor branches of the radial nerve can avoid the dispersion of axons and improve the number of fibers that intend to reach the triceps brachii; moreover, it also avoids the potential of damaging some residual intact fibers within the radial nerve. 3) Elbow extension and shoulder adduction are synergistic actions, thereby simplifying the postoperative training for relearning.

Three problems must be kept in mind when the surgeon decides to sacrifice the MPN for reinnervation of the triceps. First, in patients with upper brachial plexus injuries in whom the lateral pectoral nerve has been paralyzed, sacrifice of the MPN leads to paralysis of the pectoralis major and minor muscles, and the power for shoulder adduction and internal rotation is, consequently, weakened. In this study, it was noted that all patients were still able to use the thoracobrachioabdominal pinch following surgery by activating in particular the latissimus dorsi. It is important to remember that, most of the time, this is the only muscle that remains functional for adduction and internal rotation of the shoulder in patients sustaining C5–7 palsies if the MPN is sacrificed for the transfer. The anterior portion of the deltoid (C-5 and C-6), the subscapularis (C-5 and C-6), and the teres major (C-5 and C-6) muscles are paralyzed due to injury to the nerve roots; and the lateral pectoral nerve is frequently involved in the primary lesion (as it receives output from the injured C-5, C-6, and C-7 spinal nerves). To avoid a complete postoperative paralysis of adduction of the humerus, in my opinion the power of the latissimus dorsi must be determined before surgery, and the section of the MPN should be avoided if this muscle is considered very weak or paralyzed. Second, there is always the risk that the reinnervated triceps brachii may become more powerful than the biceps, and the main goal of the brachial plexus surgery might not be achieved (that is, no appropriate power for elbow flexion is regained). Considering that the MPN was demonstrated to be a very effective donor for recovery of elbow extension, it is also very important to properly select the source of axons for elbow flexion, and, as important as the power of the donor, ideally these axons should reach and reinnervate the biceps and brachialis muscles at the same time as those targeting the triceps. Otherwise, an earlier recovery of the triceps brachii could prevent a good functional recovery of elbow flexion. Although such problem was not observed in any of our cases, it must be considered in cases in which reinnervation of the triceps brachii is attempted.
during brachial plexus surgery. Third, co-contractions involving the triceps and the biceps/brachialis would also be considered as a source of problems for elbow flexion recovery in cases in which a strong reinnervation of elbow extension was achieved.\(^{10}\) This complication was not observed in any of our patients and, in my opinion, it can be explained by the fact that the donors used for elbow flexion restoration and elbow extension were different in all of the cases, creating 2 completely independent routes for the appropriate supraspinal control of these proximal muscles of the upper limb.

Limitations of this study include its small sample size, a lack of controls to rule out superiority of this technique compared with other techniques or compared with cases in which no methods for elbow extension recovery were used, and no blinded analysis of the postoperative power of the triceps brachii was performed.\(^{\text{Moreover,}}\) considering that all of the included cases of this series sustained partial injuries, it cannot be ruled out that spontaneous reinnervation of the triceps occurred by axons coming in from the uninjured C-8 nerve root and reaching the muscle via motor branches to the lateral or the medial heads of the triceps.

**Conclusions**

This small series of cases illustrated the feasibility of transferring the MPN for restoration of elbow extension in patients who sustained partial injuries to the brachial plexus. However, further studies encompassing larger number of patients must be conducted to establish evidence-based data regarding the real potential of this technique. Controlled studies should be conducted to compare these results with a group of patients who did not undergo reinnervation of the triceps brachii, determining the real effect of the surgery on the final outcome of these patients.

**Disclosure**

The author reports no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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