Targeted Muscle Reinnervation of the Brachium: An Anatomic Study of
Musculocutaneous and Radial Nerve Motor Points Relative to Proximal Landmarks

Short Title: TMR Anatomic Study

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ABSTRACT:

Purpose: Targeted muscle reinnervation (TMR) offers enhanced prosthetic use by harnessing additional neural control from unused nerves in the amputated limb. The purpose of this study was to document the location and number of motor end plates to each muscle commonly used in TMR in the brachium, relative to a proximally-based bony landmark.

Methods: 18 matched arms (9 fresh-frozen cadavers) were dissected. The locations of each of the nerves' muscular insertions into the medial biceps and brachialis were measured relative to the anterolateral tip of the acromion. The terminal branches to the lateral triceps were measured relative to the posterolateral tip of the acromion. Both the number of branches and the location of the muscular insertions were documented. Common descriptive statistics were used to describe the data.

Results: There was a median of 2 branches to the medial biceps located at 19.6 cm from the anterolateral tip of the acromion (range 15-25 cm). There was a median of 3.5 branches to the brachialis located at 24.2 cm from the anterolateral tip of the acromion (range 19-27.5 cm). There was a median of 2.5 branches to the lateral triceps located at 21.6 cm from the posterolateral tip of the acromion (range 11-29 cm). The mean distances to the primary branch muscle and the number of smaller branches were not significantly different when compared by sex or side.

Conclusions: Motor points for the medial biceps; brachialis and lateral triceps can be reliably identified using proximal landmarks in targeted muscle reinnervation.

Clinical Relevance: The data obtained from this study will assist the TMR surgeon in localizing the nerve branches and muscular insertions for the commonly used muscles in the TMR of the brachium.

KEY WORDS:

Prosthetics, targeted muscle reinnervation, Musculocutaneous, Radial

ABBREVIATIONS USED:

TMR: targeted muscle reinnervation

Introduction

Recent military conflicts and domestic improvements in limb trauma management have increased the number of living amputees.¹ Myoelectric prostheses, utilizing transcutaneous electromyographic signals, are widely available and might represent the future of upper extremity prosthetics. However, traditional myoelectric prostheses are limited by the number of motor inputs available in the residual limb. Generally, only two signals are available for transhumeral amputees: biceps and triceps. Recently, Kuiken et. al. described “targeted muscle reinnervation” to reharvest the information supplied by amputated nerves.² In this procedure, the axons that previously innervated distal arm muscles, including the median ulnar and distal radial nerves are transferred to functionally redundant proximal muscles. The most common nerve transfers in targeted muscle reinnervation use a transfer of the distal radial nerve to the lateral head of the triceps, and the median nerve to the medial head of the biceps.³ If there is sufficient length available, the ulnar nerve can also be transferred to the brachialis. After transfer, cutaneous monitoring of electromyographic signals allows for four or five inputs instead of just the original two (biceps and triceps). Case series numbering less than twenty subjects each are available on surgical outcomes with documentation of successful transfer and prosthesis utilization.^{2, 4, 5}

Targeted muscle reinnervation is technically demanding, involving sometimes difficult dissection and nerve mobilization. Prior studies investigated anatomic variation of the radial nerve for other applications.^{6, 7} Similarly, prior investigation addresses the anatomic variation of the musculocutaneous nerve branching to the brachialis muscle as it relates to other applications.^{8, 9} No similar studies have specifically addressed the course of the musculocutaneous nerve distally to its diverging branch inserting at the medial bicep muscle belly.

The purpose of this study was to define the anatomic variation of the musculocutaneous and radial nerves through cadaveric dissection as they transit the brachium to innervate the biceps, brachialis and triceps, respectively, specifically for assistance in planning and performing targeted muscle reinnervation for transhumeral amputees.

Methods

Eighteen matched arms from nine fresh-frozen cadavers between 60 and 90 years old were examined. There were eight Caucasians and one African-American male. Both adult male and female specimen (eight males, one female) were utilized and were excluded if there was evidence of prior surgery in the brachium.

The musculocutaneous and radial nerves were dissected as they transit distally through the brachium beginning from the inferior edge of the pectoralis major anteriorly and the inferior edge of teres minor posteriorly. The most prominent aspect of the anterolateral acromion and the most prominent aspect of the posterolateral acromion were marked with a temporary suture on the skin. The branch points of the musculocutaneous nerve to the medial head of the biceps and the brachialis were marked with a small caliber suture along with their respective muscular insertions at the muscle or where the branch formed muscular branches. With soft tissue dissection performed, the nerve was able to move freely, but best efforts were made to return the nerve to its native tension-free position to make each measurement. The branch points of the radial nerve to the lateral head of the triceps were marked in the same fashion along with their respective muscular insertions at the muscle or where the branch formed terminal muscular branches. All measurements were made with a standard metric tape measure calibrated to the level of millimeters. No staining techniques were utilized to confirm muscular

insertions, but the authors found these muscular insertions readily identifiable with the naked eye. Prior anatomic studies have not clearly stated any technique for identifying muscular insertion other than visual muscular entry.^{6, 7, 10} The distances from all points to the most anterolateral aspect of the acromion were recorded for the musculocutaneous nerve and the same measurements recorded to the most prominent posterolateral aspect of the acromion. Simple descriptive statistics including mean, median, range, and the standard deviation were recorded to describe the measurement distribution for the entire dataset including gender. The arm with absent musculocutaneous nerve was not included in the data set as there were no distances to measure anteriorly. Student's t-tests were performed to compare differences in number of branches and distances by sex and side. Student's t-test was performed as paired sets to account for paired arms. Significance level was set at $P < 0.05$.

Results

In all specimens there was only one primary branch to each muscle belly. This primary motor branch did branch into multiple muscular insertions closer to the muscle belly.. There were a median of 2 branches to the medial biceps located at 19.6 cm from the anterolateral tip of the acromion (range 15-25 cm). There were a median of 3.5 branches to the brachialis located at 24.2 cm from the anterolateral tip of the acromion (range 19-27.5 cm). There were a median of 2.5 branches to the lateral triceps located at 21.6 cm from the posterolateral tip of the acromion (range 11-29 cm). The measurements as recorded are summarized in Figures 1 and 2. The mean distances to the main branch of the motor innervation to each muscle and the number of smaller branches were not significantly different when compared by sex or side. Representative photos of the anterior and posterior dissections are noted in Figures 3 and 4, respectively.

One specimen had an anatomic variant where the musculocutaneous nerve was absent and motor branches to the brachialis and biceps were from the median nerve. This variant was present on only one side.

Discussion

Dumainian, Kuiken et. al. described the surgical technique for the original targeted muscle reinnervation and included anatomic dissections to help guide the technique, however, there were no quantitative measurements with respect to distances or muscular insertions.³ We feel that the current study provides practical information for the TMR surgeon, so they can quickly localize the motor points and potentially minimize the length of the incisions. The present study describes the number of branches present. This data assists the TMR surgeon because any branches that are not utilized for the transfers should be denervated to prevent signal from the original nerve fibers interfering with prosthetic signal recognition.

The nerve transfers performed in targeted muscle reinnervation are different from standard transfers because of the great size mismatch between the large donor nerve and its much smaller recipient. The great benefit of this technique, however, is that the donor nerve provides many more axons than the recipient requires, thus providing the opportunity for a “hyperreinnervation”. Furthermore, the opportunity to reinnervate the muscle is facilitated by the short distance from the nerve coaptation to the target muscle. In order to accommodate the size mismatch, the target nerves are then cut 1-2 millimeters before entering the muscle, and the large donor nerve is then sutured to the muscle surrounding the small target nerve, effectively smothering it with donor axons (Figure 5).

One of the issues to date with this procedure is that there was nothing to guide the surgeon on where to make the skin incisions to find the target nerves. As a result, the procedure often required long incisions exposing the entire brachium in order to find the

musculocutaneous and radial nerves proximally, and the dissect along their entire course until the branches were identified. By providing information regarding the location of this branch and where it may be found, this study can assist the TMR surgeon by allowing him or her to perform less nerve dissection and therefore perhaps better maintain the natural biology of the nerve for healing purposes. The information from the present study will allow the surgeon to more precisely place the incision and more quickly localize the target branches.

This study has described the pertinent anatomy of the musculocutaneous nerve and radial nerve as it relates to targeted muscle reinnervation in transhumeral amputees. In general, the branch points of interest are proximal to the level of a distal half transhumeral amputation and will not be affected by the previous amputation trauma.³ No previous studies have rigorously described this portion of the brachium for the musculocutaneous nerve in this application, though Kuiken et. al., have published a similarly designed study for use of TMR in transfemoral amputees.¹¹

Gu et. al. studied the brachialis muscle branch in relation to a distal transfer, but made measurements from the humeral condyles which are not generally present in this patient population. That study identified three branching patterns with a single branch present 90% of the time.⁸ The differing findings in the current study may relate to fewer cadaveric dissections (thirty two versus eighteen arms).

Chiarapattanakom et. al. studied the branching pattern to the biceps and the brachialis in approximately 100 musculocutaneous nerves with reference to the lateral aspect of the acromion. That study noted three branching patterns to the biceps, differing by the number of primary branches. The dominant pattern in their dissections had one branch that split to supply both the medial and lateral head of the biceps (63%). The next most common pattern described one branch to the medial head of the biceps (33%), the finding of all cadavers in this study. A third type was rare with three total branches (5%). That paper found 92% of brachialis muscles had one primary branch and eight percent had two branches.¹⁰ The average distances to each

of the nerve branches were approximately 3-4 centimeters less from a similar point of reference when compared to this study. The differences may be related to different cadaveric populations, fewer numbers of dissections in this study, and technique differences in measurement (further anterior position on the acromion or measuring directly from the bone). The current study utilized a skin landmark for measurements and the extra tissue may explain differences in length if the above study utilized measurements directly from bone, though this was not specified in the methods. Lengths of the biceps branch were measured and found to be similar to those noted in this study (<1cm average difference).

A prior study of the radial nerve in the brachium with its focus on the nerve to the triceps long head had similar results to those in the present study. The previous study did not measure the number of muscular insertions and made measurements in a different fashion. Their study did note specimens with greater than one main branch from the radial nerve to the lateral head.⁷ That finding was not reproduced in this study nor was it reproduced by Cho et. al. in a dissection of forty posterior arms demonstrating one main branch to the lateral triceps. Cho et. al. measured nerve lengths, but selected different landmarks that make comparisons low value.¹² The authors elected to measure from the acromion to the transepicondylar line to establish full arm length and then measured intra-nerve lengths only—such as the distance from the long head branch to the lateral branch. The authors elected to perform no branch measurements from a static landmark, such as the acromion and thus limits comparison.

Witoonchart et. al. studied the radial nerve for transfer in brachial plexus injuries focusing on the nerve to the long head of the triceps. That study similarly found one branch in each of 51 shoulders to the lateral head of the triceps.⁶

Bertelli et. al. have published anatomic studies relating to the lateral head of the triceps in the context of transfers. In a clinical study for axillary transfer, the authors note one branch to the lateral head available for transfer.¹³ In another study, the authors found two branches to the lateral head of the triceps in their cadaveric dissections.¹⁴ These studies did not report the

location and number of motor points, however, which was the primary goal of the present study in the context of TMR.

The current study also noted an absence unilaterally of the musculocutaneous nerve in one specimen. This finding has been previously described, and in one case series was found to occur at a rate of eight percent. The largest series of dissection of the musculocutaneous nerve by Chiarapattanakom did not note this variant.^{10, 15} The discordant findings both within radial nerve and musculocutaneous nerve anatomic studies demonstrate the variability in anatomic dissections and the need for ongoing research.

The primary limitations of this study are the fewer number of cadaveric dissections and the broader error introduced in measurements from skin landmarks. The authors felt that utilizing a skin landmark for measurement may be more applicable for surgical planning purposes, though it likely increases error in measurement and standard deviation because it introduces more intervening subcutaneous tissue. Marking mobile structures after soft tissue has been dissected away increases error; however, this is an inherent limitation of anatomic dissections required to clearly identify structures of interest. Clinically, the measurements should be used for guidance and not as a hard rule just as any studied anatomic information is utilized by a practicing surgeon.

The current study describes the branching patterns of the nerves and the location of the motor points utilized for targeted muscle reinnervation along with clinically applicable measurements to assist in the planning and execution of the procedure. Since the patients undergoing this procedure will not have a distal landmark present to measure from, the proximally based landmarks chosen in this study should provide a reproducible landmark from which to measure. Surgeons should be aware of variable anatomy and be prepared to extend dissection as necessary to appropriately perform a procedure that allows for a well-functioning prosthesis.

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Figure Legend

Figure 1A. Anatomic drawing of anterior dissection demonstrating average distances to main branching point to the medial biceps and the brachialis.

Figure 1B. Distances to the muscular insertions and the median number of branches for both the medial biceps and the brachialis.

Figure 2. Anatomic drawing of posterior dissection demonstrating average distances to main branches and muscular insertions and the median number of branches for the lateral triceps branch.

Figure 3. Representative anterior dissection. Two branches are seen going to the medial head of the biceps, and two to the brachialis.

Figure 4. Representative posterior dissection. Three terminal branches are seen to the lateral head of the triceps from the main branch to the lateral head.

Figure 5. The larger caliber median nerve is sutured with 6-0 prolene suture over the smaller cut end of the medial biceps. This size mismatch allows for “hyperreinnervation” of the medial biceps.

Figure 1A

Figure 1B

Figure 2

Figure 3

Figure 4

Figure 5