The Role of Ulnar Nerve Transposition in Ulnar Nerve Repair: A Cadaver Study

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Ulnar nerve transposition at the elbow is recommended to diminish nerve gaps during neurorrhaphy. We undertook a cadaver study to determine the gap distance that can be overcome by subcutaneous transposition at the elbow, evaluating lacerations 2.0 cm distal to the medial epicondyle and 2.0 cm proximal to the wrist crease. With a 100-g load on each nerve stump, gaps that could be overcome were measured before and after transposition in different elbow and wrist positions. For the distal forearm lacerations, wrist position significantly affected nerve gap, while transposition and elbow position did not. Nerve gap was significantly reduced by approximately 11 mm with wrist flexion from 0° to 45°. For proximal forearm lacerations, gap distance was significantly affected by transposition and was dependent to a greater extent on the interaction between transposition and elbow position, with wrist position having no effect. A clinically relevant scenario for the proximal laceration compared the pretransposition gap with the elbow and wrist at neutral with the posttransposition gap with the elbow and wrist flexed. Posttransposition gap reduction, with elbow and wrist flexion at 45°, was approximately 9 mm and was not significant. To span a gap near the elbow, we estimate that more than 45° of elbow flexion is required. (J Hand Surg 1998;23A:244–249. Copyright © 1998 by the American Society for Surgery of the Hand.)

Anterior transposition of the ulnar nerve at the elbow has been recommended to facilitate ulnar nerve repair in the vicinity of the elbow and forearm when a nerve gap cannot be closed with acceptable tension. Recommendations for maximal gaps that can be overcome by ulnar nerve transposition and joint positioning appear in the literature, but no current laboratory studies document the efficacy of this technique.1–4 Bunnell1 and Zachary3 reported that 5.0-in and 13.0-cm gaps, respectively, can be overcome by elbow and wrist flexion and ulnar nerve transposition at the elbow. Trumble2 reported that transposition can overcome 2-cm gaps in the forearm and 4-cm gaps at the elbow, with an additional 2 to 4 cm overcome by flexing the wrist and elbow. Sunderland4 proposed that the critical gap distance for the elbow, forearm, and wrist that can be overcome by transposition, nerve mobilization, and joint positioning is 3 to 5 cm. Our experience with transposition for overcoming ulnar nerve gaps has been disappointing, with transposition reducing gaps only when extreme joint positioning was incorporated. Concern arises about the detrimental effects of excessive neurorrhaphy site tension on nerve continuity and functional recovery during subsequent elbow mobilization.4–11 This study was undertaken to quan-
tify the efficacy of ulnar nerve transposition at the elbow for overcoming ulnar nerve gaps near the elbow and wrist.

**Materials and Methods**

**Specimen Preparation**

Ten paired upper extremities from 5 fresh cadavers were dissected without detachment from the torso. Demographic information from each specimen was recorded. The ulnas were measured from the tip of the olecranon to the ulnar styloid and recorded to the nearest millimeter.

The cadavers were warmed to room temperature. All specimens had full range of motion at the elbow and wrist. Only 1 specimen had evidence of having had an arteriovenous shunt placed in 1 forearm remote from the area of study. During the experiment, elbow and wrist angles were measured with a hand-held goniometer. The wrist was stabilized in various positions by an external fixator (Orthofix; EBI Medical Systems, Parsippany, NJ), and the elbow was held manually. Shoulder position was kept constant at 60° of abduction and neutral rotation.

Ulnar nerves were transected near the wrist or elbow, and with the nerves under a constant tension, nerve overlap was measured before and after transposition with the wrist and elbow in various positions. Changes in nerve overlap served as a direct measure of potential gap increase or reduction.

**Rationale and Experimental Protocol**

Intact nerves have a longitudinal *in situ* tension that results in gap formation immediately after nerve transection. Nerve *in situ* tension and strain vary with joint position among nerves and among species. We found no data on *in situ* strain for the ulnar nerve at the elbow. However, animal data have shown that *in situ* strain varies from 1.9% in the rat sciatic nerve to 11% in the rabbit tibial nerve. Animal studies of nerve vascularity have demonstrated that nerve blood flow is not severely compromised until strains exceed 8% to 15%. A strain of 2% to 5% was selected for this experiment and corresponded in pilot studies to a tension produced by 100 g of force applied to the transected nerve stumps. It should be noted that this tension and corresponding strain were above those found *in situ* in the intact nerve since, for all elbow and wrist positions tested before and after transposition, there was always nerve overlap during testing.

To measure strain, 2 6-0 nylon marking sutures were placed in the epineurium 100 mm apart in either the proximal or distal nerve stump. A tension of 100 g was applied using a spring gauge. The increase in distance between the markers was expressed as percent strain at 100 g.

Two spring gauges were used in this study, 1 for each nerve stump. Each spring gauge was fabricated from a tuberculin syringe graduated cylinder tube, inside of which was placed a small spring and a central plunger. The plunger was thus spring loaded and, in turn, attached to the nerve stump via a 3-0 silk suture. Using the graduations, the spring gauges were calibrated to consistently measure 100 g of tension.

**Proximal Laceration Site**

On 1 extremity from each cadaver, the ulnar nerve was exposed in the proximal forearm through a 20-cm incision centered over the medial humeral epicondyle. The nerve was mobilized over the length of the incision, preserving flexor carpi ulnaris motor branches. The nerve was transected 2 cm distal to the medial epicondyle. Spring gauges were attached to the nerve ends using 3-0 silk sutures and a constant tension of 100 g was applied (Fig. 1). Nerve end overlap was measured with a precision caliper (No. 505-637; Mitutoyo, Japan) to the nearest 0.001 inch and was converted to millimeters. Overlap was measured for 5 elbow positions (0°, 30°, 45°, 60°, and 90°) and 3 wrist positions (0°, 30°, and 45° of flexion). To reduce measurement error, overlap at each position was measured 3 times.

**Distal Laceration Site**

On the contralateral extremity of each cadaver, the ulnar nerve was exposed through a 15-cm incision extending from the midforearm to the pisiform. The nerve was mobilized over the length of the incision and then transected 2 cm proximal to the pisiform.
Figure 2. Nerve overlap after ulnar nerve laceration in the proximal forearm before (open bars) and after (solid bars) transposition with the wrist and elbow in variable positions. Wrist (W) and elbow (E) angles are shown in degrees on the x-axis.

Spring gauges were attached to the cut nerve ends as previously described. Nerve end overlap was measured as before: 3 times for each of the combined 15 elbow and wrist positions.

Subcutaneous ulnar nerve transposition was then performed on each specimen, with proximal to distal release from the arcade of Struthers to the flexor carpi ulnaris aponeurosis, as described by Eversmann. \(^{15}\) On arms with proximal nerve lacerations, wounds were left open to permit access for nerve end overlap measurements. Unnatural bowstringing of the nerve anterior to the cubital fossa, ordinarily limited by skin closure, occurred with elbow flexion of \(\geq 60^\circ\). Data for these elbow positions were discarded because we felt the data were flawed since the excessive bowstringing would overestimate the utility of transposition. On extremities with distal lacerations, elbow wounds were closed before repeating the measurements, thus preventing bowstringing.

Statistics

Raw data were screened for normality to justify the use of parametric statistics. Average ulnar nerve overlap was compared for proximal and distal lacerations using 3-way analysis of variance (ANOVA) with elbow angle (0, 30, and 45\(^\circ\)), wrist angle (0, 30, and 45\(^\circ\)), and transposition (before and after) as grouping factors. For proximal nerve lacerations, the maximal benefit of transposition was determined by comparing maximum overlap before transposition, which occurs with the elbow and wrist at neutral, with the maximum overlap after transposition, which occurs with the elbow and wrist flexed. Thus, comparisons between the most clinically relevant pre-transposition condition (i.e., wrist and elbow angles 0\(^\circ\)) and selected post-transposition conditions were made by 1-way ANOVA. The significance level was chosen as .05. Statistical power for this data set exceeded 75% in all cases. Thus, the lack of significance was due to the lack of an actual effect rather than insufficient sample size.

Results

The average age of the 5 cadaver specimens was 78 years (range, 62–87 years) at the time of death. Ulnar length averaged 25.7 cm (range, 22.0–29.5 cm). Strain at 100 g of tension averaged 3.5% ± 0.1% over the transected and naturally retracted state (range 2% to 5%). Average nerve overlap for proximal and distal laceration sites before and after transposition is demonstrated graphically in Figures 2 and 3. Greater nerve overlap indicates less potential nerve gap. Therefore, larger increases in overlap indicate greater potential gap reduction.

For proximal ulnar nerve lacerations, 3-way ANOVA, using elbow angle, wrist angle, and transposition as grouping factors, demonstrated that transposition had a significant effect (\(p < .05\)) on nerve overlap. However, nerve overlap was greatly affected by the interaction between transposition and...
elbow angle (p < .01). Although there was a significant benefit of transposition with respect to nerve overlap when comparing pretransposition and posttransposition with the elbow fixed at 45°, this would not be a clinically relevant comparison. In the clinical situation, the surgeon would attempt to repair the nerve with wrist and elbow angles at 0°, where maximal overlap (or the smallest gap) would exist without transposing the nerve. If a prohibitively large gap existed, the surgeon would then transpose the nerve and flex the elbow and wrist in hopes of diminishing the gap. To simulate the clinical situation, we compared pretransposition overlap with the wrist and elbow at 0° with posttransposition overlap with the wrist and elbow at 0°, 30°, and 45°. The maximal overlap increase was 9.0 mm. One-way ANOVA demonstrated that this increase in nerve overlap was insignificant (p > .10) (Fig. 4).

For distal lacerations, only wrist angle had a significant effect on nerve overlap (p < .0001), with elbow angle, transposition, or their interaction having no significant effect. Wrist flexion from 0° to 45° resulted in an overlap increase (potential gap reduction) of 11.0 mm (Fig. 5).

Discussion

The importance of limiting tension at the nerve repair site is well established. Consequently, maneuvers to decrease gaps caused by prolonged nerve retraction after laceration or from segmental nerve loss are justified. In addition, if it is feasible to safely repair a nerve primarily, it may be preferable to grafting due to the theoretical concerns of a worse outcome caused by nerve fibers that cross 2 repair sites during grafting. These concepts form a rationale for ulnar nerve transposition for ulnar nerve lacerations near the elbow. Ulnar nerve gaps, and thus primary neurorrhaphy site tension, are theoretically reduced when the nerve takes a “short cut” anterior to the elbow. Of concern are the potential morbidities of ulnar nerve transposition, including nerve devascularization and scarring. Additionally, there is concern about the effects of increasing repair site tension as the elbow is extended during rehabilitation after a transposition facilitated neurorrhaphy.

Excessive neurorrhaphy site tension can result in poor functional outcome; moreover, if tensions reach ultimate loads, nerve rupture results. Few studies have been conducted in the area of neurorrhaphy site tensile properties. Preliminary work in our lab-
oratories on immediate primary rat sciatic nerve repairs without nerve tissue loss demonstrated that approximately two thirds of ultimate stress were recovered within the first week after repair and that this did not increase for up to 3 months. Our values for ultimate strain for uninjured rat sciatic nerves were 16.6% ± 4.3%; for lacerated and repaired nerves at time periods ranging from 1 to 84 days, the values ranged from 14.2% ± 1.8% to 26.0% ± 3.9%. Other investigators have found ultimate strain to be similar among several different major human, pig, dog, rabbit, and mouse peripheral nerves, ranging from 18% to 23%. Ultimate stress or load appears to vary considerably among different intact nerves and in different species, but ultimate strains among different nerves in different species are relatively similar. In our present study, although we applied tensions resulting in much lower strains than would be expected to result in neuorrhaphy site rupture, it is not known what the resulting tensions and strains would be if the adjacent nerves were mobilized (as would occur when rehabilitating the injured extremity).

Considerable literature exists that demonstrates better outcomes from nerve grafting compared with primary repair performed under excessive tension. The difficulty arises in assessing during surgical repair how much tension is too much. Nerve vascularity may be 1 of the factors affected by tension that may affect nerve healing. Clark et al. and Lundborg and Rydevik independently showed that vessels in rat sciatic and rabbit tibial nerves, respectively, are occluded between 8% and 15% strain. Perineurial vessels were occluded irreversibly at 15% strain despite stress relaxation. Although nerve rupture occurs at higher strains, the upper limit for repair site tension is probably less than 10%.

Based on available data, we felt that 2% to 5% nerve strain would not compromise functional outcome or result in nerve rupture. Thus, in our experiment, tension was applied to the nerve stumps during measurements, with resulting strains averaging 3.5% ± 0.1% (range, 2%–5%). Because the nerve always overlapped, the constant tension we chose was always above in situ tension for the joint positions tested. This implies that we may have erred in our strain measurement technique or we may have selected a tension that was too high for the human ulnar nerve. If this is the case, our results would overestimate the efficacy of transposition, nerve mobilization, and joint positioning in reducing gaps, and their utility would be even more dubious than we have shown. It should be noted that our study includes some of the usual limitations present in a cadaver study. One important limitation is the inability to study the effects of nerve stiffness changes associated with injury and Wallerian degeneration.

The present study demonstrated no statistically significant benefit of transposition for reducing nerve gaps in the case of distal lacerations. Although transposition significantly affected nerve overlap (potential gap reduction) in the case of proximal lacerations, it was greatly dependent on elbow position. However, in a clinically relevant scenario for proximal lacerations, comparing the pretransposition condition with the least gap (with both the wrist and elbow at 0°) to posttransposition condition with the left gap (with the wrist at 45° and the elbow at 45°), transposition insignificantly (p > .10) decreased potential nerve gap by 9.0 mm (Fig. 5).

When we measured overlap for proximal lacerations with the elbow flexed ≥60°, the nerve would bowstring across the antecubital fossa. Overlap of the bowstringing nerve was recorded, but data from elbow angles of ≥60° were not used in our analysis because they did not simulate the clinical situation since bowstringing of the nerve would be minimized with skin approximation. Skin closure (which, in our study, could not be accomplished and effectively measure overlap) would decrease the overlap from what we measured for elbow angles where there was nerve bowstringing. Thus, our data for elbow angles of ≥60° were flawed.

We are concerned that if neurorrhaphy is performed with unnatural positioning of the elbow (and wrist), subsequent rehabilitation of the injured extremity will mechanically stress the repair, compromise the functional outcome, and result in joint stiffness. Our data do not rule out that elbow flexion beyond 45° could allow transposition to reduce a proximal forearm nerve gap. However, even if elbow flexion beyond 45° allowed gap reduction to approach statistical significance, transposition and extreme elbow positioning may not be justified due to their likely miniscule benefit, unless an elbow flexion contracture would be an acceptable outcome.

We conclude that ulnar nerve subcutaneous transposition has little to offer in facilitating ulnar nerve repair in the distal forearm. For lacerations near the elbow in the proximal forearm, transposition, with wrist and elbow flexion to 45°, will not significantly reduce nerve gap. Higher elbow flexion angles may be necessary to achieve a reduction in nerve gap. We suspect that if this is done, the nerve may rupture during rehabilitation or
may have a compromised functional recovery, or an elbow flexion contracture may result.

References