The effect of operative technique on ulnar nerve strain following surgery for cubital tunnel syndrome

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Abstract

Background The aim of this study is to compare the amount of strain on the ulnar nerve based on elbow position after in situ release, subcutaneous transposition, submuscular transposition, and medial epicondylectomy.

Methods Six matched cadaver upper extremity pairs underwent ulnar nerve decompression, transposition in a sequential fashion, while five elbows underwent medial epicondylectomy. A differential variable reluctance transducer (DVRT) was placed in the ulnar nerve. An in situ release, a subcutaneous transposition, and a submuscular transposition were performed sequentially with the strain being measured after each procedure in neutral, full elbow flexion, and extension positions. The strain was then averaged and compared for each procedure. Five cadavers underwent medial epicondylectomy and were similarly tested.

Results After the in situ release, there was no statistically significant change in strain in either flexion or extension. After a subcutaneous transposition, there was a statistically significant decrease in strain in full elbow flexion but not in extension. Similarly after a submuscular transposition, there was a statistically significant decrease in strain in full flexion but not in extension. There was not a statistically significant change in strain with medial epicondylectomy.

Conclusion An in situ release of the ulnar nerve at the elbow may relieve pressure on the nerve but does not address the problem of strain which may be the underlying pathology in many cases of ulnar neuropathy at the elbow (UNE). Transposition of the ulnar nerve anterior to the medial epicondyle addresses the problem of strain on the ulnar nerve. In addition, it does not create an increased strain on the ulnar nerve with elbow extension.

Keywords Ulnar nerve entrapment · Cubital tunnel syndrome · Neuropathy

Introduction

Ulnar nerve entrapment (UNE) is the second most common compressive neuropathy of the upper extremities [30]. The elbow is the most common site of compression due to the superficial location and inherent compressive anatomy of the ulnar nerve [30, 32, 38]. The incidence of UNE has been increasing, especially in regard to work-related causes [16, 34].

UNE presents with progressive hand weakness and paresthesias of the small and ring fingers [23]. Symptoms are exacerbated by elbow flexion, sustained pressure, and direct contact [38, 45]. Patients are often unable to localize their symptoms; as such UNE can go unrecognized and may progress to irreversible intrinsic atrophy, weakness, and disability of the upper extremity [38].

Roughly 50 % of patients will improve with conservative management while over 90 % will improve with surgery, regardless of the procedure performed [9, 10, 21, 34, 41]. The goal of transposition is to relieve nerve compression at rest and during range of motion at the elbow; the nerve should be tension-free after decompression procedures. Various surgical

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treatments have been described. Those aimed at decompression alone include endoscopic cubital tunnel release [48], in situ release [21], and medial epicondylectomy [36]. The techniques of subcutaneous [37] and submuscular [45] transposition are intended both to decompress, transpose, and relieve strain on the nerve by repositioning the nerve anterior to the elbow. The body of UNE literature [1–3, 5–8, 14, 18, 25, 26, 29, 32, 33, 39, 49] has failed to show superiority of a single technique with regard to clinical or biomechanical outcomes.

In addition to nerve compression, strain is also believed to affect function [14, 22, 35, 42]. Various biomechanical studies have analyzed the effect of strain on nerve conduction [14, 20, 27, 28, 42, 44]; however, few have applied these principles to the various techniques of ulnar nerve decompression [19, 45]. We sought to compare the amount of strain on the ulnar nerve based on elbow position after in situ release, subcutaneous transposition, submuscular transposition, and medial epicondylectomy. We hypothesize that anterior transposition decreases strain on the ulnar nerve throughout the elbow arc of motion. In addition, we hypothesize that anterior transposition will increase strain in full extension.

Materials and Methods

Approval was obtained from the Institutional Review Board to conduct this study. This biomechanical analysis used six matched pairs and five unmatched (17 total) fresh frozen cadaver arms with intact shoulder girdles. The average age of the cadaver arms was 78.4 years (70–91 years). The selected specimens did not have diagnosed flexion contractures, skin incisions, ulnar nerve subluxation, or any known pathology.

The complete brachial plexus of each specimen was initially tethered to the clavicle with non-absorbable suture to best mimic neural connection to the spinal cord and prevent nerve gliding or loosening for measurement purposes. All dissections were completed by one fellowship trained hand surgeon and two hand fellows in a single lab at room temperature. An incision was then made over medial epicondyle, and the ulnar nerve was identified proximal to the medial epicondyle and subsequently circumferentially dissected. The transducer was placed proximal to the medial epicondyle and affixed to the nerve with metal pins, as an in line pull is necessary for accurate device measurement. The elbows were then placed at 50° of flexion to initiate testing as previously described [17]. A strain transducer was placed on the neutral axis of the ulnar nerve (DVRT; Microstrain Co. Williston, VT) [4]. The distance between transducer pins was measured with a digital caliper (Mitutoyo Absolute Digital Caliper; Mitutoyo Co. Aurora, IL).

The strain was measured in neutral forearm position with the elbow in 90° of flexion (neutral position), full flexion (130°), and extension (10°) for the intact ulnar

nerve. These three elbow positions were standard for the remainder of the experiment. The measurements for full flexion and full extension would be used as a basis for comparison for the remainder of measurements for the purposes of this study. An in situ decompression was then performed, with intermuscular septum released in standard fashion, and the measurements were repeated in each position for 12 specimens [23]. The FCU fascia was released enough to freely transpose the nerve without tension. After initial testing, a subcutaneous ulnar nerve transposition was performed using a fascial sling as previously described [15]. Measurements were repeated in the same fashion, for the second time. After testing, a submuscular ulnar nerve transposition was performed using a flexor-pronator step cut lengthening as previously technically described [11]. Measurements were repeated in the same fashion, for the third time. Finally, in the five remaining specimens, a medial epicondylectomy was performed at a 45° oblique angle between the coronal and sagittal plane (anterior to posterior) [24]. Soft tissue was released overlying the ulnar nerve including excision of the intermuscular septum as previously technically described [36]. Measurements were repeated in the same fashion. The mean strain for each position of each treatment was calculated. The percent strain was then calculated and strain values of each procedure were then compared.

Statistical analyses involved the repeated measures analysis of variance and post hoc pairwise multiple comparisons using the least significant difference procedure (IBM SPSS Software, New York). Post hoc power analysis was calculated with repeated measures ANOVA of percent strain, for 80 % power to detect significant positional effect with alpha set to 0.05. Necessary sample size for in situ was 40 specimens, for subcutaneous was 14, for submuscular was 5, and for medial epicondylectomy was 7.

Results

The mean strain of the ulnar nerve after in situ decompression, subcutaneous transposition, submuscular transposition, and medial epicondylectomy are compared to the intact ulnar nerve (Table 1). The submuscular transposition offered the greatest decrease in ulnar nerve strain in flexion (10.3 %), followed by subcutaneous (9.2 %) and medial epicondylectomy (5.1 %) in flexion. There was no statistically significant difference in mean strain between in situ and intact ($p=0.302$). However, subcutaneous transposition ($p=0.048$) and submuscular transposition ($p<0.0005$) both demonstrated statistically significant decreases in ulnar nerve strain flexion versus intact control. Strain after medial epicondylectomy did not reach statistical significance between flexion and extension ($p=0.051$).

Table 1 Ulnar nerve strain

Surgical technique	Elbow position	Mean % strain	Standard deviation	<i>p</i> value (vs. intact)
In situ	Neutral	−0.64637	2.600754	0.302
	FF	0.523446	1.312023	
	FE	0.171476	1.717848	
Subcutaneous	Neutral	−1.23073	8.270768	0.048
	FF	−9.18361	8.436796	
	FE	−0.25208	11.40374	
Submuscular	Neutral	−0.33047	8.587724	<0.0005
	FF	−10.3105	8.659182	
	FE	−1.39219	9.641819	
Medial epicondylectomy	Neutral	1.203778	3.924687	0.051
	FF	−5.07129	3.249258	
	FE	−0.25885	2.889221	

Comparison of strain on ulnar nerve after in situ decompression, subcutaneous transposition, submuscular transposition, and medial epicondylectomy. The mean strain, standard deviation, and *p* values are highlighted in neutral, full elbow flexion, and full elbow extension

FF full flexion. FE full extension

Discussion

We hypothesized that anterior transposition decreases strain on the ulnar nerve throughout the elbow arc of motion. We found that after both subcutaneous and submuscular transpositions, strain on the nerve was decreased. In addition, there was no increase in strain in extension after anterior transposition. While previous cadaveric analysis has demonstrated decrease in strain after both decompression and medial epicondylectomy [9, 23], here, we present possibly the first analysis to demonstrate decrease in strain after in vitro transposition.

Since the early 1940s, nerve conduction in response to strain has been studied [12, 43]. In 1968, Sunderland reported that increasing neural traction eventually caused conduction block without any measurable morphologic change in the nerve. With increasing tension, cross-sectional area is reduced, leading to increased intrafascicular pressure and disrupted perfusion. Increasing strain further caused disruption of the microarchitecture, most notably of the perineurium, which leads to protein leak into the fascicles and resultant fibrosis, irreversibly hindering nerve function [28, 40].

Nerve dysfunction under strain is believed to be due to compromised perfusion and resulting perineural dysfunction. The amount of strain required to affect neural blood flow and conduction has been established. Nerves placed under <5 % increase in strain over baseline exhibit no physiologic changes. At an increase of 5–10 % strain, decreased blood flow predominantly in the venules and impaired conduction are seen, albeit with complete recovery after relaxation. At an increase of 10–15 % strain, nerves exhibit decreased arteriolar

blood flow with irreversible nerve damage even after relaxation. Nerves under an increase of >15 % strain exhibit complete occlusion of blood flow and eventual nerve tensile failure [13, 14, 20, 22, 27, 28, 35, 42, 44, 47].

Few studies have attempted to characterize the change of strain in the ulnar nerve resulting from the various decompression techniques [19, 46]. Williams et al. [46] found that transposition of the ulnar nerve had a significant and enduring effect on the ultimate stress, strain, and modulus in a canine model. Grewal et al. [19] compared elongation and excursion of cadaveric ulnar nerves during elbow flexion for in situ decompression and anterior subcutaneous transposition and found that anterior subcutaneous transposition resulted in an average elongation of 23 % with the elbow in full extension which was comparable to the elongation of the native segment in situ. The authors inferred that anterior subcutaneous transposition did not relieve the strain on the ulnar nerve; however, no direct measurement of strain was conducted in this study. In addition, the authors did not evaluate medial epicondylectomy or submuscular transposition.

We are not aware of any previous studies which compare strain in flexion and extension amongst all of the currently accepted surgical techniques for both decompression and transposition. The analysis demonstrated that flexion of the elbow with the ulnar nerve posterior to the medial epicondyle increases strain on the nerve, while elbow extension decreases the strain on the nerve. When the ulnar nerve was transposed anterior to the medial epicondyle, the strain was decreased in both elbow flexion and extension for subcutaneous ($p=0.012$) and submuscular ($p=0.001$) transpositions. In addition, with additional power, it is possible that the decrease in strain after medial epicondylectomy would have proved statistically significant ($p=0.051$). We believe that the decrease in strain noted after medial epicondylectomy verified in this study is clinically relevant. The decrease in strain demonstrated here underscores the previously reported symptomatic relief provided by an ulnar nerve transposition, both subcutaneous [15, 37] and submuscular transposition [46]. There was no decrease in strain in this in vitro analysis ($p=0.302$); however, strain has been reduced after decompression alone in an in vivo analysis [35]. The difference between the two findings is likely due to the less elastic and pliable cadaver tissue as compared to live tissue.

Our data did not show a trend for a reverse extension deformity strain, which is increased strain on transposed nerves in elbow extension. While it is possible that patients who are ligamentously lax may experience an increase in ulnar nerve strain after anterior transposition with the elbow extended, the data did not demonstrate any correlation in this study. No cadavers in our analysis were hyperextensible and full extension was measured at 10°; as such, this query could not be analyzed within our experiment. To date, there are also no reported cases on ulnar nerve injury caused by hyperextension

of the elbow after transposition. However, unreported post-surgical hyperextension injuries to the ulnar nerve may represent a potential complication. Hyperextension injury to the ulnar nerve strain after anterior transposition should be considered by the surgeon if symptoms return or worsen post-operatively.

The strengths of this study include that all procedures done on paired cadaver arms reducing variability. Also, each decompression procedure was performed in exactly the same fashion by fellowship-trained surgeons. However, there are a number of weaknesses intrinsic to the study. First, the study design was imperfect. As with any in vitro biomechanical study, cadaver tissue does not have living tissue properties and thus is not directly applicable for in vivo comparison. In an in vivo analysis, ulnar nerve strain was decreased 25 % after simple decompression [35]. It is likely that our findings of decreased strain in vitro would likely reflect a decrease in strain after decompression and transposition in more pliable, live tissue. Furthermore, none of the cadavers could be hyperextended; therefore, we were unable to evaluate the effect of elbow extension on the strain of the anteriorly transposed nerve. In live tissue, it is possible that strain may be increased after transposition in extension, especially in hyperextendable elbows or those with collagen disorders. Ultimately, this question may be initially queried clinically with presentation of case reports. In addition, lab conditions cannot fully simulate the effects of healing and scar tissue on actual long term results for decompression procedures. Contracture of fascial sling, created to cradle the transposed nerve, may also lead to recurrence of symptoms post-operatively. [31] No sling was created during this experiment, as the authors typically create a subcutaneous fibrofatty suture technique, although this may be a focus of further in vitro investigation. Additionally, the order of the procedures was standardized and as such the submuscular transposition was always performed last. This prolonged exposure may have affected the tissue properties. Second, the strain gage was placed at the proximal edge of the epicondyle to yield a straight line of pull and measurement. However, this mechanism does not take into account the curve of the epicondyle and may have produced slightly skewed strain testing as compared to native anatomy. Strain would be best assessed with complete upper torso cadavers as opposed to using just the limb and tethering the plexus to the clavicle. However, the torso specimens were not available to the authors. Third, endoscopic decompression techniques were not included in this study. Finally, with limited numbers of specimens, change in strain after in situ and medial epicondylectomy was not statically significant. However, with a better powered study, these values may potentially prove statically significant. In addition to analyzing the effect of anterior transposition on hyperextensible elbows, future study design may correlate in vivo strain changes before and after decompression and transposition with post-operative clinical symptoms.

In conclusion, transposing the ulnar nerve anterior to the medial epicondyle affects the strain on the ulnar nerve based on position of the arm. In situ decompression does not affect the strain in flexion or extension with our dissections. Further analysis is necessary to evaluate effect of anterior transposition during hyperextension events, especially in a patient with increased ligamentous laxity.

Disclaimers Some authors are employees of the US Federal Government and the US Army. The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or reflecting the views of William Beaumont Army Medical Center, the Department of Defense, or US government.

Conflict of Interest Justin Mitchell declares that he has no conflict of interest.

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