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Title:

The Relationship Between Ultrasonographic Hand Muscle Thickness Measurements and Muscle Strength Following Median or Ulnar Nerve Reconstruction

Running Title:

Ultrasound of Hand Muscles Following Nerve Reconstruction

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ABSTRACT

Introduction:

The aim of this study was to assess the relationship between ultrasonographic hand muscle thickness measurements and hand muscle strength in patients who underwent median or ulnar nerve reconstruction.

Methods:

In this prospective, cross-sectional study, intrinsic hand muscle thicknesses were measured using ultrasound with a 4-13-MHz linear-array probe. Measurements of hand strength were performed by using a dynamometer and a pinchmeter.

Results:

In the median group (n=11), a moderate correlation (r= 0.694; p= 0.018) was observed between lateral pinch strength and transverse thenar thickness. In the ulnar group (n=11), longitudinal thenar thickness below the flexor pollicis longus tendon was moderate to highly correlated with pinch and handgrip strengths (r=0.726-0.893; $p<0.05$); whole transverse thenar thickness was moderate to highly correlated with pinch strengths (r=0.724-0.836; $p<0.05$).

Discussion:

Sonographic measurements of intrinsic hand muscle thickness may be a useful tool for the assessment and follow-up of patients with median or ulnar nerve injury.

Key Words: median nerve, muscle strength, muscle thickness, muscle ultrasound, peripheral nerve injury, ulnar nerve, upper extremity

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Introduction

A successful rehabilitation program following peripheral nerve repair in the upper extremity is essential to restore the function of the hand. In the early post-operative period, the emphasis is on protection of the recently-repaired nerve. Therapeutic exercises are then gradually added to improve hand function.[1] Motor recovery following peripheral nerve reconstruction can be evaluated via manual or dynamometric muscle strength tests.[2,3] However, these are avoided in the early post-operative period, in order to prevent damage to the repaired nerve and tendon tissues. Therefore, a safe and objective assessment of recovery is necessary in this early period.

Quantitative ultrasound (US) measurement is a cost-effective, non-invasive and safe method to evaluate muscle innervation.[4] Sonographic changes of muscle denervation are increased echo intensity and decreased muscle bulk. Muscle bulk can be assessed by either muscle thickness or cross-sectional area (CSA).[5] Previous studies have shown that measurements of muscle thickness were more reproducible than those of echogenicity, which differed by US system. They were also more practical than CSA measurements, which were difficult because the outer muscle margins were not always distinct.[4,6,7] In addition, sonographic muscle thickness measurements had the advantage of not being influenced by the patient's effort or by pain, in contrast to strength tests.[8]

Several reliable techniques were previously described for sonographic measurement of intrinsic hand muscles.[4,9] Recently, a more standardized and practical examination technique with excellent inter- and intra-rater reliability was described.[10]

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The aim of this study was to assess the relationship between ultrasonographic hand muscle thickness measurements and muscle strength in patients who underwent median or ulnar nerve reconstruction at the forearm level.

Methods

Study Design

This prospective, cross-sectional study was conducted in a physical medicine and rehabilitation department of a university hospital. All procedures in the study were in accordance with 1964 Helsinki Declaration and its later amendments.

The Medical Ethics Committee of our university approved the study (IUC-A17), and all subjects provided written informed consent prior to their enrollment.

Study population

Patients were recruited consecutively from the hand rehabilitation unit of our department. The inclusion criteria were history of either median or ulnar nerve repair following injury at the forearm level and postoperative duration longer than 12-weeks. Patients with median or ulnar nerve injuries other than sharp objects, preexisting hand deformities, cervical disc disease, neuropathy, systemic diseases associated with neuropathy (diabetes mellitus, hypothyroidism) or cognitive dysfunction were excluded.

Outcome assessments

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All assessments were performed by two physiatrists. The first physiatrist (DP) obtained the demographic data of the patients and performed the physical examinations including strength measurements. Later on the same day, the second physiatrist (TOM), blinded to the physical examination of the patients, performed the sonographic examinations.

Strength measurements

Strength measurements of handgrip, palmar pinch (thumb tip to the tip of the index finger), lateral pinch (thumb pulp to lateral aspect of the middle phalanx of the index finger), and tip pinch (thumb tip to tips of the index and long fingers) were performed in accordance with the procedures described by Mathiowetz et al.[11] The Jamar dynamometer and the pinchmeter (Jamar Hand Evaluation Kit, Sammons Preston Inc., Bolingbrook, IL) were used for the measurements. Three measurements were performed for each strength test, and the mean score was recorded.

Ultrasound measurements

An ESAOTE My Lab 70 ultrasonography system (Esaote SpA, Genoa, Italy) with a 4-13-MHz broadband linear-array probe was used. All measurements were performed according to the protocol as previously described.[10]

All patients were scanned in supine position with their forearms in supination, elbows in full extension, and dorsum of the hands in contact with the examination table. Fingers 2-5 were adducted and extended with the thumb held in neutral position. The probe was placed directly and gently to avoid compression, onto the palmar surface of the hand with sufficient transmission gel. Starting with the unaffected hand, 5 positions were

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studied in each hand in the following order: 1-transverse thenar; 2-longitudinal to flexor pollicis longus (FPL) tendon; 3-longitudinal thenar; 4-transverse hypothenar; 5-longitudinal hypothenar. In position 1, four thickness measurements were performed; transverse thenar, transverse thenar above FPL, transverse thenar below FPL, whole transverse thenar. In position 2, three thickness measurements were performed; longitudinal thenar above FPL, longitudinal thenar below FPL, the ratio of longitudinal thenar above FPL over below FPL. One measurement was performed for each of the rest of the positions: longitudinal thenar for position 3, transverse hypothenar for position 4, and longitudinal hypothenar for position 5. These measurements are presented as Supplemental Figures S1-S10.

Statistical Analyses

All statistical analyses were performed using SPSS version 24.0 for Windows (IBM; Armonk, New York). The Mann-Whitney U test and chi-square test were used to compare the continuous and categorical variables. The Spearman correlation analysis was used to assess the correlation between the sonographic muscle thickness and strength measurements. Correlation values of <0.50, 0.50-0.74, 0.75-0.90 and >0.90 were considered as poor, moderate, good, and excellent, respectively.

Results

All subjects underwent the complete protocol. No subject found the procedure uncomfortable or asked to have the US study discontinued.

In total, 22 patients with median (n=11) or ulnar (n=11) nerve injury at the forearm level were evaluated. All patients had concomitant tendon injuries, except for 2 patients

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who had an isolated nerve injury without tendon involvement (1 patient in the ulnar, and 1 patient in the median group). The baseline characteristics of each group are shown in **Table 1**. There were no significant differences in terms of age, gender, body mass index, dominance, time since injury or operation between the groups.

Most of the strength and thickness measurements were significantly reduced on the injured side compared to the non-injured side, regardless of which nerve was injured.

Muscle strength

Intragroup (injured vs. noninjured side) comparisons of muscle strength measurements revealed a significant reduction in lateral ($p=0.041$) and palmar ($p=0.033$) pinch strengths for the median group, and all the pinch (lateral, $p=0.003$; tip, $p=0.003$; palmar, $p=0.005$) and grip ($p=0.004$) strengths for the ulnar group. Intergroup (median vs. ulnar group) comparisons revealed no significant difference for any strength measurement. Intra- and intergroup comparisons of hand strengths are shown in **Figure 1**.

Ultrasonographic muscle thickness

Intragroup comparisons of ultrasonographic muscle thickness measurements in position 1 (transverse thenar position) revealed a significant reduction in all muscle thickness measurements (transverse thenar, $p=0.01$; transverse thenar above FPL, $p=0.003$; transverse thenar below FPL, $p=0.004$; whole transverse thenar, $p=0.003$) for the median group, and transverse thenar thickness below FPL ($p=0.006$) and whole transverse thenar ($p=0.007$) thickness measurements for the ulnar group. Intergroup comparisons revealed no significant difference for any muscle thickness measurement.

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Intra- and intergroup comparisons of ultrasonographic muscle thickness measurements are shown in **Figure 2**.

For the measurements in position 2 (longitudinal to FPL tendon), longitudinal thenar thickness below FPL and the ratio of longitudinal thenar thickness above FPL over below FPL were significantly lower (p=0.005 and p=0.041, respectively) on the injured side in the ulnar group, while the intragroup difference was not significant in the median group. The muscle thickness measurements were not significantly different between the median and ulnar group **(Figure 2)**.

For the measurements in position 3 (longitudinal thenar), 4 (transverse hypothenar) and 5 (longitudinal hypothenar), all muscle thickness measurements on the injured side were significantly lower (longitudinal thenar, median group p=0.008 and ulnar group p=0.013; transverse hypothenar, median group p=0.014 and ulnar group p=0.007; longitudinal hypothenar, ulnar group p=0.003) in both groups except for longitudinal hypothenar thickness in the median group. The muscle thickness measurements were not significantly different between the median and ulnar group **(Figure 2)**.

Correlation between muscle strengths and ultrasonographic muscle thickness measurements

For the median group, there was a moderate correlation between lateral pinch strength and transverse thenar muscle thickness **(Figure 3-A)**.

For the ulnar group, all pinch and handgrip strengths showed moderate-good correlation with longitudinal thenar thickness below FPL **(Figure 3-B)**; all pinch strengths showed

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moderate-good correlation with whole transverse thenar thickness (tip pinch, r=0.836, p=0.001; palmar pinch, r=0.738, p=0.010; lateral pinch, r=0.724, p=0.012). There were also moderate correlations between transverse thenar thickness below FPL, and tip (r=0.715, p=0.013) and palmar pinch (r=0.694, p=0.018) strengths. A moderate correlation was also observed between tip pinch strength and longitudinal thenar thickness (r=0.609, p=0.047).

Discussion

This study adds to a previous study investigating whether ultrasonographic measurement of the CSA of the intrinsic hand muscles can be used to predict muscle strength in patients with peripheral nerve injury between the wrist and elbow.[9] However, in contrast to that study, the current one measured muscle thickness instead of CSA, and muscle strength was assessed with the equipment described above instead of the Rotterdam Intrinsic Hand Myometer (RIHM); since these are two practical and easy methods that can be used in routine clinical setting.

The significant reduction in lateral and palmar pinch strengths for the median group, and in all the pinch and grip strengths for the ulnar group, are in line with previous studies.[12,13] The grip strength seems to receive greater contribution from the ulnar than the median nerve.[12,13] This might explain why the significant reduction of grip strength was observed only in the ulnar group in our study. The primary intrinsic muscles responsible for the lateral and tip pinch are adductor pollicis (ADP) and first dorsal interosseous (FDI) muscles, which are innervated by the ulnar nerve, and flexor pollicis brevis (FPB) muscle, which is mostly innervated by the ulnar nerve.[14] Median innervated thumb intrinsic muscles including abductor pollicis brevis (APB), opponens

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pollicis (OP) and FPB are also assumed to play a major role for the lateral pinch strength.[15] This information supports the findings of our study that both patient groups had lower strength in lateral pinch and only the ulnar group demonstrated lower tip pinch strength. For the palmar pinch strength, the major contribution comes from the first and second lumbricals, which are innervated by the median nerve.[16] Although these two lumbrical muscles are spared in ulnar nerve palsy, paralysis of the ulnar nerve innervated intrinsic hand muscles also cause a reduction in the palmar pinch strength.[13] In our study, as expected in both patient groups, palmar pinch strengths were low.

All the thenar muscles in transverse view (position 1) had lower thickness on the injured side in the median group, and thenar muscles below FPL had lower thickness in the ulnar group. These findings were expected from anatomic point of view. As the transverse thenar thickness reflects mainly the thickness of APB and OP, and the transverse thenar thickness above FPL reflects the thickness of flexor pollicis brevis superficialis (FPBS), and all of these muscles are innervated by the median nerve; the significant reduction of muscle thickness for these sites in median group was reasonable. Likewise, as the transverse thenar thickness below FPL reflects the thickness of flexor pollicis brevis profundus (FPBP), ADP and FDI, and all of these muscles are innervated by the ulnar nerve; the significant reduction of muscle thickness for these sites in the ulnar group was also reasonable. As expected, the whole transverse thenar thickness, which reflects mainly the thickness of FPBS, FPBP, ADP, and FDI muscles, was significantly reduced in both groups. Somewhat unexpectedly, we found a reduction in the transverse thenar thickness below FPL in the median group.

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The absence of a significant change in longitudinal thenar thickness above FPL in position 2 in the median group was unexpected, as this site reflects the median nerve innervated FPBS thickness. In the ulnar group, a significant decrease in longitudinal thenar thickness below FPL and a significant increase in the ratio of longitudinal thenar thickness above FPL over below FPL was observed as expected.

The thickness of thenar muscles in the longitudinal view (position 3) was reduced on the injured side in the median group, whereas thickness of hypothenar muscles both in the longitudinal (position 4) and transverse (position 5) views were reduced in the ulnar group. These findings were expected. However, significantly reduced transverse hypothenar muscle thickness in the median group and longitudinal thenar thickness in the ulnar group were unexpected findings.

One possible explanation for these unexpected findings is that participants in our study group did not have isolated nerve injuries. In fact, most of the patients had long-standing concomitant tendon injuries which had already caused variable degrees of secondary impairments such as disuse atrophies and contractures. Therefore, from this point of view, these findings may not be completely unexpected.

The only significant correlation in the median group was between lateral pinch strength and transverse thenar muscle thickness. As the lateral and palmar pinches were the two strength measurements mostly affected by the median nerve injury in our study group, and the transverse thenar muscle thickness was significantly affected in the median group, sonographic transverse thenar thickness measurement seems to be adequate in reflecting lateral pinch strength in patients with median nerve injury. Also, as all the

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pinch and handgrip strengths were significantly decreased in ulnar group, and handgrip and lateral pinch strengths were moderately, tip and palmar pinch strengths were well correlated with the longitudinal thenar thickness below FPL, sonographic longitudinal thenar thickness below FPL measurement seems to be adequate in reflecting all the pinch and handgrip strengths in patients with ulnar nerve injury.

We found that the most useful ultrasonographic measurements were transverse thenar muscle thickness for the median group; and longitudinal thenar muscle thickness below FPL for the ulnar group. It seems that just one muscle thickness measurement with US is an easy, practical, time-efficient and safe way to get information about muscle strength in patients with median or ulnar nerve injury.

Our study has some limitations. First, our study group was not composed of patients with injuries limited only to nerves. Second, the number of patients in each group was relatively small, which could explain some of the inconsistencies in our results. Third, we did not perform any form of quantitative EMG analysis. Such analysis could have been valuable since it would have provided quantitative data regarding degree of denervation and/or reinnervation to compare with the US measurements. Future studies focusing on the correlation between EMG, muscle strength and sonographic muscle thickness measurements in patients with peripheral nerve repair at different phases of rehabilitation period should be planned. As patients with systemic diseases associated with neuropathy were excluded, studies investigating the effects of such diseases on the correlations are also recommended.

In conclusion, our study suggests that sonographic follow-up of transverse thenar muscle thickness in patients who had median nerve reconstruction surgery, and longitudinal thenar muscle thickness below FPL in patients who had ulnar nerve reconstruction surgery, may be useful for assessing hand muscle strength during a rehabilitation program. These measurements may be particularly useful in the early post-operative period when strength tests should be avoided in order to prevent damage to healing tissues.

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Abbreviations

APB: abductor pollicis brevis

ADP: adductor pollicis

CSA: cross-sectional area

FDI: first dorsal interosseous

FPB: flexor pollicis brevis

FPBP: flexor pollicis brevis profundus

FPBS: flexor pollicis brevis superficialis

FPL: flexor pollicis longus

OP: opponens pollicis

US: ultrasound

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Tables

Table 1. Baseline characteristics of patients

	Median (n=11)	Ulnar (n=11)	P-value
Age (years)	29 (17-55)	25 (13-30)	0.395
Body mass index (kg/m^2)	25.10 (17.92-31.28)	22.38 (18.94-33.22)	0.670
Gender (Female: Male)	1:10	3:8	0.586
Dominant hand (Right:Left)	11:0	10:1	1.00
Injured hand (Right:Left)	8:3	6:5	0.659
Injured hand (Dominant:Nondominant)	8:3	5:6	0.387
Time since injury (Days)	228 (98-538)	179 (85-861)	1.00
Time since operation (Days)	228 (78-537)	124 (82-854)	1.00

Age, body mass index, time since injury, time since operation presented as median (min-max).

**P<0.05.*

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Figure Legends

Figure 1. Box plots demonstrate the median (horizontal line), the mean (x), the first and third quartiles (lower and upper limits of the boxes), the minimum and maximum values for muscle strength in Newtons.

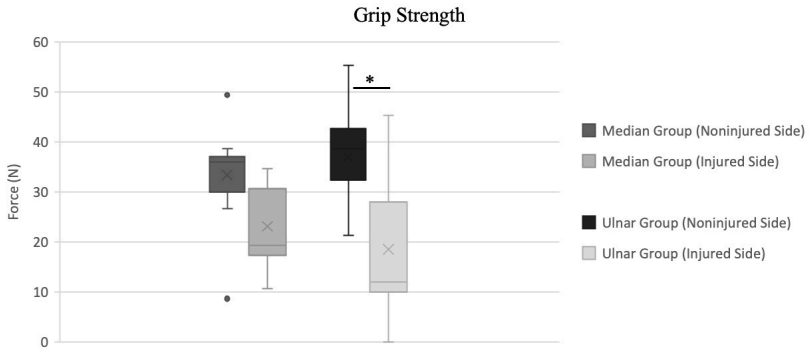
**P<0.05.*

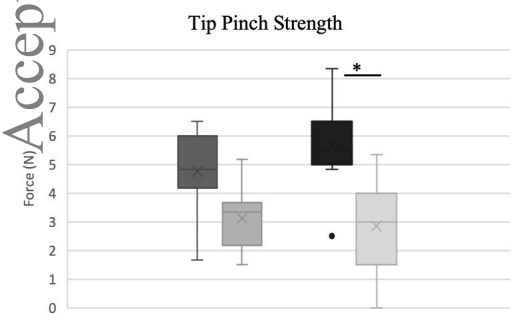
Figure 2. Comparison of median ultrasonographic muscle thickness measurements. **P<0.05.*

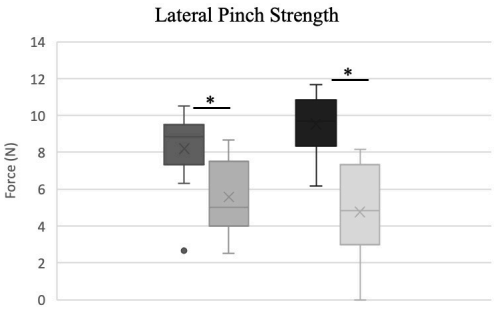
Figure 3. Scatter plot showing the correlation between A) transverse thenar muscle thickness and lateral pinch strength for the median group; B) longitudinal thenar thickness below FPL tendon and grip and pinch strengths for the ulnar group.

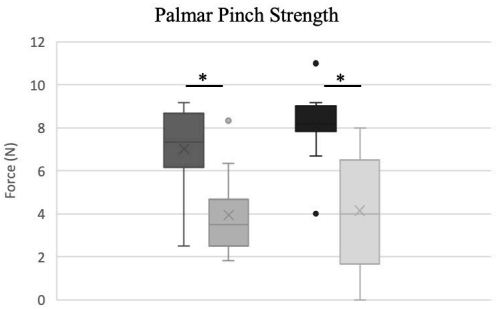
Abbreviation: FPL, flexor pollicis longus.

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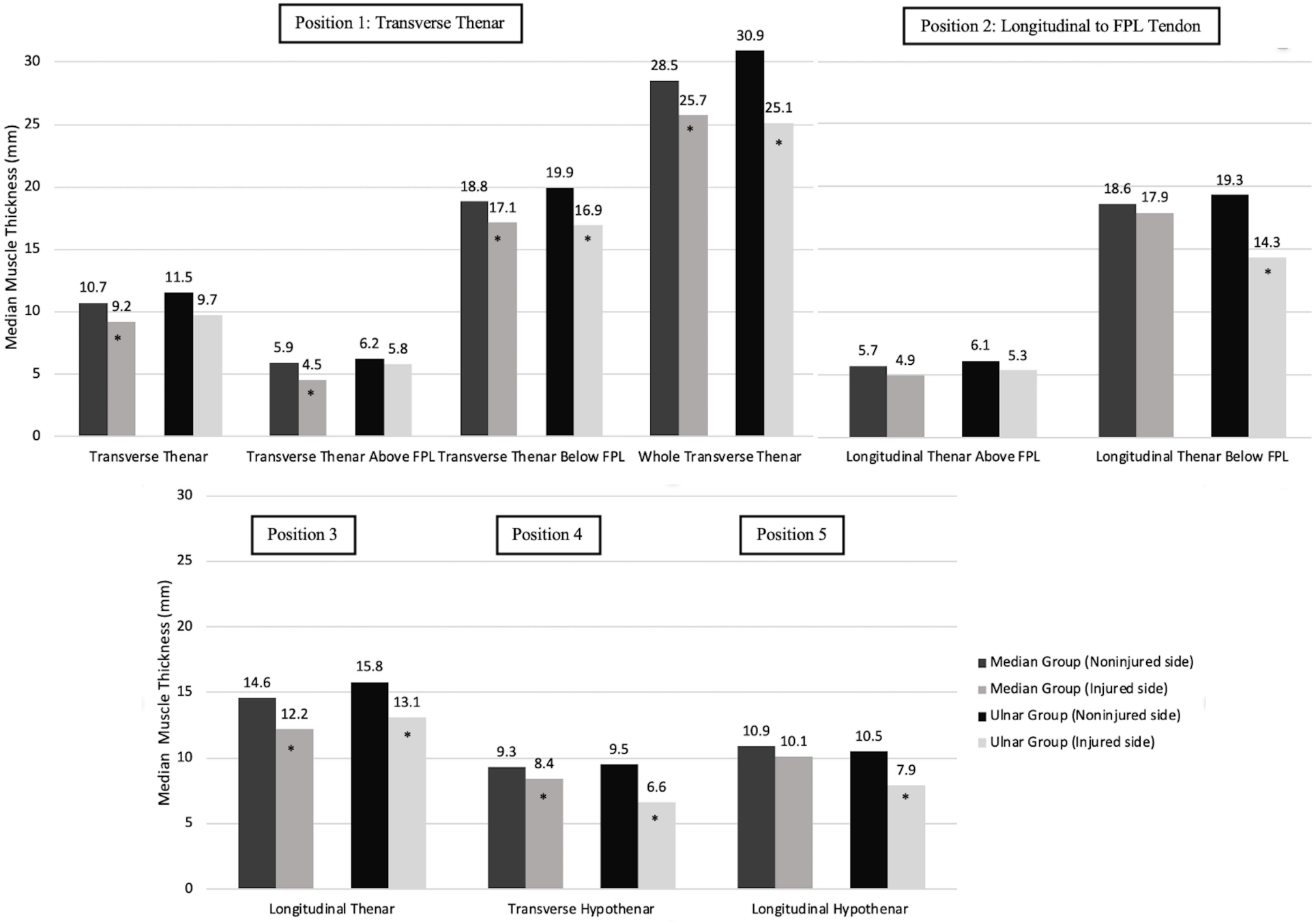




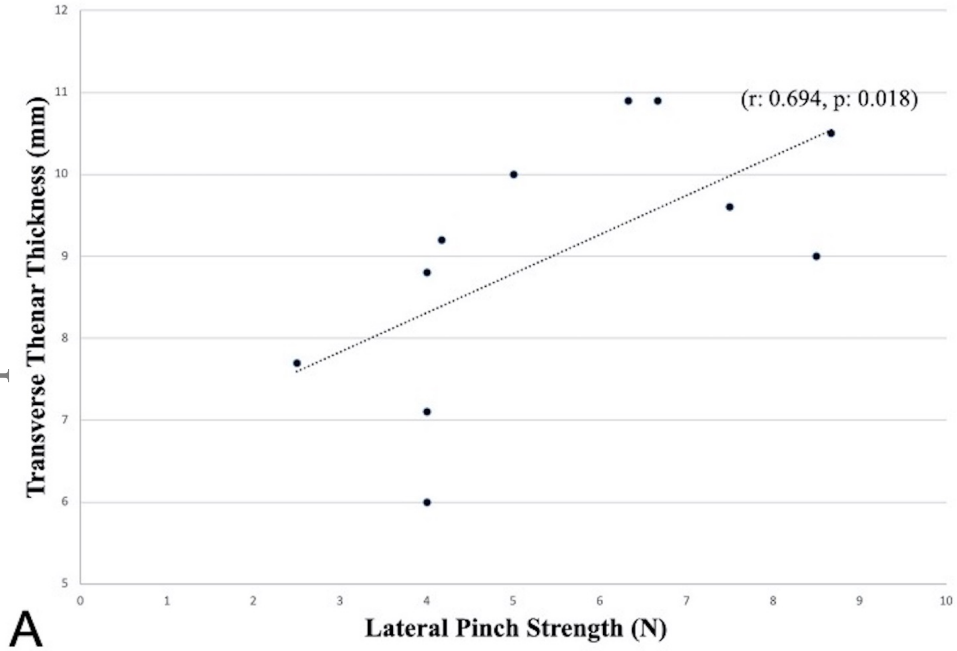




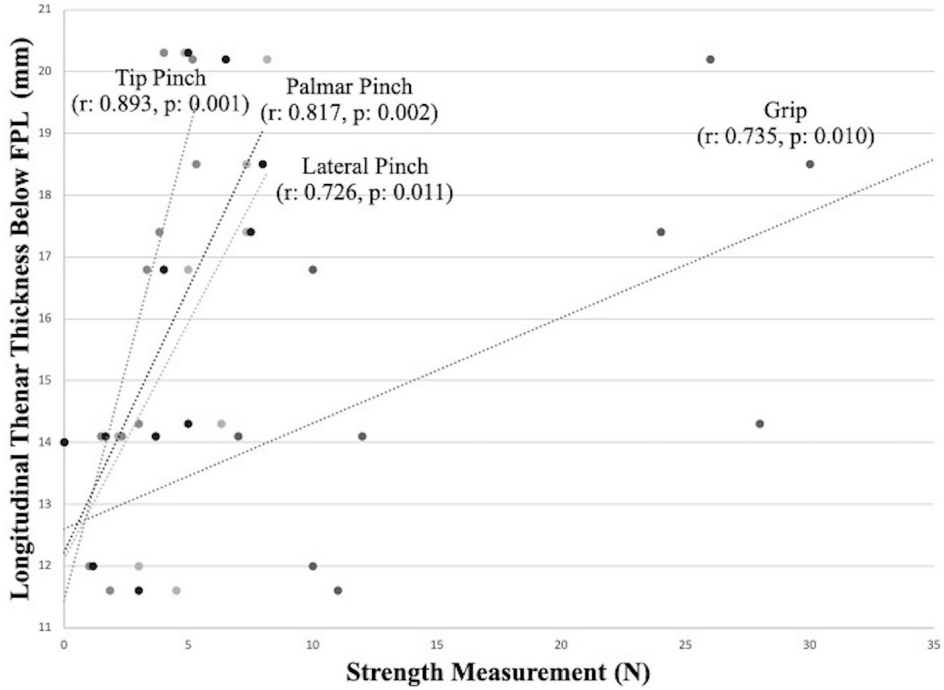
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