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RESEARCH ARTICLE

Morphological Changes of Medial Epicondyle-Olecranon Ligament and Ulnar Nerve in the Cubital Tunnel Syndrome: An Ultrasonic Study

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Abstract

Objective: Few studies have performed detailed ultrasound measurements of medial epicondyle-olecranon (MEO) ligament that cause the entrapment of ulnar nerve. This study aims to comprehensively evaluate dynamic ultrasonographic characteristics of MEO ligament and ulnar nerve for clinical diagnosis and accurate treatment of cubital tunnel syndrome (CuTS).

Methods: Thirty CuTS patients (CuTS group) and sixteen healthy volunteers (control group) who underwent ultrasound scanning from October 2016 to October 2020 were retrospectively collected, with 30 elbows in each group. Primary outcomes were thickness at six points, length and width of MEO ligament. Secondary outcomes were thickness of ulnar nerve under MEO ligament at seven parts and the cross-sectional area (CSA) of ulnar nerve at proximal end of MEO ligament ($P_{0\ mm}$). The thickness of MEO ligament and ulnar nerve in different points of each group was compared by one-way ANOVA analysis with Bonferroni *post hoc* test, other outcomes were compared between two elbow positions or two groups using independent-samples *t* test.

Results: Thickness of MEO ligament in CuTS group at epicondyle end, midpoint in transverse view, olecranon end, proximal end, midpoint in axial view, and distal end was 0.67 ± 0.31, 0.37 ± 0.18, 0.89 ± 0.35, 0.39 ± 0.21, 0.51 ± 0.38, 0.36 ± 0.25 at elbow extension, 0.68 ± 0.34, 0.38 ± 0.27, 0.77 ± 0.39, 0.32 ± 0.20, 0.48 ± 0.22, 0.32 ± 0.12 (mm) at elbow flexion, respectively. Compared with control group, they were significantly thickened except for proximal end at elbow flexion. MEO ligament thickness at epicondyle end and olecranon end was significantly larger than midpoint in two groups. No significant difference was found in length and width of MEO ligament among different comparisons. Ulnar nerve thickness at 5 mm proximal to MEO ligament ($P_{5\ mm}$, 3.25 ± 0.66 mm) was significantly increased than midpoint of MEO ligament (Mid), distal end of MEO ligament ($D_{0\ mm}$), 5 mm ($D_{5\ mm}$), 10 mm ($D_{10\ mm}$) distal to MEO ligament at extension in CuTS group. Compared with control group, ulnar nerve thickness at $P_{5\ mm}$ in CuTS group was significantly increased at extension position, at $D_{5\ mm}$ and $D_{10\ mm}$ was significantly decreased at flexion position. CSA of ulnar nerve at extension position ($14.44 \pm 4.65\ mm^2$) was significantly larger than flexion position ($11.83 \pm 3.66\ mm^2$) in CuTS group, and CuTS group was significantly larger than control group at two positions.

Conclusions: MEO ligament in CuTS patients was thickened, which compressed ulnar nerve and caused its proximal end swelling. Ultrasonic image of MEO ligament thickness was a significant indicator for CuTS and can guide surgeons in selecting the appropriate treatment.

Key words: cubital tunnel syndrome; medial epicondyle-olecranon ligament; ulnar nerve; ultrasound

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Introduction

Cubital tunnel syndrome (CuTS) is the second most common peripheral nerve compression syndrome after the carpal tunnel syndrome[1]. Patients with severe signs and symptoms or for whom conservative treatment have failed would require surgical intervention[2,3], and accurate preoperative diagnosis is essential to determine optimal surgical modalities[4,5]. It is difficult to make a proper treatment decision only based on clinical presentation and an electrodiagnostic study. High-resolution ultrasonography can provide more information about the space-occupying lesion or surrounding anatomy and allow for optimal visualization of the nerve condition in different positions and quantitative size of the nerve itself[6,7]. Some studies have been performed to investigate the feasibility of ultrasound for CuTS and believe that ultrasound can be utilized as an alternative or valuable adjunctive method in the diagnosis, screening, and follow-up of CuTS[8–11].

Ulnar nerve compression is a common cause of CuTS. A band of fibrous tissue that spanned between the medial epicondyle and the olecranon is one site of anatomic compression of ulnar nerve at the elbow. This ligament tissue was rarely carefully identified and was excised indiscriminately during surgery, which and has been confusingly referred to by several authors as Osborne's ligament, Osborne's band, Osborne's fascia, cubital tunnel retinaculum (CTR), and so on[12–16]. However, these terms were not used consistently across the literature and were often used to describe the connective tissue between the two heads of the flexor carpi ulnaris (FCU) muscle[17–20]. To distinguish these structures and reliably describe ulnar nerve compression at the elbow, we propose the term "Medial epicondyle-Olecranon ligament" (MEO ligament) to denote the connective tissue between the medial epicondyle and the olecranon in this article (Figure 1). Abnormal MEO ligament has the potential to compress ulnar nerve, resulting in nerve dysfunction[21]. Studying MEO ligament could explain the etiology of certain types of ulnar neuropathy, help the diagnosis of CuTS and selection of surgical procedures.

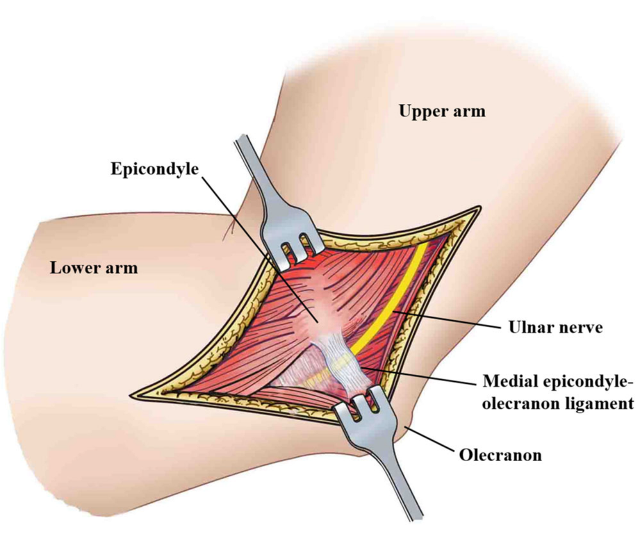

Fig. 1 The schematic diagram of Medial epicondyle-Olecranon ligament. Medial epicondyle-Olecranon ligament that connects the medial epicondyle and olecranon spans over the ulnar nerve

Technological advances in ultrasonography have allowed for direct visualization of the involved ulnar nerve and MEO ligament[9,22]. Cross-sectional area (CSA) and diameter of ulnar nerve were the indicators used in the ultrasonography study and were verified smaller than intraoperative measurements[23,24]. However, MEO ligament which was superficially located on ulnar nerve and appears as hyperechoic tissue on ultrasound was rarely concerned. To our knowledge, the detailed ultrasonic characteristics of MEO ligament and the relationship between MEO ligament and ulnar nerve have not been systematically investigated.

In the current study, ultrasonic scanning and measurement were performed to explore MEO ligament and ulnar nerve in detail for patients with CuTS, the results were compared with healthy volunteers. The aims of the study were as follows: (i) to comprehensively estimate morphological features of MEO ligament using ultrasonic scanning; (ii) to identify the change of ulnar nerve under MEO ligament and assess the exact compression extent of ulnar nerve caused by MEO ligament; and (iii) be conducive to a better understand the positional relationship between MEO ligament and ulnar nerve and improve clinicians' awareness of the ultrasonic image of CuTS patients.

Materials and Methods

Participants

The protocol for this study was approved by the Academic Ethics Committee of Tianjin Hospital (approval no. 2017–003). Thirty patients who were clinically diagnosed with the CuTS in Tianjin Hospital of China between October 2016 and October 2020 were included in the CuTS group. Sixteen healthy volunteers with 30 elbows were included in the control group. The general information of CuTS group and control group was recorded and presented in Table 1. All patients and healthy volunteers gave their informed consent in accordance with the Declaration of Helsinki before ultrasonic scanning and measurement. The inclusion criteria and exclusion criteria for participants were as follows.

The inclusion criteria: (i) patients who were diagnosed with the CuTS by standard clinical symptoms, signs and decrease in nerve conduction by electrodiagnosis; (ii) age >18 years old; (iii) patients without severe disease history of heart, lung, or other important organs; and (iv) healthy adult volunteers with no CuTS symptoms and no history of diabetes, tumor, or elbow injury.

The exclusion criteria: (i) participants who had history of injury of the same elbow; (ii) accompanied by severe soft tissue or nerve injuries; (iii) congenital deformities, tumor, or cyst in the elbow joint that may lead to anatomical change of

TABLE 1 Characteristics of patients with CuTS and healthy controls

	CuTS ($n = 30$)	Control ($n = 16$)
Sex (female/male)	9/21	7/9
Age (years) (mean ± SD, range)	(58.16 ± 8.33, 42–75)	(60.68 ± 5.53, 50–69)
Scanned elbow side (left/right)	10/20 (affected side)	16/14
Laborer/non-laborer	6/24	1/15

the cubital tunnel; and (iv) patients with mental disorder that could not be effectively treated.

Ultrasonic Image Analysis

CuTS group and control group underwent ultrasound scanning by two professional sonographers on ultrasound system (GE Medical system and LOGIQ E9) with a 15-MHz probe in B-mode. During the examination, all patients with CuTS and healthy volunteers were in the supine position with their involved elbow moved from extension position to 90° flexion position. MEO ligament and ulnar nerve underlying it were examined in transverse and axial views, and their images were captured at elbow extreme extension and 90° flexion position, respectively. Each outcome of interest was independently measured by the first two authors (Duan X and Xu B) using Adobe Photoshop CS6 ver.13.0. Any disagreement generated during measurement was resolved by discussion with each other or with the help from the third author (Ma X).

Morphological Indicators of MEO Ligament

Characteristic of MEO ligament was evaluated with thickness at six points including epicondyle end, midpoint, and olecranon end in transverse view and proximal end, midpoint, and distal end in axial view (Figure 2). In addition, the length (transverse view) and width (axial view) of MEO ligament were also measured. To evaluate the characteristic of MEO ligament, the thickness of MEO ligament in different points of the same group, and all outcomes between two groups were compared. All outcomes were also compared between elbow extension and elbow flexion to 90° to assess dynamic change of MEO ligament during elbow flexion.

Morphological Indicators of Ulnar Nerve

Regarding ulnar nerve in the cubital tunnel, it was evaluated using longitudinal scans and CSA of ulnar nerve in transverse view. The thickness at seven continuous points on the long axis at elbow extreme extension and 90° flexion position was measured to evaluate morphological change of ulnar nerve. Measuring points included 5 mm proximal to MEO ligament ($P_{5\ mm}$), proximal end of MEO ligament ($P_{0\ mm}$), midpoint of MEO ligament (Mid), distal end of MEO ligament ($D_{0\ mm}$), 5 mm ($D_{5\ mm}$), 10 mm ($D_{10\ mm}$) and 15 mm ($D_{15\ mm}$) distal to MEO ligament, respectively (Figure 2B). Secondly, the CSA of ulnar nerve at $P_{0\ mm}$ in transverse view was additionally measured at elbow extension position and flexion position. Comparison of all outcomes to evaluate the characteristic and dynamic change of ulnar nerve closed to MEO ligament.

Statistical Analysis

Statistical analysis was performed using SPSS version 25.0 (IBM Corp., Armonk, NY, USA). All outcomes were described using mean ± standard deviation (SD). For thickness, length, and width of MEO ligament, and thickness and CSA of ulnar nerve outcomes were compared between CuTS group and control group using independent-samples t test. Comparison of thickness between different points was performed using one-way ANOVA analysis with Bonferroni *post hoc* test. The rest comparisons of outcomes were performed using independent-samples t test. p value <0.05 was regarded as statistical significance.

Results

Thickness of MEO Ligament

CuTS Group

We measured the thickness of MEO ligament of CuTS group in current study. In transverse view, the thickness of MEO ligament at epicondyle end, midpoint, and olecranon end was 0.67 ± 0.31 mm, 0.37 ± 0.18 mm, 0.89 ± 0.35 mm at elbow extension, 0.68 ± 0.34 mm, 0.38 ± 0.27 mm, 0.77 ± 0.39 mm at elbow flexion, respectively. There were significant differences in the thickness of MEO ligament at the three points in both of elbow extension ($F = 16.654$, $p < 0.001$) and elbow flexion ($F = 11.848$, $p < 0.001$). The thickness of MEO ligament at olecranon end at elbow extension was extremely significantly larger than that at midpoint ($p < 0.001$). In addition, the thickness of MEO ligament at olecranon end at elbow flexion ($p = 0.031$) and at epicondyle end at two positions (elbow extension, $p = 0.043$; elbow flexion, $p = 0.048$) was significantly larger than that at midpoint.

In axial view, the thickness of MEO ligament at proximal end, midpoint, and distal end was 0.39 ± 0.21 mm, 0.51 ± 0.38 mm, 0.36 ± 0.25 mm at elbow extension, 0.32 ± 0.20 mm, 0.48 ± 0.22 mm, 0.32 ± 0.12 mm at elbow flexion, respectively. There was no significant difference in the thickness of MEO ligament between proximal end, midpoint, and distal end in both of elbow extension ($F = 1.919$, $p = 0.155$) and elbow flexion ($F = 2.763$, $p = 0.078$) (Figure 3A).

Control Group

In transverse view of control group, the thickness of MEO ligament at epicondyle end, midpoint, and olecranon end was 0.43 ± 0.18 mm, 0.22 ± 0.06 mm, 0.35 ± 0.18 mm at elbow extension, 0.41 ± 0.17 mm, 0.20 ± 0.05 mm, 0.31 ± 0.10 mm at elbow flexion, respectively. Similar with

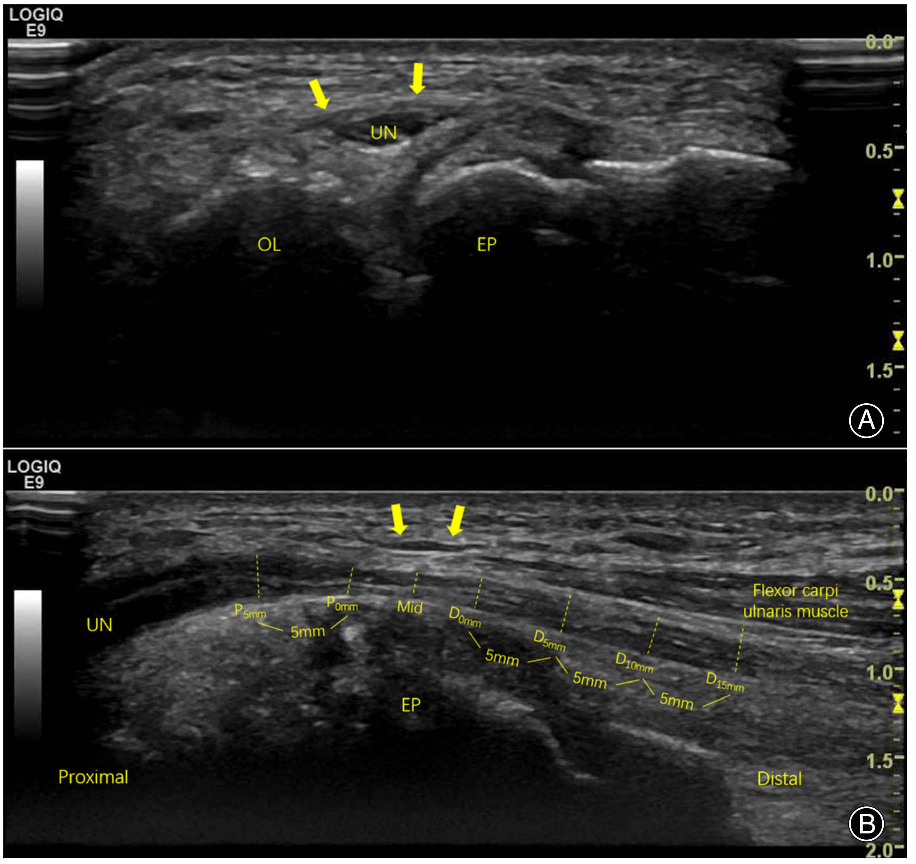

Fig. 2 Medial epicondyle-Olecranon ligament and ulnar nerve on ultrasonography. (A) Transverse view. (B) Axial view. The arrow refers to Medial epicondyle-Olecranon ligament. $D_{0\ mm}$, distal end of Medial epicondyle-Olecranon ligament; $D_{5\ mm}$, 5 mm distal to Medial epicondyle-Olecranon ligament; $D_{10\ mm}$, 10 mm distal to Medial epicondyle-Olecranon ligament; $D_{15\ mm}$, 15 mm distal to Medial epicondyle-Olecranon ligament; Mid, midpoint of Medial epicondyle-Olecranon ligament; $P_{0\ mm}$, proximal end of Medial epicondyle-Olecranon ligament; $P_{5\ mm}$, 5 mm proximal to Medial epicondyle-Olecranon ligament; UN, ulnar nerve; EP, epicondyle; OL, olecranon

CuTS group, obvious differences were found among the thickness of MEO ligament at the three points in both of elbow extension ($F = 8.395$, $p = 0.001$) and elbow flexion ($F = 12.937$, $p < 0.001$). The thickness of MEO ligament at olecranon end was significantly larger than midpoint (elbow extension, $p = 0.040$; elbow flexion, $p = 0.038$). In addition, thickness of MEO ligament at epicondyle end was extremely significantly larger than midpoint at two elbow positions (elbow extension, $p = 0.001$; elbow flexion, $p < 0.001$), and significantly larger than olecranon end at elbow flexion ($p = 0.049$).

In axial view, the thickness of MEO ligament at proximal end, midpoint, and distal end was 0.21 ± 0.08 mm, 0.19 ± 0.05 mm, 0.18 ± 0.04 mm at elbow extension, 0.19 ± 0.06 mm, 0.18 ± 0.07 mm, 0.18 ± 0.05 mm at elbow flexion, respectively. There was also no significant difference was found between proximal end, midpoint, and distal end in both of elbow extension ($F = 0.899$, $p = 0.413$) and elbow flexion ($F = 0.179$, $p = 0.836$) (Figure 3A).

CuTS Group vs *Control Group*

Comparison of MEO ligament thickness of CuTS group with control group was performed. The thickness of MEO ligament at eight positions (elbow extension, midpoint in transverse view [0.37 ± 0.18 mm *vs* 0.22 ± 0.06 mm, $t = 3.384$, $p = 0.001$], olecranon end [0.89 ± 0.35 mm *vs* 0.35 ± 0.18 mm, $t = 5.809$, $p < 0.001$], midpoint in axial view [0.51 ± 0.38 mm *vs* 0.19 ± 0.05 mm, $t = 4.142$, $p < 0.001$], distal end [0.36 ± 0.25 mm *vs* 0.18 ± 0.04 mm, $t = 3.322$, $p = 0.003$]; elbow flexion, epicondyle end [0.68 ± 0.34 mm *vs* 0.41 ± 0.17 mm, $t = 3.735$, $p = 0.001$], midpoint in transverse view [0.38 ± 0.27 mm *vs* 0.20 ± 0.05 mm, $t = 3.462$, $p = 0.002$], olecranon end [0.77 ± 0.39 mm *vs* 0.31 ± 0.10 mm, $t = 4.884$, $p < 0.001$], midpoint in axial view [0.48 ± 0.22 mm *vs* 0.18 ± 0.07 mm, $t = 4.391$, $p = 0.001$]) was extremely significantly increased and at three positions (elbow extension, epicondyle end [0.67 ± 0.31 mm *vs* 0.43 ± 0.18 mm, $t = 2.350$, $p = 0.026$], proximal end [0.39 ± 0.21 mm *vs* 0.21 ± 0.08 mm, $t = 2.155$, $p = 0.046$], elbow flexion, distal end [0.32 ± 0.12 mm *vs* 0.18 ± 0.05 mm, $t = 3.111$, $p = 0.018$]) was significantly increased in CuTS group compared with control group. However, the thickness of MEO ligament at proximal end at elbow flexion (0.32 ± 0.20 mm *vs* 0.19 ± 0.06 mm, $t = 2.002$, $p = 0.056$) did not show statistical difference between CuTS group and control group (Figure 3B).

Length and Width of MEO Ligament

We also analyzed the length and width of MEO ligament based on the ultrasonography. In CuTS group, the length and width of MEO ligament were 13.55 ± 5.24 and 6.54 ± 2.61 mm at elbow extension, 11.21 ± 4.02 and 4.95 ± 1.94 mm at elbow flexion, respectively. In control group, the length and width of MEO ligament were

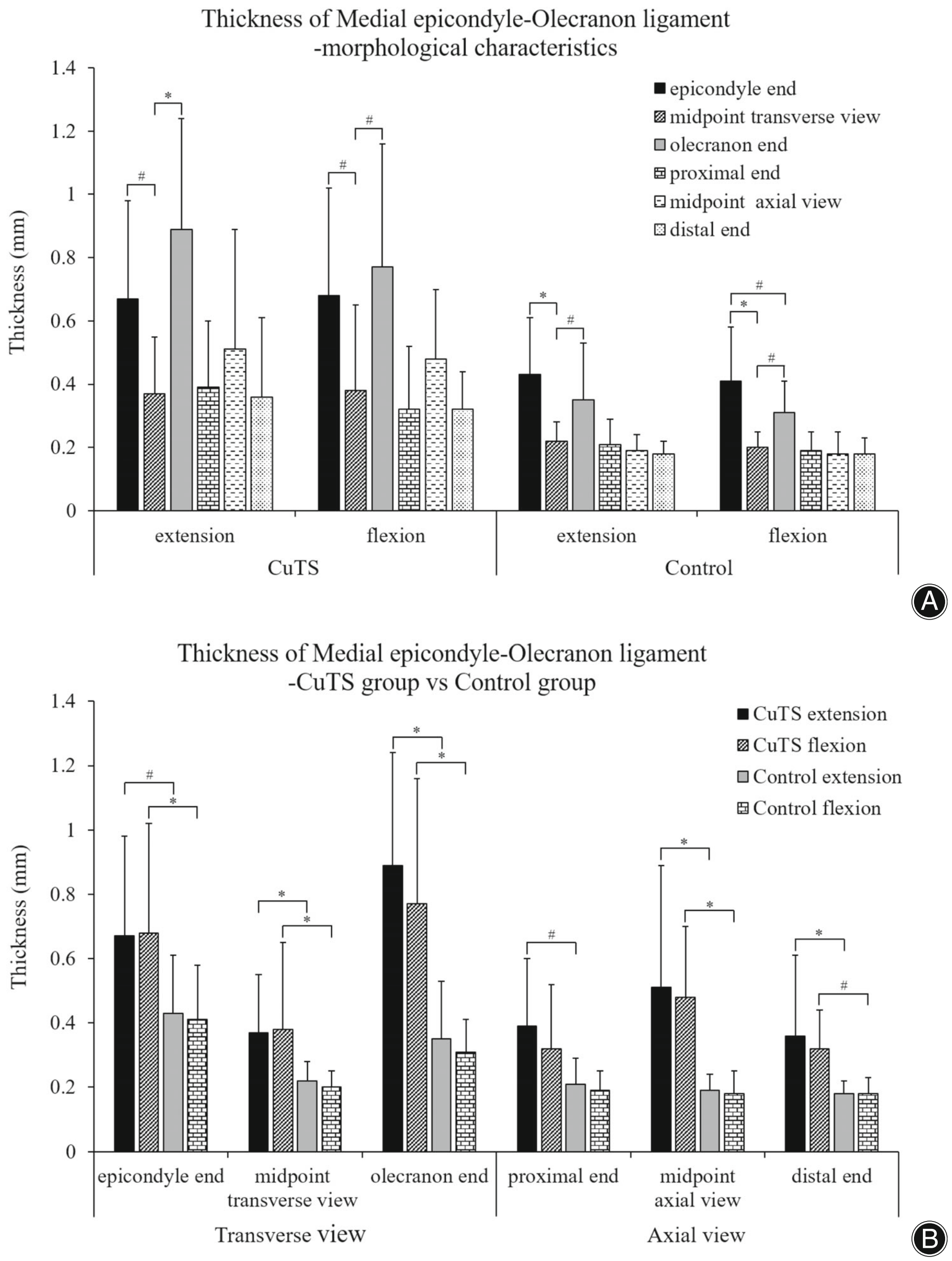

Fig. 3 Comparison of thickness of Medial epicondyle-Olecranon ligament. (A) Morphological characteristics of Medial epicondyle-Olecranon ligament were evaluated by comparing the thickness of six points of Medial epicondyle-Olecranon ligament (epicondyle end, midpoint, and olecranon end in transverse view; proximal end, midpoint, and distal end in axial view). (B) Comparison of thickness of Medial epicondyle-Olecranon ligament between CuTS group and control group. #, $p \le 0.05$; *, $p \le 0.01$

14.03 ± 3.30 and 5.56 ± 1.53 mm at elbow extension, 12.00 ± 4.23 and 5.14 ± 1.30 mm at elbow flexion, respectively. No significant difference was found in length (CuTS group, $t = 1.544$, $p = 0.131$; control group, $t = 1.589$, $p = 0.122$) and width (CuTS group, $t = 1.492$, $p = 0.146$; control group, $t = 0.914$, $p = 0.367$) of MEO ligament between elbow extension and elbow flexion. There was also no significant difference in length (elbow extension, $t = -0.343$, $p = 0.733$; elbow flexion, $t = -0.561$, $p = 0.579$) and width (elbow extension, $t = 1.540$, $p = 0.132$; elbow flexion, $t = -0.287$, $p = 0.777$) of MEO ligament between CuTS group and control group (Figure 4).

Thickness of Ulnar Nerve under MEO Ligament

In CuTS group, the thickness of ulnar nerve at seven points was $P_{5\,mm}$ 3.25 ± 0.66 mm, $P_{0\,mm}$ 2.82 ± 0.71 mm, Mid 2.34 ± 0.95 mm, $D_{0\,mm}$ 2.21 ± 0.87 mm, $D_{5\,mm}$ 2.21 ± 0.73 mm, $D_{10\,mm}$ 2.43 ± 0.58 mm, and $D_{15\,mm}$ 2.58 ± 0.62 mm at elbow extension, and $P_{5\,mm}$ 2.06 ± 1.22 mm, $P_{0\,mm}$ 1.95 ± 1.14 mm, Mid 1.88 ± 1.21 mm, $D_{0\,mm}$ 1.82 ± 1.45 mm, $D_{5\,mm}$ 1.59 ± 0.70 mm, $D_{10\,mm}$ 1.79 ± 0.52 mm, and $D_{15\,mm}$ 2.13 ± 0.21 mm at elbow flexion, respectively. At elbow extension, there were obvious differences among the seven points ($F = 5.355$, $p < 0.001$). The thickness of ulnar nerve at $P_{5\,mm}$ was significantly increased than that at Mid

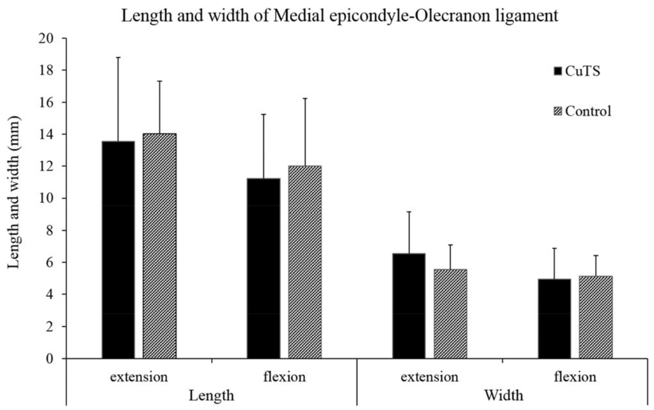

Fig. 4 Comparison of length and width of Medial epicondyle-Olecranon ligament. Two comparisons were conducted, (1) Comparison of measurements between CuTS group and control group. (2) Comparison of measurements between elbow extension and elbow flexion to 90° in each group

($p = 0.002$), $D_{0\ mm}$ ($p < 0.001$), $D_{5\ mm}$ ($p < 0.001$), and $D_{10\ mm}$ ($p = 0.010$) at elbow extension. However, there was no significant difference between $P_{5\ mm}$ and $P_{0\ mm}$ ($p = 1.000$) or $D_{15\ mm}$ ($p = 0.100$), and among other points. At elbow flexion, no obvious difference was found between the seven points ($F = 0.183$, $p = 0.980$) (Figure 5).

In control group, the thickness of ulnar nerve at seven points was $P_{5\ mm}$ 2.50 ± 0.77 mm, $P_{0\ mm}$ 2.53 ± 0.80 mm, Mid 2.55 ± 0.76 mm, $D_{0\ mm}$ 2.61 ± 0.78 mm, $D_{5\ mm}$ 2.62 ± 0.75 mm, $D_{10\ mm}$ 2.70 ± 0.68 mm, and $D_{15\ mm}$ 2.73 ± 0.66 mm at elbow extension, and $P_{5\ mm}$ 2.29 ± 0.67 mm, $P_{0\ mm}$ 2.16 ± 0.68 mm, Mid 2.06 ± 0.63 mm, $D_{0\ mm}$ 2.13 ± 0.60 mm, $D_{5\ mm}$ 2.34 ± 0.63 mm, $D_{10\ mm}$ 2.35 ± 0.50 mm, and $D_{15\ mm}$ 2.39 ± 0.50 mm at elbow flexion, respectively. There was no significant difference between seven points in both of elbow extension ($F = 0.249$, $p = 0.959$) and elbow flexion ($F = 0.774$, $p = 0.592$) (Figure 5).

When compared with control group, ulnar nerve at $P_{5\ mm}$ in CuTS group was significantly increased at elbow extension position (3.25 ± 0.66 mm *vs.* 2.50 ± 0.77 mm, $t = 3.293$, $p = 0.002$). However, the thickness of ulnar nerve at $D_{5\ mm}$ (1.59 ± 0.70 mm *vs.* 2.34 ± 0.63 mm, $t = -2.627$, $p = 0.015$) and $D_{10\ mm}$ (1.75 ± 0.52 mm *vs.* 2.35 ± 0.50 mm, $t = -2.518$, $p = 0.020$) was significantly decreased in CuTS group compared with control group at elbow flexion. Thickness at the rest points showed no obvious difference between CuTS group and control group ($p > 0.05$). Comparison of ulnar nerve thickness between elbow extension and elbow flexion was not conducted because ulnar nerve obviously moved in the cubital tunnel during elbow flexion movement.

CSA of Ulnar Nerve in Transverse View

The CSA of ulnar nerve at $P_{0\ mm}$ in CuTS group was 14.51 ± 4.61 mm^2 at elbow extension position and 11.83 ± 3.66 mm^2 at flexion position, and in control group was 8.83 ± 3.03 mm^2 at extension position and 7.76 ± 2.45 mm^2 at flexion position.

Comparison of CSA of ulnar nerve at extension position with 90° flexion position was performed. The result showed that the CSA of ulnar nerve at extension position was significantly larger than flexion position ($t = 2.497$, $p = 0.015$) in CuTS group. However, no significant change was shown in control group ($t = 1.514$, $p = 0.136$). In addition, the CSA of ulnar nerve in CuTS group at both elbow positions was significantly enlarged compared with that in control group (elbow extension, $t = 5.645$, $p < 0.001$; elbow flexion, $t = 5.071$, $p = 0.006$) (Figure 6).

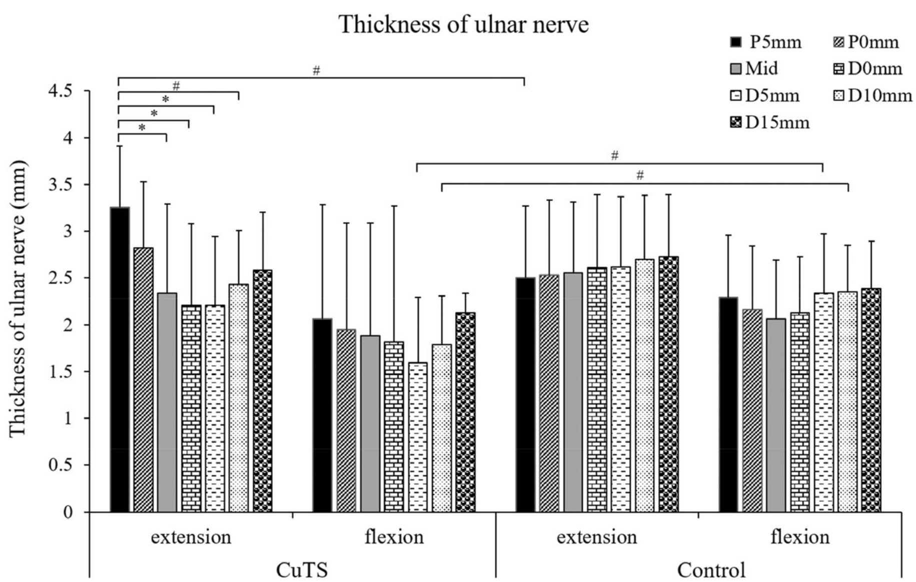

Fig. 5 Comparison of thickness of ulnar nerve. (1) Comparison of measurements between seven positions in each group. (2) Comparison of measurements between CuTS group and control group. $P_{5\ mm}$, 5 mm proximal to Medial epicondyle-Olecranon ligament; $P_{0\ mm}$, proximal end of Medial epicondyle-Olecranon ligament; Mid, midpoint of Medial epicondyle-Olecranon ligament; $D_{0\ mm}$, distal end of Medial epicondyle-Olecranon ligament; $D_{5\ mm}$, 5 mm distal to Medial epicondyle-Olecranon ligament; $D_{10\ mm}$, 10 mm distal to Medial epicondyle-Olecranon ligament; $D_{15\ mm}$, 15 mm distal to Medial epicondyle-Olecranon ligament. #, $p \leq 0.05$; *, $p \leq 0.01$

Discussion

Summary of the Major Results of the Study

In our research, MEO ligament was thickened to varying degrees at all measuring points in CuTS group. MEO ligament thickness at epicondyle end and olecranon end was significantly larger than that at midpoint. No significant difference was found in length and width of MEO ligament among different comparisons. The thickening MEO ligament compressed ulnar nerve and caused its proximal end swelling. The thickness of ulnar nerve at $P_{5\ mm}$ in CuTS group at elbow extension was significantly increased than that at Mid, $D_{0\ mm}$, $D_{5\ mm}$, and $D_{10\ mm}$, and was significantly increased than that in control group. Ulnar nerve at $D_{5\ mm}$ and $D_{10\ mm}$ in CuTS group at flexion position was significantly thinned than that in control group.

Review the Terminology of MEO Ligament

Ulnar nerve entrapment is a common cause of CuTS which presents in patients of all ages that can result in discomfort, weakness, and loss of function[2,25]. Our hand surgeons found a band of fibrous tissue that spanned between the medial epicondyle and the olecranon often compressed ulnar nerve during the surgery of patient with CuTS. The anatomically distinct structure between the olecranon and the medial epicondyle has been confusingly referred to as Osborne's ligament, Osborne's band, Osborne's fascia, CTR, and so on[15,21,26,27]. Kleinman was the earliest used "Osborne's ligament" as the roof of the bony retrocondylar groove at the elbow between the medial epicondyle and the olecranon[13]. O'Driscoll *et al.* proposed the term "cubital tunnel retinaculum" to denote this structure and some authors defined Osborne's fascia as synonymous with the term CTR[12,15,16]. However, Gervasio equated "Osborne's ligament" to "Osborne's band" and Karatas *et al.* described Osborne's ligament as the CTR defined as the connective tissue between the two heads of the FCU muscle[14,19]. Poujade described Osborne's fascia as not only the fascial structure connecting the two heads of the FCU but also a distinct extension of the CTR[28]. All of above demonstrated that these terms were used inconsistently to denote distinct structures, the use of eponymous terminology might cause confusion and result in failure to communicate precisely. Therefore, to clarify this structure for future use, we used the term "Medial epicondyle-Olecranon ligament" to clearly describe the fibrous tissue between the medial epicondyle and the olecranon in this study.

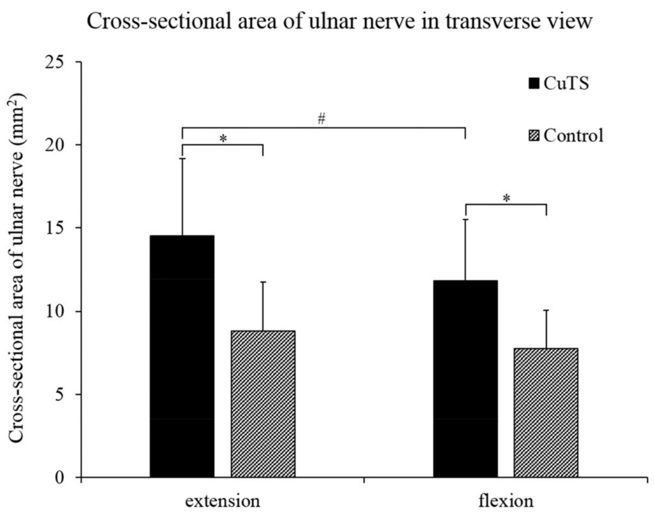

Fig. 6 Comparison of cross-sectional area of ulnar nerve at proximal end of Medial epicondyle-Olecranon ligament. First comparison was performed between CuTS group and control group; Second comparison was performed between elbow extension position and elbow 90° flexion position. #, $p \leq 0.05$; *, $p \leq 0.01$

Ultrasonic Morphological Characteristics of MEO Ligament

The high resolution and dynamic capability of ultrasound makes it an excellent tool for assessment of the integrity and continuity of ligaments and nerves in real time in positions of stress, which allow better depiction of nerves and appreciation of ligaments[7,22]. In this study, we further characterized the morphology of MEO ligament and ulnar nerve under ultrasound, and a correlation analysis was performed between them, which was conducive to making treatment plan. The results showed that in CuTS group and control group, MEO ligament was thicker at epicondyle end and olecranon end and thin in the middle in transverse view, the changes were significant in both of elbow extension and flexion position. However, MEO ligament had no significant change in axial view. Some studies had demonstrated that Osborne's ligament became taut at elbow flexes 90° and 135° and allowed the capsular floor of ulnar nerve to protrude into the cubital tunnel, transverse compression might occur under the ligament[29,30]. In the current study, we observed that the ulnar nerve was also compressed by the MEO ligament, but there was no significant change in the thickness of MEO ligament in both CuTS group and control group during elbow flexion. The length and width of MEO ligament were reduced at elbow flexion position compared to the extension position, but the changes were also not significant. Based on the characteristics of mentioned above, we speculated that MEO ligament might be a connective tissue with toughness and relatively small elasticity. Therefore, MEO ligament tightened during elbow flexion and caused dynamic compression of ulnar nerve[19,30]. On the other hand, pathologically thickened MEO ligament occupied more space, which decreased the capacity of the cubital tunnel and resulted in the compression of ulnar nerve. All of these factors play a role in producing the typical symptoms of CuTS.

The width of CTR that extended from the medial epicondyle to the olecranon was 4 mm in cadavers in a published study[12]. The variation might be caused by different judgment of ends of ligament in cadaver study. Although the result in the current study was different from the previous studies, we found that ultrasound could provide clear edge of MEO ligament and stable measurement result. James[31] measured the thickness of cadaveric CTR before its removal and after excised, the results were 0.14–0.15 and 0.18–0.31 mm, which were similar to the measurement results of the control group in the current study. Cadaver ultrasound study showed that a thin hyperechoic laminar structure above the ulnar nerve microscopically presented a tri-laminar structure corresponding to fascial, tendinous, and muscular layers, with an average thickness of 0.9 mm, which was larger than the current study[32]. Traumatic, inflammatory, or degenerative pathologies might cause a metaplasia of the three layers and acquire a ligamentous appearance, which could reduce its plasticity and cause compression of ulnar nerve[12,32]. Therefore, the so-called ligaments could represent the end-stage of different pathologies. These could partly explain the differences researchers observed in their studies and the discrepancy in their measurements. The MEO ligament in this study came from patients with CuTS, which was different from the above research, and the corresponding histological investigation needed to be confirmed by further study. Moreover, ethnic difference or swelling change of tissue in cadaver should also be taken into account for the difference in measurement result.

Analysis of the Relationship between MEO Ligament and Ulnar Nerve

To assess the exact compression site and extent of the ulnar nerve which were caused by MEO ligament and explore the positional relationship between MEO ligament and ulnar nerve, the thickness of ulnar nerve was measured. The thickness of ulnar nerve at $P_{5\,mm}$ at elbow extension was significantly increased than Mid, $D_{0\,mm}$, $D_{5\,mm}$, and $D_{10\,mm}$ in CuTS group, and was also significantly increased when compared with control group. The measuring results suggested that thickened MEO ligament caused compression and partial thickening of ulnar nerve, which was consistent with the thickness of ulnar nerve becoming thinner at the compression site and became thicker at proximal in patients with CuTS[8,33]. Compared with control group, the thickness of ulnar nerve was decreased in CuTS group at flexion position, and the difference was significant at $D_{5\,mm}$ and $D_{10\,mm}$. This indicated that thickened MEO ligament had a greater impact on ulnar nerve entrapment during elbow flexion, especially for the distal end. The largest thickness of ulnar nerve at seven points was $P_{5\,mm}$ 3.25 mm at elbow extension and $P_{5\,mm}$ 2.06 mm at elbow flexion in this study, which were smaller than some studies[24,34]; this may be caused by different measurement methods. The measurement was made within the echogenic rim of the ulnar nerve in this study, and the difference might be associated with the exclusion of the thickness of epineurium and perineural fibrous tissue[23,35]. In addition, the researchers chose different measurement sites, the values obtained might not be the maximum diameter. However, this did not affect the measurement results providing us with a better understanding of the morphological change of ulnar nerve relative to the position of MEO ligament.

The CSA of ulnar nerve is frequently used as one of quantitative parameters for ultrasonographic evaluation of CuTS[8,11,33,36]. We observed that ulnar nerve at proximal end was thickened in this study, so the CSA of ulnar nerve at $P_{0\,mm}$ in transverse view was also measured to evaluate the effect of MEO ligament on the ulnar nerve. The CSA of ulnar nerve was larger in patients with CuTS and varies at different positions in the cubital tunnel[24,36], which was in accordance with the current study. In the research, the CSA of ulnar nerve in CuTS group was 14.51 ± 4.61 mm^2 at extension position and 11.83 ± 3.66 mm^2 at flexion position, which was significantly larger than that in control group. Studies have shown that ulnar nerve swelling was one of the manifestations of ulnar neuropathy in CuTS, the cross-sectional threshold of ulnar nerve was 10 mm^2, which was correlated with a sensitivity and specificity of greater than 88% in the diagnosis of CuTS[11,33,36]. In addition, the CSA of ulnar nerve in CuTS group was significantly reduced during elbow flexion. However, no significant change was shown in control group. These also suggested that thickened MEO ligament put more pressure on the ulnar nerve during elbow flexion, which could explain why the symptom of ulnar neuropathy was often exacerbated at elbow flexion position.

The available evidence in the current study suggested that ulnar nerve at proximal end of MEO ligament was pathologically thickened in patients with CuTS and was significantly compressed by MEO ligament during elbow flexion. Moreover, ulnar nerve from Mid to $D_{10\,mm}$ was obviously compressed by MEO ligament in CuTS group[8,24]. With these results in hand, we could infer that the thickening and tightness of MEO ligament aggravate the compression of ulnar nerve and cause CuTS.

Limitations

Researchers have paid much less attention to MEO ligament. This was the first study performing detailed ultrasonographic measurement to evaluate characteristics of MEO ligament and investigate the morphological change of ulnar nerve under MEO ligament, and to explore the positional relationship between MEO ligament and ulnar nerve in patients with CuTS. Still, authors of the study noted that there were several limitations in this study. First of all, the sample size of this study was relatively small, which may lead to sampling error. Based on the results, we calculated through power analysis that each group needed about 135 people to verify the results. In future studies, 105 more people in each group are needed, at which point the test efficiency can reach 90%. Second, we did not perform intraoperative direct measurements of MEO ligament and ulnar nerve, so we could not assess the consistency between preoperative ultrasonographic and intraoperative measurements of MEO ligament and ulnar nerve. Future study is still needed to confirm our results. Third, the possibility of measurement error could not be ruled out, although the measurement procedure was standardized.

Conclusions

MEO ligament was thickened in patients with CuTS. Thickened MEO ligament compressed ulnar nerve, caused ulnar nerve to swell at proximal end and be thin from Mid to $D_{10\ mm}$, especially at elbow flexion. MEO ligament thickness was a significant indicator for CuTS. Ultrasonic results could provide more helpful diagnostic information for clinician and significant guidance for the precise minimally invasive treatment to remove the compression of MEO ligament on ulnar nerve.

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Authors' Contribution

All authors have contributed significantly to this study. XYD and BX had directly participated in the planning and execution of the study and were the major contributors in drafting the manuscript. KTG, YY, and JMG had reviewed the patients' medical record and collected the clinical data. JXM and XLM had designed the study and revised the manuscript critically. All authors read and approved the final draft of the manuscript.

Conflicts of Interest

All authors declared that they have no conflicts of interest.

Declaration

All authors listed meet the authorship criteria according to the latest guidelines of the International Committee of Medical Journal Editors, and all authors are in agreement with the manuscript.

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