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ORIGINAL ARTICLE

The proximal origins of the flexor–pronator muscles and their role in the dynamic stabilization of the elbow joint: an anatomical study

**Kenichi Otoshi · Shin-ichi Kikuchi ·
Hiroaki Shishido · Shin-ichi Konno**

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Abstract

Purpose The purpose of this study was to anatomically investigate the proximal origin of flexor–pronator muscles (FPMs) and clarify their contribution to dynamic stabilization of the elbow joint during valgus stress.

Methods 52 elbows from 26 donated formalin-fixed cadavers were examined. The pronator teres muscle (PT), flexor carpi radialis muscle (FCR), palmaris longus muscle (PL), flexor digitorum superficialis muscle (FDS), and flexor carpi ulnaris muscle (FCU) were identified, and their proximal origin and relationship to the anterior bundle of the medial ulna collateral ligament (AOL) were macroscopically and histologically investigated.

Results The PT, FCR, PL, and FDS converged and formed a common tendon at their proximal origin (the anterior common tendon: ACT). The ACT was attached to the medial epicondyle and the joint capsule, just anterior and parallel to the AOL. The histological morphology of the ACT was quite similar to that of the AOL. The ulnar head of the PT was observed in 48 of 52 elbows (92.3 %), just behind the humeral head of PT. It mainly originated from the anterior edge of the sublime tubercle, while the upper part of ulnar head transitioned directly into the thickened joint capsule just anterior to the AOL.

Conclusion The proximal attachment of the FPMs had a characteristic morphology. According to our results, the ACT and PT might assist the AOL by sharing static and dynamic traction forces applied to the medial elbow joint.

Keywords Dynamic stabilizer · Flexor–pronator muscles · Anterior common tendon · Pronator teres

Introduction

The medial ulnar collateral ligament (MUCL) of the elbow joint is thought to be one of the primary static restraints to valgus stress [4, 9, 13, 15, 17, 21]. The MUCL consists of three ligaments: anterior oblique ligament (AOL), posterior oblique ligament, and transverse ligament. AOL is considered to play the most important role in stabilizing the elbow joint against valgus stress. The MUCL is commonly injured in sports-related overuse injuries (such as overhead throwing). During throwing motion, especially in the acceleration phase, up to 120 Nm of valgus torque can be experienced in the elbow [25]. The demand on the medial ulnar collateral ligament during the acceleration phase is estimated to be 35 Nm [8], which exceeds the failure strength of the MUCL [2]. This tremendous repetitive valgus force may lead to microtrauma and failure of the medial ulnar collateral ligament over time.

It is believed that some of the valgus force to the elbow joint is alleviated by the overlying flexor–pronator muscles (FPMs) and that the FPMs might contribute to the dynamic stabilization of the elbow joint during throwing motions [5, 6, 11, 12, 14, 19, 22, 24].

Several studies have described the importance of the FPMs in elbow valgus stability. An anatomical study conducted by Davidson et al. [5] showed that the flexor carpi ulnaris (FCU) and flexor digitorum superficialis (FDS) were the predominant musculotendinous units for elbow stability because of their position directly over the MUCL while in the elbow flexion position, Several electromyographic studies showed that the FPMs demonstrated

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K. Otoshi (✉) · S. Kikuchi · H. Shishido · S. Konno
Department of Orthopaedic Surgery, Fukushima Medical University School of Medicine, 1 Hikarigaoka,
Fukushima, Fukushima 960-1295, Japan
e-mail: kootoshi@fmu.ac.jp

very high activity during the late cocking and acceleration phases [6, 11, 12, 22], and several cadaveric biomechanical studies demonstrated that the FCU would be the primary contributor to elbow valgus stability [14, 19, 24].

It is well known that almost all FPMs originate from the medial epicondyle. However, little is known about the precise anatomy of their proximal attachment and relationship to the MUCL [23].

The purpose of the present study is to macroscopically and histologically investigate the anatomical features of the proximal origin of the FPMs to determine their contribution to elbow valgus stability.

Materials and methods

52 elbows from 26 donated formalin-fixed cadavers were examined.

The study group consisted of 13 males and 13 females with a mean age of 81.5 years (range 64–97 years). All of the elbows were grossly normal. Skin and subcutaneous tissues were carefully removed to expose the superficial fasciae of the FPMs at the medial aspect of the elbow and forearm. The pronator teres muscle (PT), flexor carpi radialis muscle (FCR), palmaris longs muscle (PL), flexor digitorum superficialis muscle (FDS), and flexor carpi ulnaris muscle (FCU) were distinguished from each other by their distal attachments. After carefully removing the muscles, the MUCL and common tendon of the FPMs were identified and their proximal and distal origins were carefully observed.

Following macroscopic examination, the medial joint capsule was carefully dissected, and 10-μm-thick horizontal and longitudinal sections were obtained and placed on slides. The sections were stained with hematoxylin and eosin, and the histological structures were examined.

Results

Anatomy of the AOL

The AOL originated from the anteroinferior surface of the medial epicondyle and inserted on the surface of the sublime tubercle of the ulna. The AOL had a cord-like appearance in the proximal part and became flat and spread toward the distal attachment. The width of the proximal origin was 8.3 ± 1.2 mm (6–12 mm), and the thickness was 10.0 ± 1.6 mm (6–14 mm). The width of the distal attachment was 11.7 ± 1.8 mm (4.5–10 mm), the thickness was 1.1 ± 0.1 mm (0.8–1.2 mm) (Fig. 1).

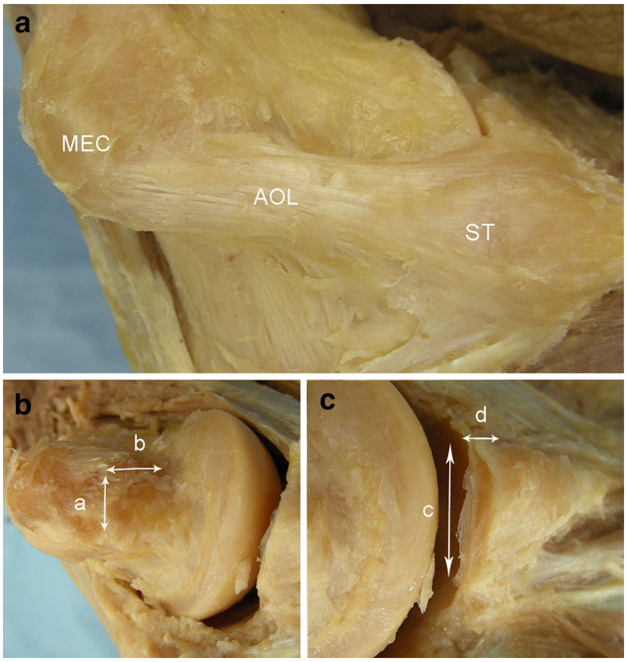

Fig. 1 Dissection of the MUCL (*medial view* of a *left elbow*). The AOL originates from the anteroinferior surface of the medial epicondyle (MEC) and inserts onto the surface of the sublime tubercle (ST) of the ulna **a**. The width of the proximal origin is 8.3 ± 1.2 mm (*a*), and the thickness is 10.0 ± 1.6 mm (*b*) **b**. The width of the distal attachment is 11.7 ± 1.8 mm (4.5–10 mm), and the thickness is 1.1 ± 0.1 mm (0.8–1.2 mm) (**c**) *MEC* medial epicondyle, *AOL* anterior oblique ligament, *ST* sublime tubercle

Macroscopic examination of FPMs

The humeral head of the PT originated directly from the anterosuperior aspect of the medial epicondyle and medial intermuscular septum. The PL and FCR originated from the medial epicondyle via their intermuscular fascia. The humeral head of FCU originated directly from the medial epicondyle and the ulnar head of FCU originated directly from the medial aspect of the olecranon (Fig. 2a). The FDS was located deep to the PL and FCR, and its muscle fiber directly originated from the anterior aspect of the medial epicondyle to the medial joint capsule, just over the AOL (Fig. 2b). The intermuscular fascia between the humeral heads of the PT, FCR, PL, and FDS converged and formed the common tendon at their proximal origin (anterior common tendon: ACT). The ACT was attached to the medial epicondyle and the anterior joint capsule, just anterior and parallel to the AOL. The mean length of ACT attachment was 28.3 ± 4.3 mm (range 18–36 mm), and it passed across the medial ulnohumeral joint line in 45 of 52 elbows (86.5 %). The intermuscular fascia between the FDS and FCU also formed the common tendon (posterior common tendon: PCT), which was attached to the inferior end of the medial epicondyle and medial joint capsule, just posterior to the AOL. The average thicknesses of ACT and PCT were 2.5 ± 0.7 and 0.9 ± 0.3 mm, respectively (Figs. 3, 4).

The joint capsule where the ACT attached was hyperplastic and had a cord-like appearance similar to that of a ligament (Fig. 5a, b). The mean width of the thickened capsule was 4.9 ± 1.4 mm at the proximal attachment and 7.1 ± 1.4 mm at the joint line. The proximal origin of the ACT was attached to the medial epicondyle as it encircled the upper border of the AOL (Fig. 5c).

The ulnar head of the PT was observed in 48 of 52 elbows (92.3 %), just behind the humeral head of PT. It usually originated from the anterior edge of the sublime tubercle; however, the upper part of the ulnar head transitioned directly into the thickened joint capsule just anterior to the AOL (humeral branch) where the ACT was attached. The mean width of the ulnar head was 9.5 ± 2.8 mm, and the mean width of the humeral branch was 3.9 ± 1.4 mm (Fig. 6).

Histological examination of the ACT and AOL

In the longitudinal sections, well-oriented collagen fibers were identified within both the ACT and the AOL. The histological morphologies and the density of collagen fibers of the ACT and the AOL were quite similar. In the cross section, there were multiple bundles of collagen fibers within the ACT, while there was uniform appearance within the AOL (Fig. 7).

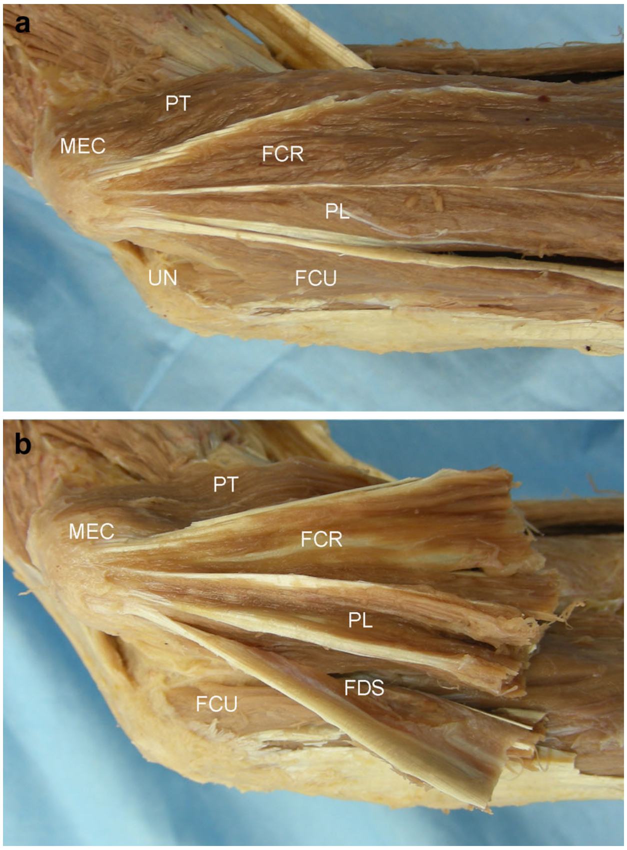

Fig. 2 Superficial dissection of the FPMs (*medial view* of a *left elbow*). The humeral head of the PT, FCR, PL, and FCU were clearly distinguished macroscopically **a**. The FDS was located deep into the PL and FCR **b**. *MEC* medial epicondyle, *UN* ulnar nerve, *PT* pronator teres, *FCR* flexor carpi radialis, *PL* palmaris longus, *FDS* flexor digitorum superficialis, *FCU* flexor carpi ulnaris

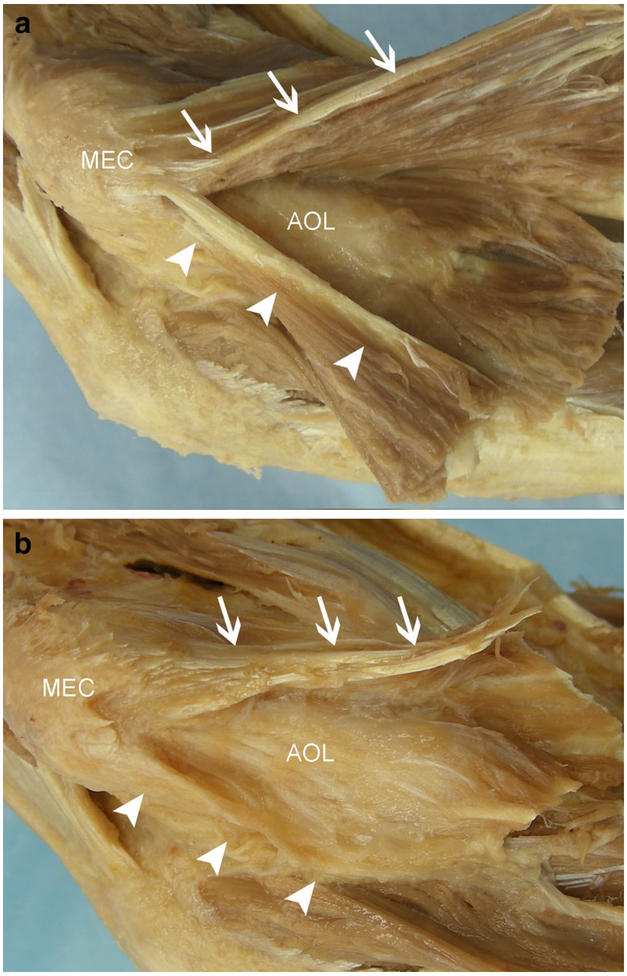

Fig. 3 Deep dissection of the FPMs (*medial view* of a left *elbow*). The intermuscular fascia between the humeral heads of the PT, FCR, PL, and FDS converged and formed the common tendon at their proximal origin (anterior common tendon) (*arrows*). The intermuscular fascia between the FDS and FCU also formed the common tendon (posterior common tendon) (*arrowheads*) **a**. Compared with the anterior common tendon (*arrows*), the posterior common tendon (*arrowheads*) appeared relatively thin **b**. *PT* pronator teres, *FCR* flexor carpi radialis, *PL* palmaris longus, *FDS* flexor digitorum superficialis, *FCU* flexor carpi ulnaris

Discussion

The present study demonstrated the morphological features of the common tendons of the FPMs. While several studies have referred to the deep flexor–pronator aponeurosis (which is one of the causes of ulnar nerve entrapment) [1, 10], the

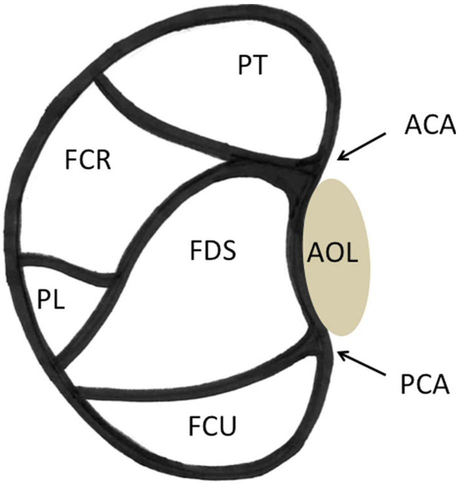

Fig. 4 Schema of the AOL and FPMs (*axial view* of a *left elbow*). The ACT was attached to the medial epicondyle and the anterior joint capsule, just anterior and parallel to the AOL. The PCT was attached to the inferior end of the medial epicondyle and medial joint capsule, just posterior to the AOL. *ACT* anterior common tendon, *PCT* posterior common tendon. *ACT* anterior common tendon, *PCT* posterior common tendon, *PT* pronator teres, *FCR* flexor carpi radialis, *PL* palmaris longus, *FDS* flexor digitorum superficialis, *FCU* flexor carpi ulnaris

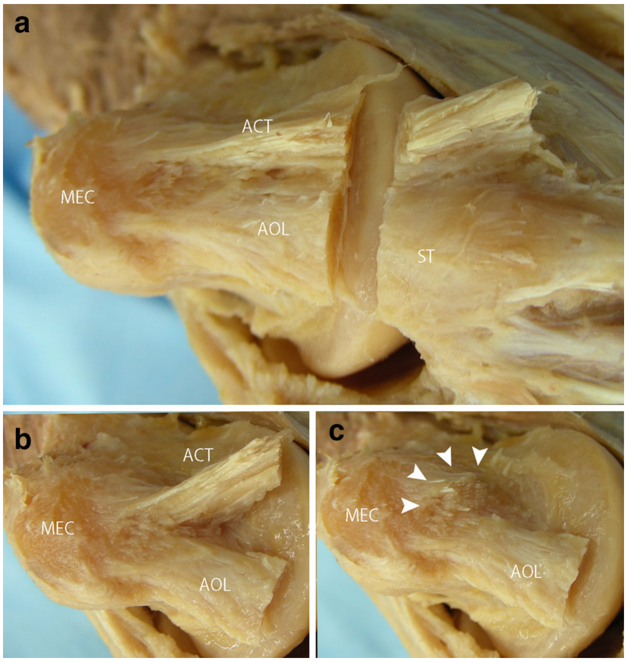

Fig. 5 Dissection of the AOL and ACT (*medial view* of a *left elbow*). The joint capsule was thickened and formed a cord-like appearance at the site where the ACT was attached (**a**, **b**). The proximal origin of the ACT was attached to the medial epicondyle as it encircled the upper border of AOL (*arrowheads*) **c**. *MEC* medial epicondyle, *ST* sublime tubercle *ACT* anterior common tendon, *AOL* anterior oblique ligament

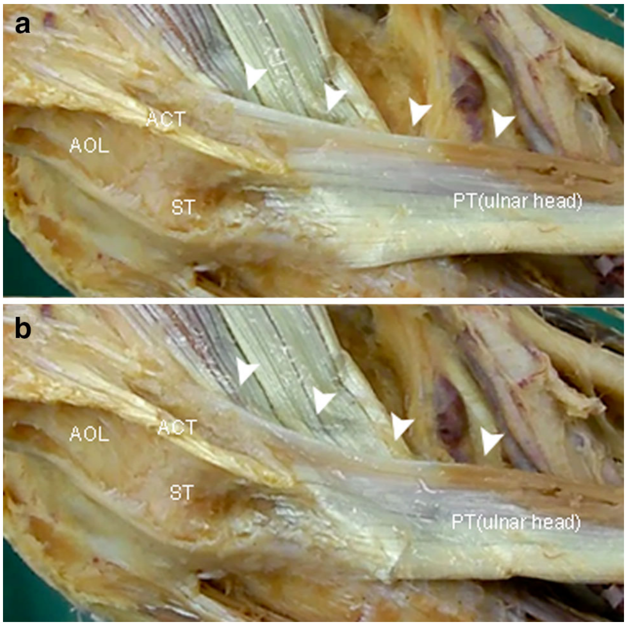

Fig. 6 Dissection of the ulnar head of PT (*anteromedial view* of a *left elbow*). The upper part of the ulnar head transitioned directly into the thickened joint capsule, just anterior to the AOL (*arrowheads*). The strain on the humeral branch increased as the ulnar head of PT was tensioned **a**, and decreased as the ulnar head became lax **b**. *PT* pronator teres, *ST* sublime tubercle *ACT* anterior common tendon, *AOL* anterior oblique ligament

precise anatomy of the proximal origin of the FPMs have not previously been well described.

In the present study, the ACT and PCT were identified. The intermuscular fascia between the humeral heads of the PT, FCR, PL, and FDS formed the ACT, while the intermuscular fascia between the FDS and FCU formed the PCT. Both common tendons were attached to the medial epicondyle and medial joint capsule, just anterior and posterior to the AOL. The ACT was thicker than the PCT, and the joint capsule where the ACT was attached was hyperplastic.

According to anatomical studies, the AOL was divided into anterior and posterior fibers [16, 23]; the anterior fibers tended to stretch as the elbow joint was extended [18, 20]. In addition, during a throwing motion, the maximum valgus force was applied across the elbow during the acceleration phase, with peak force generated immediately before ball release [7]. These results suggested that the anterior fiber of the AOL might be subjected to greater traction force just before ball release, and that the location and morphology of the ACT might allow it to assist the AOL by sharing the static traction force applied to the medial elbow joint. Furthermore, the ACT might also

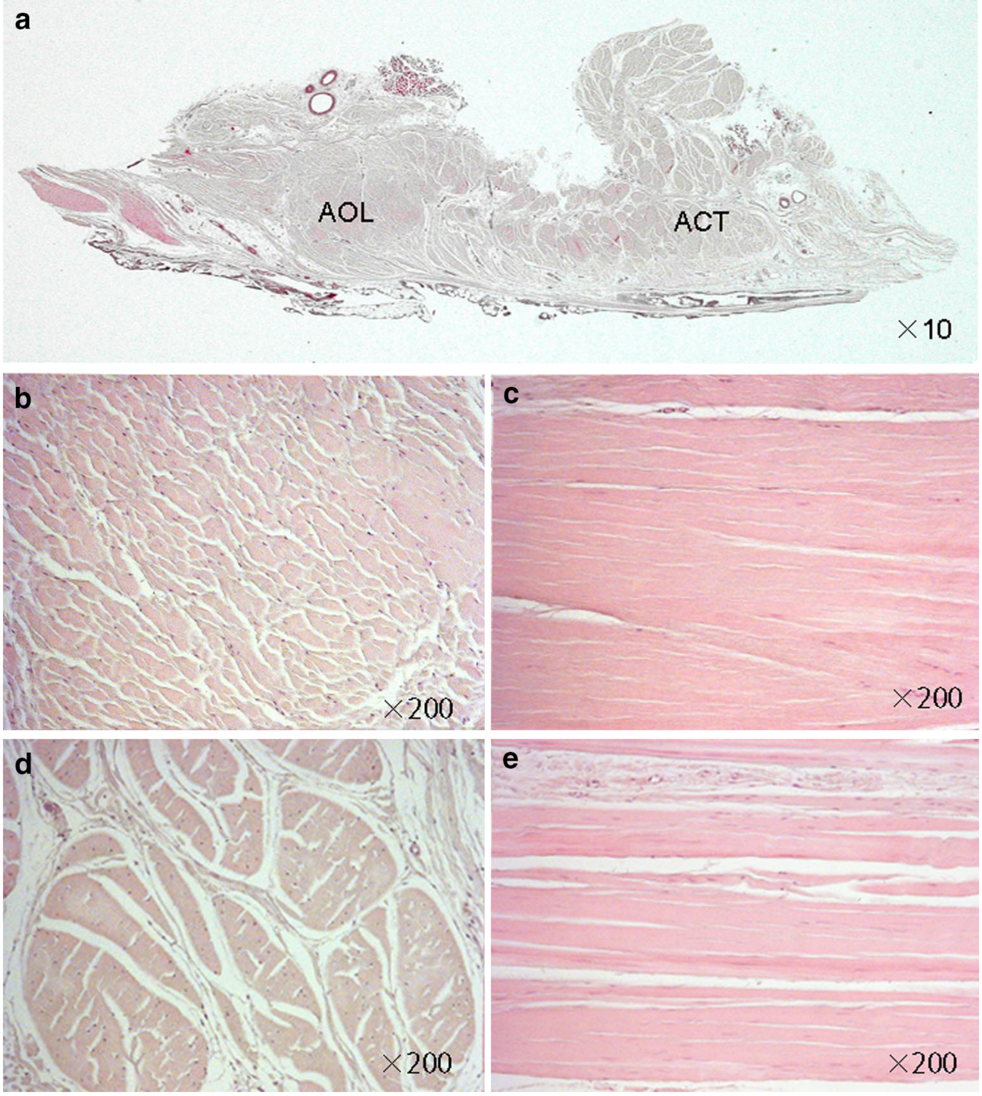

Fig. 7 There were multiple bundles of collagen fibers within the ACT and thickened joint capsule, while there was a uniform appearance within the AOL. Well-oriented collagen fibers were identified within both the ACT and the AOL; the histological morphology and the density of collagen fiber within ACT and the AOL quite resembled each other. Gross cross section of the AOL and the ACT **a**. Cross section of the AOL **b**. Longitudinal section of the AOL **c**. Cross section of the ACT **d**. Longitudinal section of the ACT **e**. *ACT* anterior common tendon, *AOL* anterior oblique ligament

dynamically stabilize the elbow. According to several electromyographic studies, the FPMs demonstrated very high activity during late cocking and acceleration phases [6, 11, 12, 22, 25]. The active contractions of the FPMs during acceleration phase, especially immediately before ball release, would increase the tension of the medial joint capsule where the ACT was attached and assist the AOL dynamically.

The present study also demonstrated the morphological features of the PT. The PT has been described as having two anatomical origins: the humeral head and the ulnar head. The ulnar head origin has been reported to be absent in some cases [3]. In the present study, the ulnar head origin was observed in 48 of 52 elbows (92.3 %), which was the same as that noted in previous reports. Furthermore, the upper part of the ulnar head was attached directly to the medial epicondyle via a thickened joint capsule, just anterior to the AOL in all specimens (humeral branch). These results suggested that the muscle activation of the PT might directly increase the strain of the medial joint capsule via the humeral branch of ulnar head. During the acceleration phase of throwing, the forearm would gradually pronate as the elbow extended toward ball release. Several electromyographic studies demonstrated that the PT as well as other FPMs were activated during the late cocking and acceleration phases [6, 11, 12, 22, 25]. Activation of the PT might stabilize the elbow against valgus force by dynamically tensioning the medial joint capsule.

Several limitations of our study must be considered. This study was an anatomical morphological study, and not a biomechanical study. It would be necessary to conduct a physiological biomechanical study preserving the proximal attachment of FPMs. Furthermore, a cadaveric anatomical or biomechanical study cannot assess the in vivo kinetics of each FPMs. Dynamic arthrokinematic and kinesiological studies must be conducted to investigate the in vivo function of the FPMs.

In conclusion, the proximal attachment of the FPMs had a characteristic morphology. The ACT was located just anterior to the AOL. Part of the ulnar head of the PT transitioned directly into the thickened joint capsule, just anterior to the AOL. Based on these results, due to its location and morphology, the ACT and ulnar head of the PT might assist the AOL by sharing dynamic and static traction forces applied to the medial elbow joint.

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standards This work had been approved by the ethical committee of Fukushima Medical University School of Medicine (No.1423).

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