Morphological Features of the Ulnar Collateral Ligament of the Elbow and Common Tendon of Flexor-Pronator Muscles

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Background: The anterior bundle (AB) of the ulnar collateral ligament is the most important structure for valgus stabilization of the elbow. However, anatomic relationships among the AB, posterior bundle (PB) of the ulnar collateral ligament, and common tendon (CT) of the flexor-pronator muscles have not been fully clarified.

Purpose: To classify the AB, PB, and CT and to clarify their morphological features.

Study Design: Descriptive laboratory study.

Methods: This investigation examined 56 arms from 31 embalmed Japanese cadavers. The CT investigation examined 34 arms from 23 embalmed Japanese cadavers with CTs remaining. Type classification was performed by focusing on positional relationships with surrounding structures. Morphological features measured were length, width, thickness, and footprint for the AB and PB and attachment length, thickness, and footprint for the CT.

Results: The AB was classified as type I (44 elbows; 78.6%), can be separated as a single bundle, or type II (12 elbows; 21.4%), cannot be separated from the PB and joint capsule. The PB was classified as type I (28 elbows; 50.0%), can be separated as a single bundle; type IIa (6 elbows; 10.7%), posterior edge cannot be separated; type IIb (7 elbows; 12.5%), anterior edge cannot be separated; or type III (15 elbows; 26.8%), cannot be separated from the joint capsule. The CT was classified as type I (18 elbows; 52.9%), can be separated from the AB, or type II (16 elbows; 47.1%), cannot be separated from the AB. Significant differences in frequencies of AB, PB, and CT types were identified between men and women. Morphological features were measured only for type I of each structure, and reliability was almost perfect.

Conclusion: These results suggest that the AB, PB, and CT each can be classified into an independent form and an unclear form. Presence of the unclear form was suggested as one factor contributing to morphological variation.

Clinical Relevance: This study may provide basic information for clarifying functional roles of the AB, PB, and CT.

Keywords: elbow; anatomy; baseball; ulnar collateral ligament injury
whereas other studies have stated that they cannot.\textsuperscript{23} Anato-
mic features of the medial elbow thus appear inconsis-
tent. Other ligaments and tendons have been reported to
function differently because of differences in anatomic fea-
tures.\textsuperscript{13,14} A detailed examination of the anatomic charac-
teristics of the AB, PB, and CT may thus provide useful
information to clarify the functional roles of each structure.
The purpose of this study was to classify the AB, PB, and
CT and to clarify their morphological features.

METHODS

Cadavers

This investigation examined 56 elbows from 31 Japanese
cadavers (mean age at death, 82 ± 11 years; 36 sides from men,
20 sides from women; 28 right sides, 28 left sides) donated to
the university anatomy program. No CT remained in 22 of
these 56 elbows. The CT was therefore investigated in the
remaining 34 elbows from 23 Japanese cadavers (mean age
at death, 81 ± 11 years; 27 sides from men, 7 sides from women;
16 right sides, 18 left sides). All cadavers were placed in 10%
formalin and then dehydrated in alcohol. No sides showed
signs of previous major surgery around the upper extremity.

Procedures

Referring to previous studies\textsuperscript{23,30} for dissection, we sec-
tioned the humerus and forearm at their midpoints to pre-
pare an isolated elbow joint. The skin, subcutaneous tissue,
and muscular parts (pronator teres, flexor carpi radialis,
palmaris longus [PL], flexor digitorum superficialis [FDS],
flexor carpi ulnaris [FCU], biceps brachii, brachialis, and
triceps brachii muscles) were then removed, and the AB,
PB, anterior common tendon (ACT), and posterior common
tendon (PCT) were carefully dissected. Specimens were then
moved through elbow flexion and extension, and the
AB, PB, and CT were classified by positional relationships
with surrounding structures. Regarding the positional rela-
tionships with surrounding structures, characterization of
the AB focused on the positional relationships with the PB
and joint capsule, characterization of the PB focused on the
positional relationship with the joint capsule, and character-
ation of the CT focused on the positional relationship with
the AB.

Morphological measurements were performed by 2 exam-
iners, with 1 examiner (M.I.) taking the measurement and
the other examiner (K.M. or S.S.) ensuring that the specimen
did not move. All measurements were performed with the
cadaveric elbow in 90° of flexion/forearm supination, in
accordance with a previous study.\textsuperscript{9} Morphological features
of the AB and PB that were measured included length, width,
thickness, and footprint. Morphological features of the ACT
and PCT that were measured included attachment length,
thickness, and footprint (Figures 1 and 2).

AB and PB length, width, and thickness and ACT and
PCT attachment length and thickness were measured
using digital calipers (model IP54; Shinwa Rules). AB and PB
lengths were measured by connecting the midpoint of the
origin and insertion. ACT and PCT humeral attach-
ments were structures that could not be separated from
each other. The mixed ACT and PCT attachment was there-
fore designated as the humeral attachment. ACT and PCT
attachment lengths were measured by connecting the prox-
imal end of the humeral attachment and the distal end of
the ulnar attachment. AB and PB widths were measured at
3 sites: a proximal site (humeral attachment), intermediate
site, and distal site (ulnar attachment). Thickness was
measured at the intermediate site of each. The footprint
was marked using a marking pen, and the circumference
of the footprint was digitized at about 2-mm intervals
through use of the MicroScribe system (G2XSYS;
Revware) with reference to a previous study (Figure 2).\textsuperscript{9}
A computational mesh was then created from the digitized
points, and the footprint was calculated as the total area of
the plane of the resulting computational mesh. Rhinoceros
3D software (McNeel) was used to analyze the footprint.
All measurements were made by the same examiner
(M.I.); each site was measured 3 times, and the mean
value and SD was then calculated.

This study examined the intrarater reliability of
morphological characteristics. Retesting was performed
at an interval of 3 to 7 days and involved moving the
specimen and then repositioning it before repeated
measurement. The one exception was for retest of the
footprint, which was performed the same day because
ink bled over time and could be overestimated during
digitization.

Statistical Analysis

Intersession measurement reliability was assessed using
the intraclass correlation coefficient (ICC) (1,3). The crite-
ria for ICC were as follows\textsuperscript{26,28}: <0.20 = poor; 0.20-0.40 =
slight; 0.40-0.60 = fair; 0.60-0.80 = moderate; 0.80-1.00 = sub-
stantial; and 0.81-1.00 = almost perfect. Minimal
detectable difference at the 95% CI (MDD\textsubscript{95%}) was calcu-
lated as follows\textsuperscript{34}: MDD\textsubscript{95%} = z × SEM × \sqrt{2}, where z =
1.96 and SEM = SD/\sqrt{(1 − ICC)}.
The Fisher exact test was used for comparisons between male and female specimens and between left and right arms for the AB, PB, and CT types, and multiple comparisons were performed through use of the Ryan nominal level for post hoc testing. Statistical analyses were performed using SPSS (Version 26.0; SPSS Japan Inc., Tokyo, Japan). The level of statistical significance was $P < .05$.

**RESULTS**

Intrarater Reliability and MDD$_{95\%}$ of Morphological Characteristics for Type I

The ICC(1,3) for the measurement of morphological characteristics for type I was 0.846 to 0.999 (Table 1). In this study, measurement of the morphological characteristics...
for type I showed almost perfect reliability, according to the criteria of Landis and Koch.26

Classification of the AB, PB, and CT

The AB was classified as follows: type I (44 elbows; 78.6%), the AB was located superficial to the PB and joint capsule and could be separated as a single bundle, or type II (12 elbows; 21.4%), the AB was located in the same layer as the PB and joint capsule and could not be separated from them (Figure 3). Regarding sex differences, AB type II was only observed in male specimens, with female specimens only demonstrating AB type I (Table 2). No significant differences were seen between right and left arms ($P = .165$).

The PB was classified as follows: type I (28 elbows; 50.0%), anterior and posterior edges of the PB were located superficial to the joint capsule and could be separated as a single bundle; type IIa (6 elbows; 10.7%), the anterior edge of the PB could be separated from the joint capsule, but the posterior edge could not; type IIb (7 elbows; 12.5%), the posterior edge of the PB could be separated from the joint capsule, but the anterior edge could not; and type III (15 elbows; 26.8%), no parts of the PB could be separated from the joint capsule (Figure 3). Regarding sex differences, PB type IIa and type IIb were only observed in male specimens, with female specimens only demonstrating PB type I and PB type III (Table 2). No significant differences were seen between right and left arms ($P = .192$).

The CT was classified as follows: type I (18 elbows; 52.9%), the AB was superficial to the ACT and PCT, with structures separable from each other; and type II (16 elbows; 47.1%), the AB was located in the same layer as the ACT and PCT, and the structures could not be separated from each other (Figure 3). Regarding sex differences, CT type II was only observed in male specimens, with female specimens only demonstrating CT type I (Table 2). No significant differences were seen between right and left arms ($P = .508$).

### TABLE 1

Intrarater Reliability and MDD\textsubscript{95\%} of Morphological Characteristics for Type I

| Characteristics   | First Rater | Second Rater | ICC (1,3) MDD\textsubscript{95\%} |
|-------------------|-------------|--------------|----------------------------------|
| Anterior bundle   |             |              |                                  |
| Length, mm        | 21.8        | 21.6         | 0.948                            | 2.1 |
| Width, mm         | 3.9         | 3.9          | 0.928                            | 0.5 |
| Proximal          | 4.8         | 4.8          | 0.948                            | 0.6 |
| Middle            | 6.5         | 6.5          | 0.967                            | 0.8 |
| Distal            | 1.9         | 1.8          | 0.872                            | 0.4 |
| Thickness, mm     | 24.8        | 25.2         | 0.980                            | 3.3 |
| Footprint, mm\textsuperscript{2} | 79.9 | 80.6 | 0.992 | 5.3 |
|
| Posterior bundle  |             |              |                                  |
| Length, mm        | 12.6        | 12.7         | 0.982                            | 0.8 |
| Width, mm         | 4.4         | 4.5          | 0.919                            | 0.8 |
| Proximal          | 4.7         | 5.0          | 0.912                            | 1.1 |
| Middle            | 6.9         | 6.9          | 0.895                            | 1.6 |
| Thickness, mm     | 1.0         | 1.0          | 0.927                            | 0.2 |
| Footprint, mm\textsuperscript{2} | 18.7 | 18.8 | 0.998 | 0.4 |
| Humeral           | 10.8        | 11.3         | 0.999                            | 0.2 |
|
| Anterior common tendon |     |              |                                  |
| Length, mm        | 32.8        | 32.5         | 0.930                            | 2.6 |
| Thickness, mm     | 2.4         | 2.4          | 0.846                            | 0.6 |
| Footprint, mm\textsuperscript{2} | 109.2 | 108.2 | 0.987 | 9.5 |
| Humeral           | 30.7        | 31.6         | 0.987                            | 4.7 |
|
| Posterior common tendon |    |              |                                  |
| Length, mm        | 37.3        | 37.4         | 0.989                            | 1.2 |
| Thickness, mm     | 1.0         | 1.0          | 0.983                            | 0.1 |
| Footprint, mm\textsuperscript{2} | 109.2 | 108.2 | 0.987 | 9.5 |
| Humeral           | 23.3        | 23.9         | 0.970                            | 4.4 |

\textsuperscript{a}ICC, intraclass correlation coefficient; MDD\textsubscript{95\%}, minimal detectable difference at the 95\% CI.

### TABLE 2

Left and Right Differences and Sex Differences for Each Type of AB, PB, and CT

|               | AB                  | PB                  | CT                  |
|---------------|---------------------|---------------------|---------------------|
|               | Type I | Type II | Type I | Type Ia | Type Iib | Type III | Type I | Type II |
| Male          | 24 (66.7)<sup>b</sup> | 12 (33.3)<sup>b</sup> | 10 (27.8) | 6 (16.7) | 7 (19.4) | 13 (36.1)<sup>c</sup> | 11 (40.7)<sup>f</sup> | 16 (59.3)<sup>f</sup> |
| Female        | 20 (100.0)<sup>b</sup> | 0 (0.0) | 18 (90.0)<sup>c</sup> | 0 (0.0) | 0 (0.0) | 2 (10.0) | 7 (100.0)<sup>g</sup> | 8 (50.0) | 8 (50.0) |
| Right         | 20 (71.4)<sup>b</sup> | 8 (28.6) | 12 (42.9) | 2 (7.1) | 6 (21.4) | 8 (28.6) | 8 (50.0) | 8 (50.0) | 8 (50.0) |
| Left          | 24 (85.7) | 4 (14.3) | 16 (57.1) | 4 (14.3) | 1 (3.6) | 7 (25.0) | 10 (55.6) | 8 (44.4) | 8 (44.4) |
| Total         | 44 (78.6) | 12 (21.4) | 28 (50.0) | 6 (10.7) | 7 (12.5) | 15 (26.8) | 18 (52.9) | 16 (47.1) |

<sup>a</sup>Values are expressed as n (%). AB, Anterior bundle; CT, common tendon; PB, posterior bundle.

<sup>b</sup>$P < .001$ vs AB type II females.

<sup>c</sup>$P < .001$ vs PB type Ia females.

<sup>d</sup>$P < .001$ vs PB type Iib females.

<sup>e</sup>$P < .001$ vs PB type III females.

<sup>f</sup>$P < .001$ vs CT type II females.

<sup>g</sup>$P = .023$ vs CT type II females.
Morphological Characteristics of the AB, PB, and CT

Morphological characteristics of AB type I, PB type I, and CT type I are shown in Table 3. AB type II, PB type IIa, PB type IIb, PB type III, and CT type II were unclear and could not be measured.

**DISCUSSION**

This study examined morphological features of the AB, PB, and CT using Japanese cadavers. Several studies have reported anatomic features of the medial elbow. However, none have classified the AB, PB, and CT by focusing on the...
positional relationship with surrounding structures and characterized these morphological features.

In this study, we saw AB type I in 78.6% of specimens, PB type I in 50.0%, and CT type I in 52.9%, as the independent forms of each. In contrast, we saw AB type II in 21.4% of specimens, PB type IIa in 10.7%, PB type IIb in 12.5%, PB type III in 26.8%, and CT type II in 47.1%, as the unclear forms. Davidson et al. reported that AB forms were cord-shaped in 9 ligaments (82%) and fan-shaped in 2 ligaments (18%). Regarding the PB, Morrey and An reported the PB as a thickened posterior joint capsule, with no clear definition provided. Regarding the CT, Otoshi et al. reported that the intermuscular fascia between the humeral heads of the PT, flexor carpi radialis, palmaris longus, and FDS converged and formed a common tendon at their proximal origin (ACT), which was attached to the medial epicondyle and anterior joint capsule, just anterior and parallel to the AB. Hoshika et al. reported that the tendinous septa between the PT and FDS, the tendinous septa between the FDS and FCU, the medial part of the brachialis tendon, and the deep FDS and FCU aponeuroses formed a tendinous complex, with the traditional AB as part of the tendinous complex and joint capsule. In the current study, the AB, PB, and CT each showed an independent form and at least 1 unclear form, and this appears to be the first study to clarify these variations.

### TABLE 3
Morphological Features of the Anterior Bundle, Posterior Bundle, and Common Tendon in Present Study and Previous Studies

|                      | Footprint, mm² | Length, mm | Width, mm | Thickness, mm | Humeral | Ulnar |
|----------------------|----------------|------------|-----------|---------------|---------|-------|
| **Anterior bundle**  |                |            |           |               |         |       |
| Morrey²⁵ (1985)       | 10             | 27.1 ± 4.3 | M: 4.7 ± 1.2 | —             | —       | —     |
| Regan²⁶ (1991)        | 7              | 21.13 ± 2.29 | 7.6 | —             | —       | —     |
| Timmerman²⁵ (1994)    | 10             | —          | 6         | 4.8          | —       | —     |
| Cage² (1995)          | 20             | —          | 7.9       | 2.8          | —       | —     |
| Floris²⁸ (1998)       | 18             | —          | 5.8 (5-7) | —             | —       | —     |
| Beckett¹ (2000)       | 39             | 26.7 ± 3.7 | —         | —             | —       | —     |
| Eygendaal¹⁵ (2002)    | 5              | 26 (24-31) | 5 (4-7)   | —             | —       | —     |
| Gurbuz²² (2005)       | 20             | R: 21.1 ± 6.3 | D (R): 12.7 ± 2.8 | —         | —       | —     |
|                      |                | L: 21.7 ± 5.3 | D (L): 13.9 ± 2.4 | —         | —       | —     |
| Safran³³ (2005)       | 6              | —          | 7.2 ± 1.7 | —             | —       | —     |
| Dugas⁹ (2007)         | 13             | —          | P: 6.8 ± 1.4 | —             | 45.5 ± 9.3 | 127.8 ± 35.7 |
|                      |                | —          | M: 6.8 ± 1.3 | —             | —       | —     |
|                      |                | —          | —         | D: 9.2 ± 1.6 | —       | —     |
| Farrow¹⁶ (2011)       | 10             | 53.9 ± 0.7 | —         | —             | —       | —     |
| Farrow¹⁷ (2014)       | 12             | 21.5 (16.7-27.6) | —   | —             | —       | —     |
| Otoshi³⁰ (2014)       | 52             | —          | P: 8.3 ± 1.2 | —             | —       | —     |
|                      |                | —          | M: 10.0 ± 1.6 | —             | —       | —     |
|                      |                | —          | D: 11.7 ± 1.8 | D: 1.1 ± 0.1 | —       | —     |
| Camp³ (2018)          | 10             | —          | —         | —             | 32.3 ± 6.8 | 187.6 ± 47.3 |
| Frangiamore¹⁹ (2018)  | 10             | 21.5 (20.0-23.0) | —   | —             | 17.0 (14.9-19.1) | 66.4 (54.0-78.7) |
| Dutton¹⁰ (2019)       | 18             | —          | —         | —             | —       | 216.9 ± 42.1 |
| Present study         | 44             | 21.8 ± 3.3 | P: 3.9 ± 0.7 | M: 1.9 ± 0.4 | 24.8 ± 8.5 | 79.9 ± 21.2 |
|                      |                | —          | M: 4.8 ± 0.9 | —             | —       | —     |
|                      |                | —          | D: 6.5 ± 1.2 | —             | —       | —     |
| **Posterior bundle**  |                |            |           |               |         |       |
| Morrey²⁵ (1985)       | 10             | 24.2 ± 4.3 | M: 5.3 ± 1.1 | —             | —       | —     |
| Regan²⁶ (1991)        | 7              | 16.51 ± 1.52 | 8.8 | —             | —       | —     |
| Timmerman²⁵ (1994)    | 10             | —          | 8         | 2-3          | —       | —     |
| Beckett¹ (2000)       | 39             | 23.2 ± 3.7 | —         | —             | —       | —     |
| Camp³ (2018)          | 10             | —          | —         | 25.9 ± 10.0 | 15.8 ± 7.2 | —     |
| Frangiamore¹⁹ (2018)  | 10             | 15.0 (13.5-16.5) | —   | —             | 18.5 (13.6-23.4) | 17.6 (14.7-20.6) |
| Present study         | 28             | 12.6 ± 2.2 | P: 4.4 ± 1.0 | M: 1.0 ± 0.3 | 18.7 ± 3.5 | 10.8 ± 2.3 |
|                      |                | —          | M: 4.7 ± 1.4 | —             | —       | —     |
|                      |                | —          | D: 6.9 ± 1.8 | —             | —       | —     |
| **Anterior common tendon** |          |            |           |               |         |       |
| Otoshi³⁰ (2014)       | 52             | 28.3 ± 4.3 | 2.5 ± 0.7 | —             | —       | —     |
| Present study         | 18             | 32.8 ± 3.6 | 2.4 ± 0.5 | 106.4 ± 28.7 | 30.3 ± 15.1 |
| **Posterior common tendon** |        |            |           |               |         |       |
| Otoshi³⁰ (2014)       | 52             | —          | 0.9 ± 0.3 | —             | —       | —     |
| Present study         | 18             | 37.3 ± 4.3 | 1.0 ± 0.3 | 106.4 ± 28.7 | 23.6 ± 9.4 | —     |

`Values represent mean ± SD or range. Dashes indicate data not reported. D, distal; L, left; M, middle; P, proximal; R, right.`

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Based on the results of type classifications in this study, the frequencies of the AB, PB, and CT forms differed significantly between men and women and also within women. Sex differences related to the elbow joint include the carrying angle and range of motion of the elbow joint, both of which have been reported as greater in women than in men. A phenomenon specific to female patients is the menstrual cycle, which has been reported to affect relaxation of the ligaments. However, relationships between these factors and forms of the AB, PB, and CT remain unclear. Further study of these issues is needed in the future.

Measurement of morphological features was performed only for AB type I, PB type I, and CT type I as the independent forms, but reliability for these was almost perfect. In previous studies (Table 3), morphological features of the AB and PB were not consistent. This is because limb positions at the time of measurement have included the elbow joint in extension with the forearm in supination, elbow flexion at 25°, elbow flexion at 90°, maximum tension position, maximum tension position in neutral position of the forearm, neutral position of the forearm, and even undescribed positions that presumably varied widely among studies. In addition, the AB is generally measured as a single bundle originating from the anteroinferior aspect of the medial epicondyle of the humerus and inserting at the sublime tubercle of the ulna. However, a previous study reported that the traditional AB measurement might have included a mixed construct of the joint capsule and tendinous complex as the AB. In the present study, the AB, PB, and CT each showed an independent form and at least 1 unclear form. Previous studies could thus have potentially measured unclear forms along with independent forms of each structure.

This study has several limitations that need to be considered when interpreting the results. First, whether donors had been involved in overhead sports during their lifetime was unknown. A previous study reported that throwing athletes show changes in the morphology of the UCL, such as UCL thickening and calcifications due to repeated throwing motions. Therefore, if the donor had been involved in overhead sports during life, the form of the UCL would presumably have been influenced. Second, the cadavers included in this study were only from Japanese donors, and the results cannot be generalized to different ethnicities in the absence of additional investigations. Several anatomic studies have reported ethnic differences in skeletal muscles and tendons, and this may also apply to ligaments. In addition, the cadavers used in this study were embalmed specimens, and the embalming processes could potentially have affected the quality of ligaments and tendons so as to affect dissection and apparent interconnections. Third, this study did not investigate interrater reliability. Fourth, this study was an anatomic study; future biomechanical studies using these results as basic information are necessary to clarify the functional roles of the AB, PB, and CT.

CONCLUSION

The AB, PB, and CT were each classified into an independent form and at least 1 unclear form. Presence of the unclear form was suggested as one of the factors causing morphological variation. In the future, biomechanical studies using these research results as basic information are needed.

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