J Shoulder Elbow Surg (2019) 28, 2253–2258

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Transverse ligament of the elbow joint: an anatomic study of cadavers

Kentaro Kimata[a,b], Masaya Yasui, PhD[a,*], Hiroki Yokota, PhD[a], Shuichi Hirai, MD, PhD[a], Munekazu Naito, MD, PhD[a], Takashi Nakano, MD, PhD[a]

[a]*Department of Anatomy, Aichi Medical University School of Medicine, Nagakute, Aichi, Japan*
[b]*Department of Judo Therapy, Chuwa Professional Training College of Medical Care, Inazawa, Aichi, Japan*

Background: The medial collateral ligament of the elbow joint consists of the anterior oblique ligament (AOL), posterior oblique ligament (POL), and transverse ligament (TL). This study aimed to clarify the structure of the TL, with a focus on the continuity between the TL and AOL.
Methods: A total of 42 cadavers (18 males, 24 females) were dissected at Aichi Medical University between 2016 and 2018. Cases of elbow deformity or atrophy were excluded, and 60 elbows (15 males, 15 females) were dissected to assess the fibers of both the TL and AOL using a stereomicroscope.
Results: The TL could be detected in all elbows and always continued to the AOL. The TL was classified into 2 types. The TLs continuing to the distal half of the AOL (type I) were observed in 44 elbows (73.3%), whereas the TLs continuing to the entire AOL (type II) were found in 16 elbows (26.7%). Type II TLs were significantly more frequently observed in the elbows of females than in those of males ($P =$ .041). Stereomicroscopic observation revealed that the TL fibers entered perpendicularly to the distal half of the AOL in both types.
Conclusions: The TL frequently continues to the distal half of the AOL, but rarely continues to the entire AOL. The TLs continuing to the entire AOL were more frequently detected in the elbows of females than in those of males. The TL possibly contributes to medial elbow stability via its continuity to the AOL.
Level of evidence: Anatomy Study; Cadaver Dissection

Keywords: Elbow joint; medial collateral ligament; transverse ligament; anterior oblique ligament; medial elbow stability; cadaver

The medial collateral ligament of the elbow consists of 3 ligaments, namely, the anterior oblique ligament (AOL), posterior oblique ligament (POL), and transverse ligament (TL). Both the AOL and POL originate from the medial epicondyle; however, the AOL inserts into the sublime tubercle (ridge of the medial coronoid process), whereas the POL inserts into the medial margin of the trochlear notch. The TL originates from and inserts into the olecranon and sublime tubercle of the ulna, respectively.

The AOL mainly contributes to medial elbow stability, whereas the POL imposes secondary constraint.[4,7,14,15] Some reports have suggested that the TL does not

This study was approved by the ethics committee of Aichi Medical University School of Medicine (approval no. 2016-M043).

*Reprint requests: Masaya Yasui, PhD, Department of Anatomy, Aichi Medical University, 1-1 Yazakokarimata, Nagakute, Aichi 480 1195, Japan.

E-mail address: yasui.masaya.237@mail.aichi-med-u.ac.jp (M. Yasui).

1058-2746/$ - see front matter © 2019 Published by Elsevier Inc. on behalf of Journal of Shoulder and Elbow Surgery Board of Trustees.
https://doi.org/10.1016/j.jse.2019.04.048

contribute to medial elbow stability, as it does not cross the joint,[10] is not consistently present,[4] and is not well developed.[16] Conversely, other reports have indicated the contribution of the TL to medial elbow stability via its continuity to the AOL.[3,5]

In major anatomy textbooks, the TL is clearly shown; however, some differences in the continuity between the TL and AOL exist.[11,13,18] In brief, the detailed structure of the TL remains unclear. This study aimed to clarify the structure of the TL, with a focus on the continuity between the TL and AOL.

Materials and methods

This anatomic study aimed to clarify the structure of the TL, with a focus on the continuity between the TL and AOL. A total of 42 cadavers (18 males, 24 females) donated to Aichi Medical University between 2016 and 2018 were examined in this study. The cadavers were embalmed using 10% formaldehyde so as to deter rotting for an extended period. Before their death, the donors signed documents confirming their agreement to donate their bodies for use in clinical studies. The format of the document was in accordance with the expectation of the Japanese law "Act on Body Donation for Medical and Dental Education." The average age of cadavers was 81.0 ± 9.1 years (range, 61-90 years; males, 77.8 ± 8.4 years; females, 84.3 ± 8.7 years). Cases of elbow deformity or atrophy were excluded from the analysis, and 60 elbows (15 males, 15 females) were dissected to assess the fibers of both the TL and AOL using a stereomicroscope.

All soft tissues except for the elbow ligaments were removed. In particular, the ulnar nerve and common flexor-pronator origins adjacent to the ligaments were carefully dissected and distinguished. Gross anatomic examination of the TL's form and continuity to the AOL was performed with the elbow joint flexed at 90°. Fibers at the continuous portion of both the TL and AOL were observed and analyzed 3-dimensionally using a stereomicroscope (Model SZ2-ILST; Olympus, Tokyo, Japan). The length of the AOL (A in Fig. 1) and the width of the TL (B in Fig. 1) were measured using a digital caliper (Model 19981; Shinwa, Nagoya, Japan) to assess the continuity between the TL and AOL. To quantify the continuity between the TL and AOL, the B to A ratio was calculated (Fig. 1). Furthermore, after removing the TL, its length and the thickness of the center were measured. Thickness was measured using a digital thickness gauge (Model PK-1012APX; Mitutoyo, Kawasaki, Japan). All these measurements were performed three times, and the average value was calculated.

Statistical analysis

Sex differences and left/right differences were evaluated using the χ^2 test. Statistical analysis was performed using R 3.5.0 (R Foundation for Statistical Computing, Vienna, Austria). Differences were considered significant if the *P* value was less than .05.

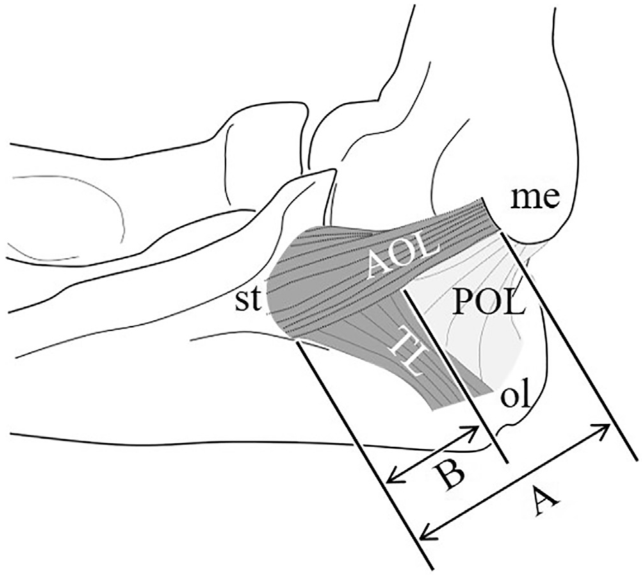

Figure 1 Measurement of the transverse ligament (TL) and anterior oblique ligament (AOL). *A*, length of the AOL; *B*, width of the TL; *me*, medial epicondyle; *ol*, olecranon; *POL*, posterior oblique ligament; *st*, sublime tubercle.

Results

The TL was located beneath the connective tissue surrounding the ulnar nerve and the aponeurosis of the flexor digitorum superficialis originating from the olecranon. These structures could be detached from the TL with careful dissection. The TL was observed in all specimens as a clear fiber extending from the olecranon to the sublime tubercle (Fig. 2). Finally, the TL inserted not only into the sublime tubercle but also into the AOL. The TL continued to the AOL in all specimens and could be classified into 2 types according to its continuity to the AOL. The TLs continuing from the olecranon to the distal half of the AOL perpendicularly (type I) were detected in 44 elbows (73.3%), whereas the TLs continuing to the entire AOL (type II) were found in 16 elbows (26.7%). In type II, the proximal fiber of the TL ran arcuately and extended to the medial epicondyle after crossing over the humeroulnar joint (Fig. 3, *a* and *c*). The B to A ratio (Fig. 1) is shown in Figure 4, *a*; the mean B to A ratio was 0.46 ± 0.06 in type I and 1.00 ± 0.00 in type II. The TL ran and covered just above the POL at the medial margin of the trochlear notch.

Stereomicroscopic observation revealed that the TL fibers entered perpendicularly to the distal half and superficial layer of the AOL in both types I and II (Fig. 3, *b* and *d*). In addition, type II fibers were noted to run parallel to the proximal half of the AOL (Fig. 3, *d*).

There was a statistically significant sex difference between the TL types (Fig. 4, *b*, $P = .041$). Type II TLs were

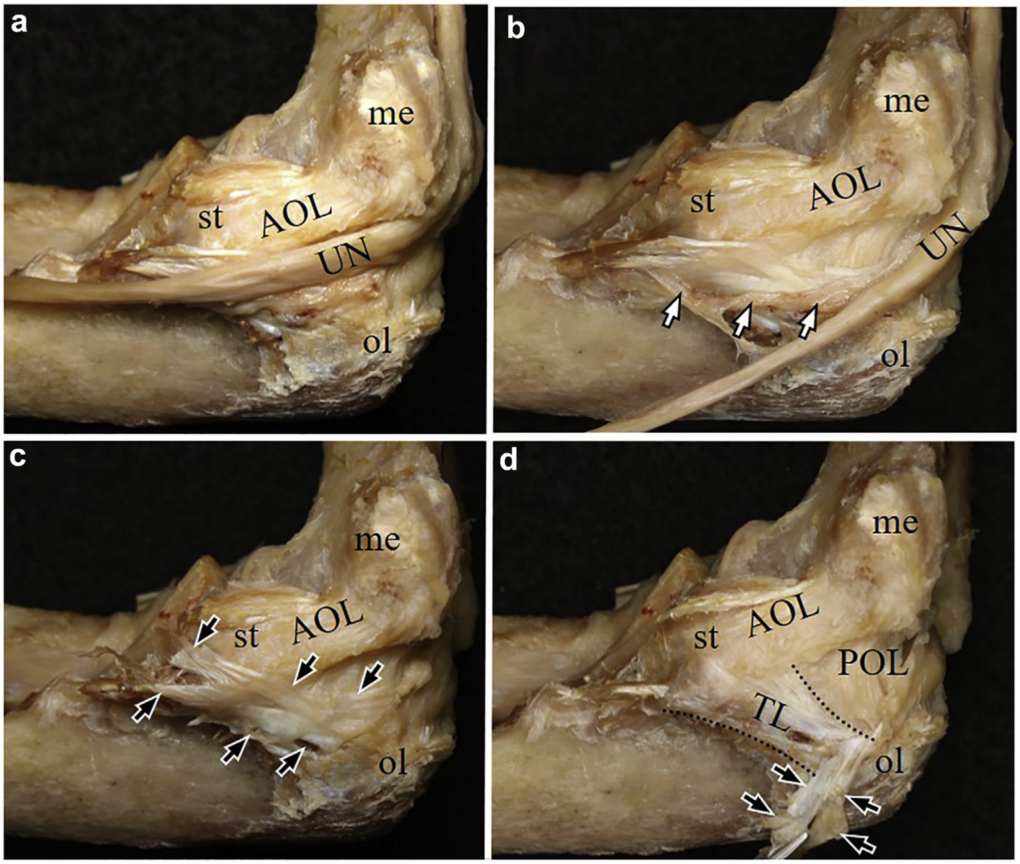

Figure 2 Dissection and identification of the transverse ligament (TL) (medial view of the right elbow). (**a**) The ulnar nerve running over the TL. (**b**) The connecting tissues (⇦) surrounding the ulnar nerve. (**c**) The aponeurosis of the flexor digitorum superficialis originating from the olecranon (➛). (**d**) The TL extending from the olecranon to the sublime tubercle *(dotted lines)*. The aponeurosis of the flexor digitorum superficialis was turned over (➛). *AOL*, anterior oblique ligament; *UN*, ulnar nerve; *st*, sublime tubercle; *me*, medial epicondyle; *ol*, olecranon.

more frequently observed in the elbows of females than in those of males. Eleven males and 6 females had type I TLs at both sides of the elbows. No males had type II TLs at both sides of the elbows, whereas 3 females had them. Four males and 6 females had different TL types in their elbows. However, no significant difference was noted between the right and left sides (Fig. 4, *c*).

The average length of the TL was 15.2 ± 2.5 mm (males, 16.5 ± 2.0 mm; females, 14.0 ± 2.3 mm). The average thickness of the TL center was 0.37 ± 0.10 mm (males, 0.38 ± 0.11 mm; females, 0.36 ± 0.08 mm).

Discussion

In this study, the TLs continuing from the olecranon to the distal half of the AOL perpendicularly (type I) were detected in 44 elbows (73.3%), whereas the TLs continuing to the entire AOL (type II) were found in 16 elbows (26.7%). Type II TLs were more frequently observed in the elbows of females than in those of males. This is the first report focusing on the detailed structure of the TL.

The TL attaches to 2 sites of the same bone, that is, the olecranon and the sublime tubercle of the ulna. Prior studies reported conflicting findings concerning the TL and its insertions. Morrey and An[16] reported that the TL often could not be readily separated from the capsule itself and was not well defined in many specimens. Callaway et al[4] reported that the TL was not consistently present. Mullen et al[17] showed that the TL was a much less well-developed component of the medial collateral ligament. However, several reports indicated that the TL was present in all specimens from cadaveric observations.[2,3,9,21] According to Beckett et al,[2] the TL was not poorly developed but was instead a well-demarcated structure. It is speculated that the different results for the existence of the TL was due to its unclear definition. In this study, the TL was dissected very carefully while distinguishing it from its adjacent structures. Consequently, the TL was observed in all specimens as a clear fiber. However, the TL was located beneath the connective tissue surrounding the ulnar nerve and the aponeurosis of the flexor digitorum superficialis originating from the olecranon. In addition, the TL was

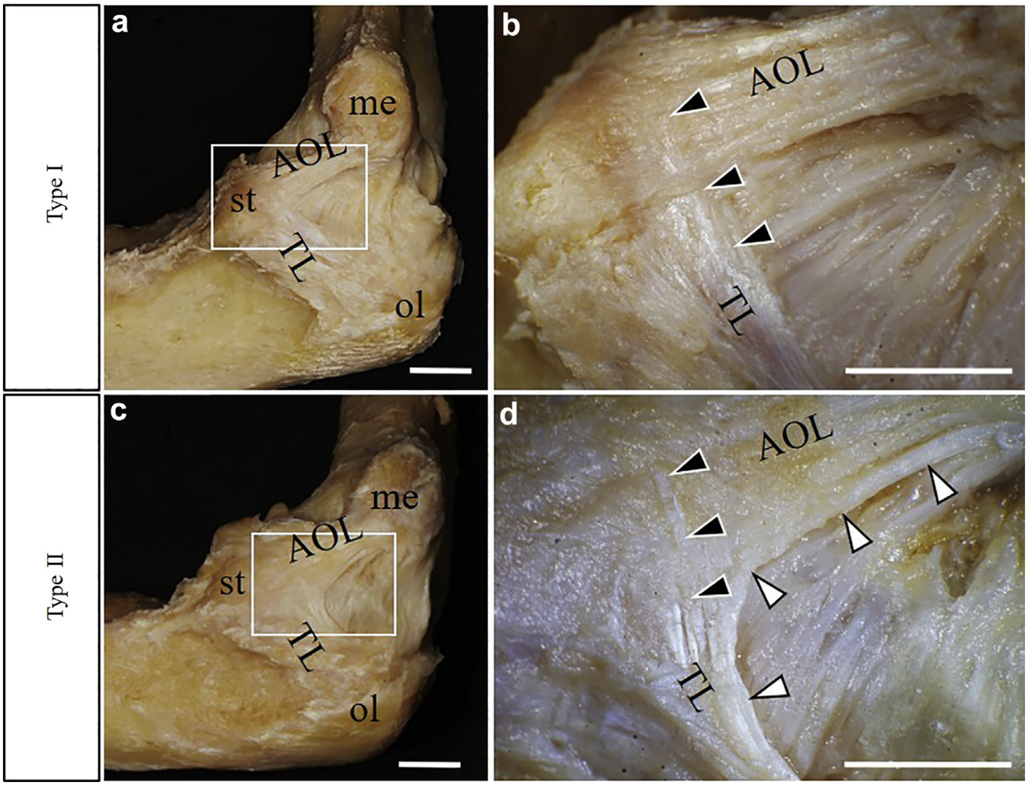

Figure 3 Gross anatomic and stereomicroscopic findings for the transverse ligament (TL) (medial view of the right elbow). (**a**) Type I: the TL continues to the distal half of the anterior oblique ligament (AOL). (**b**) Stereomicroscopic view of the squared area in (**a**). (**c**) Type II: the TL continues to the entire AOL. (**d**) Stereomicroscopic view of the squared area in (**c**). The ► indicate the TL fiber that enters perpendicularly to the distal side of the AOL. The ▻ indicate the arcuate type II fiber that runs parallel to the proximal side of the AOL. *st*, sublime tubercle; *me*, medial epicondyle; *ol*, olecranon; bar, 1 cm.

very thin and membranous. Therefore, it was suggested that the TL might be mistaken for its adjacent structures. In this study, the cadavers were embalmed using 10% formaldehyde; hence, the ligaments and other connective tissues were stiffer. This could be regarded as the consequence of intermolecular cross-link formation due to the reaction of formaldehyde with proteins.[8] As a result, dissection was facilitated and the TL could be observed in detail. If not embalmed such as in surgery, detailed observation of the TL might be difficult.

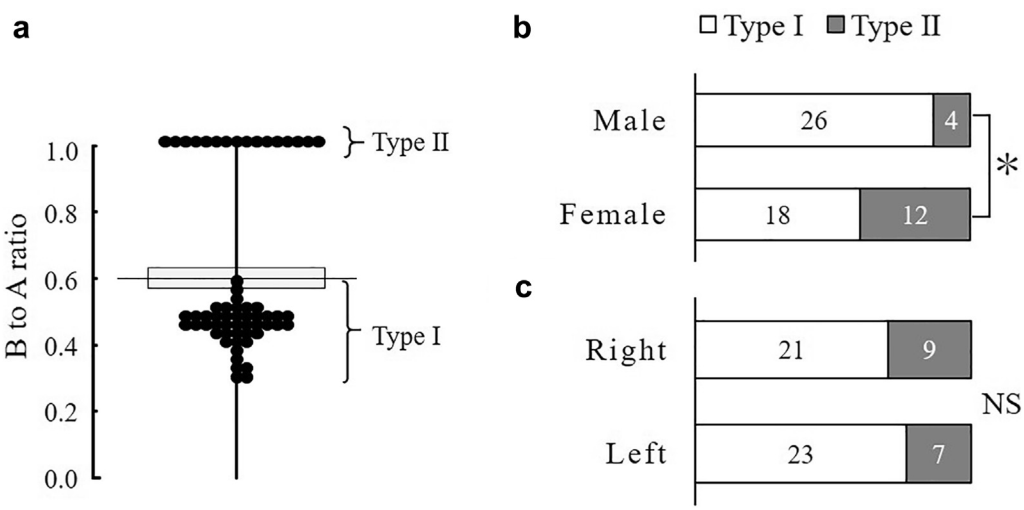

Figure 4 Statistical analysis of the transverse ligament (TL). (**a**) B to A ratio. (**b**) Type classification, male vs. female. (**c**) Right vs. left. *$P < .05$. *NS*, not significant.

The TL was classified into 2 types according to its continuity to the AOL. Type II TL continued to the entire AOL and had fibers extending to the medial epicondyle. Thus, the type II TL crossed over the humeroulnar joint. To the best of our knowledge, the type II TL has not yet been reported previously. When the elbow joint was extended, type II TL fibers were difficult to find because they were compressed by the medial epicondyle with the AOL and POL. However, when the elbow joint was flexed, these fibers were stretched by the medial epicondyle and the arcuate fiber of the type II TL became subsequently clear (Supplementary movie 1). Therefore, it was determined that the type II TL can be found with the elbow joint in flexion, but not necessarily always found in extension.

Distinguishing the arcuate fiber of the type II TL from the AOL proved to be difficult. However, the arcuate fiber moved together with the distal fiber of the TL through flexion and extension of the elbow joint (Supplementary movie 1). Therefore, the arcuate fiber was considered a part of the TL.

Beckett et al[2] investigated the variation in the medial collateral ligament and reported that 23% of specimens had an extra band (bundle) extending from behind the capsule to the TL. In our study, the extra band (bundle) was not observed in all specimens. Through careful dissection, the aponeurosis of the flexor digitorum superficialis was identified to originate from the olecranon, and type II TL fibers were similar to the extra band (bundle) referred to by Beckett et al. It was speculated that the extra band (bundle) could be the aponeurosis of the flexor digitorum superficialis originating from the olecranon or the arcuate fiber of the type II TL. Furthermore, they reported that the type in which the TL continued to the AOL was observed in 43% of specimens. In our study, the TL continued to the AOL in all specimens.

Berg and DeHoll[3] reported that the TL tethered the distal portions of both the AOL and POL to complete a triangular configuration. Camp et al[5] speculated that the TL may support the AOL and provide some resistance to valgus loading because the TL continued to the AOL. However, they did not actually verify the involvement of the TL in medial elbow stability. Ciccotti et al[6] investigated the increase in humeroulnar joint gapping in 12 fresh-frozen cadaveric elbows by stepwise sectioning of medial elbow stabilizers including the AOL, POL, TL, and flexor-pronator mass with valgus loading. They showed that sectioning the AOL resulted in the greatest increase in humeroulnar joint gapping with valgus loading and that sectioning the TL significantly increased the joint gapping with valgus loading. Our stereomicroscopic observation revealed that the TL fibers entered perpendicularly to the distal side of the AOL in both types and that the type II TL fibers ran parallel to the proximal side of the AOL. These findings suggest the possibility that the TL supports the AOL and contributes to medial elbow stability, especially in type II.

The TL fibers entered perpendicularly to the distal half and superficial layer of the AOL in both types I and II. The TL ran and covered just above the POL at the medial margin of the trochlear notch. Timmerman and Andrews[21] reported that the thickness of the AOL and POL ranged from 4 to 8 mm and from 2 to 3 mm, respectively. In this study, the average thickness of the TL center was 0.37 ± 0.10 mm. The TL was very thin and membranous; hence, it might not adequately function by itself. However, the TL might reinforce the attachment of the AOL and POL, thereby preventing detachment due to valgus loading. Type I, which constituted majority of the TLs, was considered to contribute to medial elbow stability, albeit not as much as type II.

It remains unclear why type II TLs were more frequently observed in the elbows of females than in those of males. We infer that this may be attributed to a congenital factor and not to an acquired factor owing to the absence of significant difference in TL types between the right and left sides. With respect to the morphologic feature of the elbow joint, the carrying angle, defined as the angle between the ulnar long axis and humeral long axis, is known to be larger in females than in males.[1,12,19] Some reports have described a larger range of motion (both flexion and extension) of the elbow joint in females than in males.[12,20,22] These sex differences may be related to the formation of type II TL.

It is known that injuries to the medial collateral ligament, especially the AOL, frequently occur in throwing athletes because of strong repetitive valgus stresses to the elbow during the cocking and acceleration phases of throwing. When they occur, conservative therapy or surgery is selected depending on the patient's state. AOL reconstruction surgery was first performed by Jobe in 1974. To date, the reconstruction technique has achieved remarkable progress with many improvements. Although the contribution of the TL to medial elbow stability might be small compared with that of the AOL, anatomic knowledge of the TL, which is closely related to the AOL, might be necessary for the future development of surgical operation.

Although this study has quantitatively shown the structure of the TL for the first time, it has some limitations. In this study, we did not analyze the mechanical properties of the TL and AOL because the specimens were from formalin-fixed cadavers. Several studies that focused on the mechanical properties of the medial collateral ligament used frozen or fresh cadavers;[7,14,16] hence, mechanical tests in which other fixation methods are employed would elucidate the mechanical properties of the TL and AOL. In addition, future development of measurement methods for quantifying the morphologic and mechanical properties of the TL in vivo may reveal the functional roles of the TL during exercise. Such knowledge may further lead to the development of effective interventions to improve the functions of the medial collateral ligament during exercise and sport.

Conclusions

The TL frequently continues to the distal half of the AOL, but rarely continues to the entire AOL. The TLs continuing to the entire AOL were more frequently observed in the elbows of females than in those of males. These findings may have important implications for the surgical reconstruction of elbow ligaments.

Acknowledgments

The authors thank Kanae Umemoto, Daisuke Mizuno, Ryo Takahashi, and Takanori Kusumoto for their contributions to this study. They would like to thank Editage (www.editage.jp) for English language editing.

Disclaimer

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jse.2019.04.048.

References

1. Balasubramanian P, Madhuri V, Muliyil J. Carrying angle in children: a normative study. J Pediatr Orthop B 2006;15:37-40. https://doi.org/10.1097/01202412-200601000-00008
2. Beckett KS, McConnell P, Lagopoulos M, Newman RJ. Variations in the normal anatomy of the collateral ligaments of the human elbow joint. J Anat 2000;197:507-11.
3. Berg EE, DeHoll D. Radiography of the medial elbow ligaments. J Shoulder Elbow Surg 1997;6:528-33.
4. Callaway GH, Field LD, Deng XH, Torzilli PA, O'Brien SJ, Altchek DW, et al. Biomechanical evaluation of the medial collateral ligament of the elbow. J Bone Joint Surg Am 1997;79:1223-31.
5. Camp CL, Jahandar H, Sinatro AM, Imhauser CW, Altchek DW, Dines JS. Quantitative anatomic analysis of the medial ulnar collateral ligament complex of the elbow. Orthop J Sports Med 2018;6:2325967118762751. https://doi.org/10.1177/2325967118762751
6. Ciccotti MC, Hammoud S, Dodson CC, Cohen SB, Nazarian LN, Ciccotti MG. Stress ultrasound evaluation of medial elbow instability in a cadaveric model. Am J Sports Med 2014;42:2463-9. https://doi.org/10.1177/0363546514542805
7. Floris S, Olsen BS, Dalstra M, Søjbjerg JO, Sneppen O. The medial collateral ligament of the elbow joint: anatomy and kinematics. J Shoulder Elbow Surg 1998;7:345-51.
8. Fox CH, Johnson FB, Whiting J, Roller PP. Formaldehyde fixation. J Histochem Cytochem 1985;33:845-53.
9. Frangiamore SJ, Moatshe G, Kruckeberg BM, Civitarese DM, Muckenhirn KJ, Chahla J, et al. Qualitative and quantitative analyses of the dynamic and static stabilizers of the medial elbow: an anatomic study. Am J Sports Med 2018;46:687-94. https://doi.org/10.1177/0363546517743749
10. Fuss FK. The ulnar collateral ligament of the human elbow joint. Anatomy, function and biomechanics. J Anat 1991;175:203-12.
11. Gilroy AM, MacPherson BR, Schünke M, Schulte E, Schumacher U, Voll MM, et al. Atlas of anatomy. New York: Thieme; 2016. ISBN No. 978-1626232525.
12. Golden DW, Jhee JT, Gilpin SP, Sawyer JR. Elbow range of motion and clinical carrying angle in a healthy pediatric population. J Pediatr Orthop B 2007;16:144-9. https://doi.org/10.1097/BPB.0b013e328010fcf2
13. Gray H, Standring S, Anand N. Gray's anatomy: the anatomical basis of clinical practice. London: Elsevier; 2016. ISBN No. 978-0702052309.
14. Hotchkiss RN, Weiland AJ. Valgus stability of the elbow. J Orthop Res 1987;5:372-7.
15. Morrey BF, An KN. Articular and ligamentous contributions to the stability of the elbow joint. Am J Sports Med 1983;11:315-9.
16. Morrey BF, An KN. Functional anatomy of the ligaments of the elbow. Clin Orthop Relat Res 1985;201:84-90.
17. Mullen DJ, Goradia VK, Parks BG, Matthews LS. A biomechanical study of stability of the elbow to valgus stress before and after reconstruction of the medial collateral ligament. J Shoulder Elbow Surg 2002;11:259-64. https://doi.org/10.1067/mse.2002.122622
18. Netter FH. Atlas of human anatomy. Philadelphia: Elsevier; 2018. ISBN No. 978-0323596770.
19. Paraskevas G, Papadopoulos A, Papaziogas B, Spanidou S, Argiriadou H, Gigis J. Study of the carrying angle of the human elbow joint in full extension: a morphometric analysis. Surg Radiol Anat 2004;26:19-23. https://doi.org/10.1007/s00276-003-0185-z
20. Soucie JM, Wang C, Forsyth A, Funk S, Denny M, Roach KE, et al. Range of motion measurements: reference values and a database for comparison studies. Haemophilia 2011;17:500-7. https://doi.org/10.1111/j.1365-2516.2010.02399.x
21. Timmerman LA, Andrews JR. Histology and arthroscopic anatomy of the ulnar collateral ligament of the elbow. Am J Sports Med 1994;22:667-73.
22. Walker JM, Sue D, Miles-Elkousy N, Ford G, Trevelyan H. Active mobility of the extremities in older subjects. Phys Ther 1984;64:919-23.