Quantitative and Qualitative Analyses of the Lateral Ligamentous Complex and Extensor Tendon Origins of the Elbow

An Anatomic Study

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Background: The lateral collateral ligament complex of the elbow is important in preventing posterolateral rotary instability of the elbow. Understanding the quantitative anatomy of this ligamentous complex and the overlying extensor musculature can aid in the surgical treatment of problems affecting the lateral side of the elbow.

Purpose: To perform qualitative and quantitative anatomic evaluations of the lateral elbow ligamentous complex and common extensor muscle origins with specific attention to pertinent osseous landmarks.

Study Design: Descriptive laboratory study.

Methods: A total of 10 nonpaired, fresh-frozen human cadaveric elbows (mean age, 42.2 years; all male) were utilized. Quantitative analysis was performed using a 3-dimensional coordinate measuring device to quantify the location of pertinent bony landmarks, tendons, and ligament footprints of the lateral side of the elbow.

Results: The extensor carpi radialis brevis was the only humeral footprint found to cross the radiocapitellar joint line, extending a mean 5.9 mm (95% CI, 4.7-7.0) distal to the joint line. With the elbow in full extension, the lateral ulnar collateral ligament (LUCL) humeral footprint was found 7.1 mm (95% CI, 4.7-9.4) anterior and 9.8 mm (95% CI, 8.4-11.2) distal to the lateral epicondyle and 8.6 mm (95% CI, 7.5-9.7) proximal to the radiocapitellar joint line, while the radial collateral ligament humeral footprint was found 6.6 mm (95% CI, 5.5-7.8) anterior and 5.6 mm (95% CI, 4.0-7.2) distal to the lateral epicondyle and 12.7 mm (95% CI, 11.4-14.0) proximal to the radiocapitellar joint line. The center of the ulnar attachment of the LUCL was found 1.4 mm (95% CI, 0.7-2.1) anterior and 2.4 mm (95% CI, 1.2-6.0) proximal to the supinator tubercle and 24.4 mm (95% CI, 22.7-26.1) distal to the radiocapitellar joint line. The center of the ulnar attachment of the annular ligament was found to be 17.3 mm proximal to the supinator tubercle.

Conclusion: The current study provides measured distances of LUCL and radial collateral ligament attachments in reference to clinically relevant landmarks, which can potentially aid surgeons in performing more anatomic reconstruction or repair of the lateral ligamentous complex of the elbow.

Keywords: lateral elbow anatomy; radial collateral ligament; annular ligament; lateral ulnar collateral ligament; extensor carpi radialis brevis

Elbow dislocations are the second most common major joint dislocation and account for up to 25% of all traumatic elbow injuries.[18] An injury to the lateral ligamentous complex is the primary lesion associated with elbow dislocations.[16] Some patients with elbow dislocations will develop chronic laxity of the lateral ligamentous complex, resulting in posterolateral rotary instability (PLRI) of the elbow, which can result in pain and functional limitation.[1,16] Although the lateral ulnar collateral ligament (LUCL) was initially described as the primary ligament needed to prevent PLRI,[14] biomechanical research has indicated that an injury or sectioning of the radial collateral ligament (RCL) is also required to develop PLRI.[7,12] Furthermore, sectioning of the extensor musculature as it crosses the elbow joint increases PLRI.[12] The annular ligament and the osseous components of the elbow joint have also been shown to play a role in preventing PLRI.[4,12]

Previous studies have characterized the lateral ligamentous complex of the elbow as consisting of the RCL, the accessory posterior ligament, the LUCL, and the annular

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ligament.[13] Different normal anatomic variants of these ligamentous components have been described.[3,5,7,9,10,14,15,19] None of these previous anatomic studies has provided quantitative descriptions of attachment sites of the lateral ligamentous complex relative to bony landmarks, and none has provided quantitative descriptions of attachments of the adjacent extensor musculature. Given that repair and reconstruction of the LUCL and RCL are commonly performed, a more detailed description of the attachment sites of the lateral ligamentous complex may help surgeons to achieve more anatomic repair or reconstruction of these ligaments. Furthermore, in addition to its role in elbow stability, the extensor musculature, particularly the extensor carpi radialis brevis (ECRB), has substantial clinical importance because of its role in lateral epicondylitis. The treatment of lateral epicondylitis sometimes necessitates surgery; thus, detailed descriptions of the ECRB and other extensor tendon origins are of clinical importance to surgeons.

The aim of this study was to perform qualitative and quantitative anatomic evaluations of the lateral elbow ligamentous complex and common extensor muscle origins with specific attention to pertinent osseous landmarks. Specifically, we aimed to provide numeric measurements of the LUCL and RCL humeral and ulnar attachment sites from bony landmarks that could be palpated during surgery. We also aimed to provide quantitative and qualitative analyses of the extensor tendon origins, particularly the ECRB footprint.

METHODS

Specimen Preparation

A total of 10 nonpaired, fresh-frozen, human cadaveric distal humerus–to–fingertip specimens (all male; mean age, 42.2 years [range, 28-64 years]; body mass index range, 18-35) with no history of injuries or surgery to the elbow, osteoarthritis, or joint disease were used for testing. All specimens were donated to a tissue bank for the purpose of medical research and then purchased by our institution. Specimens were stored at –20°C and thawed at room temperature for 24 hours before preparation. All specimens were dissected free of all skin and subcutaneous tissue, leaving only the arm and forearm musculature and all elbow capsular and ligamentous structures intact.

Data Collection

Dissection and measurement methodology was similar to that described by Frangiamore et al.[8] Specimens were stored at –20°C and thawed at room temperature for 24 hours before dissection. During dissection, we removed the skin and subcutaneous tissue, leaving the muscles and lateral elbow structures intact. For qualitative anatomic observations, dorsal compartment and mobile wad musculature were carefully dissected along fascial planes by a single orthopaedic surgeon (D.L.B.) beginning from the extensor retinaculum and progressing proximally. Qualitative anatomic relationships of the common extensor muscle bellies and insertions were noted. Qualitative descriptions of the lateral elbow ligamentous complex were also noted as dissection continued deep to the tendon origins. After complete dissection and the identification of relevant lateral elbow musculature attachment sites, specimens were clamped in full extension and supination using 3 clamps (Figure 1). Anatomic measurements were collected using a coordinate measuring machine (Romer Absolute Arm; Hexagon Manufacturing Intelligence). Rhino 5 software (Robert McNeel & Associates) was used to record these points as 3-dimensional coordinates. During testing, the specimen and coordinate measuring machine were rigidly fixed to the same table to ensure stability; reference points were also taken initially and after all measurements were recorded to validate no movement of the specimen throughout testing, with a threshold of less than 1 mm of variation between the start and finish reference points.

Before anatomic measurements, a joint coordinate frame was established using previously described techniques.[8,20] The proximal-distal axis was defined as the axis passing through the centers of 3 rings digitized on the shaft of the humerus. A line connecting the medial and lateral epicondyles created the mediolateral axis. The anteroposterior axis was mutually perpendicular to these 2 axes. A list of bony and soft tissue structures measured is shown in Table 1. Quantitative anatomic measurements began with extensor tendon origins, measuring the borders of each individual extensor tendon origin directly. After measurements were made, the tendons were dissected away to allow for exposure of the underlying capsuloligamentous and bony structures. The periphery of each ligamentous structure listed in Table 1 was then digitized using the coordinate measuring machine to directly measure attachment sites before resection.

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Ethical approval was not sought for the present study.

Figure 1. A left elbow specimen is rigidly fixed in full extension and supination using 3 clamps to ensure stabilization throughout testing.

TABLE 1
Lateral Elbow Structures Measured During Testing of All Specimens[a]

Bony Structures	Soft Tissue
Lateral epicondyle	Extensor carpi radialis longus
Lateral epicondylar ridge	ECRB
Supinator tubercle	EDC/extensor digiti minimi
Supinator crest	Extensor carpi ulnaris
Radiocapitellar joint line	Anconeus
Ulnohumeral joint line	Humeral attachment
	Ulnar attachment
	RCL
	Humeral attachment
	LUCL
	Humeral attachment
	Ulnar attachment
	Annular ligament
	Ulnar attachment

[a]ECRB, extensor carpi radialis brevis; EDC, extensor digitorum communis; LUCL, lateral ulnar collateral ligament; RCL, radial collateral ligament.

Quantitative Analysis of Measurements

The collected data points were analyzed using custom script in MATLAB (MathWorks). To calculate muscle and ligament footprint areas, a best-fit plane was created through the circumferential points, the circumferential points were projected onto the plane, and the area of the resulting 2-dimensional polyhedron was computed. For muscular attachments, distances were calculated as the 3-dimensional linear distance (deconstructed onto the 3 anatomic axes) between the most distal or proximal points of the muscle body and the nearest point of the referenced landmark. For ligaments, the distance was measured using the calculated center of the footprint, unless otherwise stated. The mean and 95% CI were computed for all 10 specimens.

RESULTS

Qualitative Anatomy

Images of a lateral elbow with all relevant musculature intact and after dissection and the identification of ligaments are shown in Figure 2.

In all specimens, the extensor digiti minimi muscle belly began to coalesce with the extensor digitorum communis (EDC) muscle belly in the distal-third of the forearm, with muscle fibers inserting onto a shared fascial layer. For this reason, the extensor digiti minimi and EDC tendon origins were measured as a single unit for the quantitative portion of this study. It was noted that EDC fibers were closely associated with thick ECRB fascia, which ran deep to the EDC muscle belly. EDC muscle fibers began inserting on this fascia approximately 5 cm distal to the lateral epicondyle. A thick, bandlike extensor carpi ulnaris fascia was present in all specimens, running directly superficial to the LUCL over the radiocapitellar joint.

Qualitative findings of the lateral ligamentous complex included presence of the LUCL in all 10 specimens. The LUCL was noted to have a less distinct proximal attachment, with fibers blending and overlapping with the RCL proximal attachment; however, the distal attachment was more distinct. The distal attachment of the LUCL was adjacent to the supinator tubercle which was identified as a small bony prominence near the proximal end of the supinator crest. Both unilobed and bilobed ulnar attachments were observed as previously described,[5] with 4 of 10 specimens having a bilobed attachment and 6 of 10 specimens having a unilobed attachment. The RCL and annular ligament were also present in all 10 specimens, with the RCL fibers blending into the annular ligament distally.

Quantitative Anatomy

Muscular Anatomy. The areas of each humeral muscular attachment, as well as the distances from the most proximal and most distal points of the muscle body to the lateral epicondyle, are reported in Table 2. The ECRB was the only humeral footprint found to cross the radiocapitellar joint line, with robust attachment to the elbow joint capsule. The muscle spanned a mean 5.9 mm (95% CI, 4.7-7.0) distal to the joint line, with a mean area of 52.4 mm^2 (95% CI, 26.3-78.4), which comprised, on average, 20.4% of the muscle (95% CI, 11.2-29.5). The anconeus ulnar attachment was the only quantified ulnar muscle, and its area was 388.6 mm^2. From the supinator tubercle, the most proximal point was 25.8 mm (95% CI, 20.9-30.6; anterior, –13.2 mm [95% CI, –15.7 to –10.8]; proximal, 17.7 mm [95% CI, 12.9-22.6]; lateral, –12.2 mm [95% CI, –14.5 to –10.1]), and the most distal point was 41.8 mm (95% CI, 33.5-50.1; anterior, –1.8 mm [95% CI, –7.2 to 3.6]; proximal, –40.3 mm [95% CI, –48.2 to –32.3]; lateral, 6.1 mm [95% CI, 2.5-9.8]). An illustration based on quantitative findings is demonstrated in Figure 3.

Ligamentous Anatomy. The areas for the LUCL and RCL humeral attachments and their distances to the

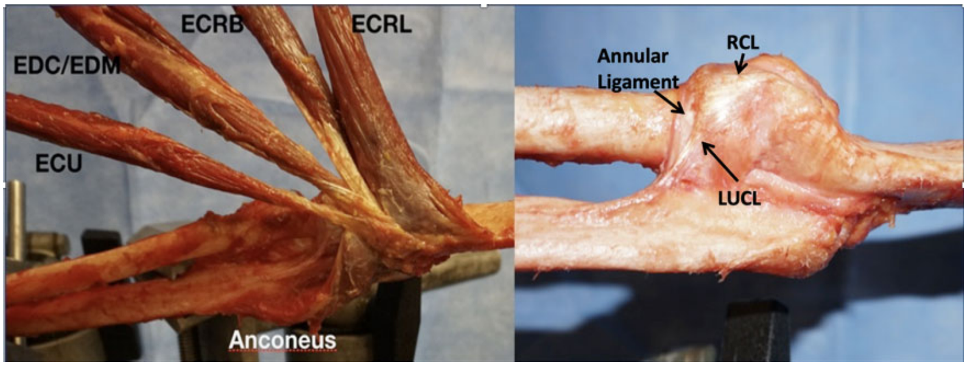

Figure 2. A lateral elbow with intact musculature (left) and after dissection to identify ligamentous structures (right). ECRB, extensor carpi radialis brevis; ECRL, extensor carpi radialis longus; ECU, extensor carpi ulnaris; EDC, extensor digitorum communis; EDM, extensor digiti minimi; LUCL, lateral ulnar collateral ligament; RCL, radial collateral ligament.

TABLE 2
Areas and Distances for Humeral Muscular Attachments[a]

	Extensor Carpi Radialis Longus	ECRB	EDC/Extensor Digiti Minimi	Extensor Carpi Ulnaris	Anconeus
Area, mm^2	451.2 (363.5 to 538.8)	237.2 (191.7 to 282.6)	157.6 (113.6 to 201.6)	32.5 (23.1 to 41.9)	157.3 (93.5 to 221.1)
Distance from most proximal to lateral epicondyle, mm					
Total	50.8 (45.0 to 56.5)	9.0 (5.6 to 12.5)	7.0 (4.9 to 9.1)	8.9 (6.2 to 11.6)	22.5 (18.8 to 26.2)
Anterior	–12.9 (–15.0 to –10.8)	5.5 (1.0 to 10.0)	–1.4 (–3.4 to 0.6)	1.2 (0.3 to 2.1)	–10.7 (–12.8 to –8.7)
Proximal	45.2 (39.2 to 51.2)	0.1 (–3.0 to 3.1)	4.4 (2.1 to 6.7)	–8.5 (–11.2 to –5.9)	–3.0 (–6.1 to 0.2)
Medial	19.9 (–17.4 to 50.8)	3.7 (–0.8 to 9.0)	4.8 (–1.4 to 7.0)	2.3 (–0.9 to 8.9)	22.4 (–15.6 to 22.5)
Distance from most distal to lateral epicondyle, mm					
Total	16.9 (13.8 to 20.1)	28.5 (26.6 to 30.4)	19.0 (14.7 to 23.3)	15.3 (12.6 to 18.1)	22.2 (20.8 to 23.7)
Anterior	15.6 (12.6 to 18.5)	18.2 (14.9 to 21.4)	7.7 (5.5 to 10.0)	4.1 (2.3 to 5.9)	–2.9 (–5.5 to –0.3)
Distal	4.2 (2.3 to 6.2)	20.7 (18.2 to 23.3)	16.4 (11.6 to 21.1)	13.8 (10.8 to 16.8)	15.8 (13.1 to 18.5)
Medial	2.3 (–0.3 to 4.8)	0.9 (–1.9 to 3.7)	0.1 (–2.2 to 2.4)	3.2 (1.2 to 5.1)	14.5 (12.6 to 16.4)

[a]Data are shown as mean (95% CI). ECRB, extensor carpi radialis brevis; EDC, extensor digitorum communis.

lateral epicondyle and radiocapitellar joint line are reported in Table 3. The ulnar attachment of the LUCL had a mean area of 13.6 mm^2 (95% CI, 6.8-20.3). The center of the LUCL footprint was 5.6 mm (95% CI, 3.4-7.7; anterior, 1.4 mm [95% CI, 0.7-2.1]; proximal, 2.4 mm [95% CI, –1.2 to 6.0]; medial, 1.2 mm [95% CI, 0.5-1.8]) from the supinator tubercle, 24.4 mm (95% CI, 22.7-26.1) distal to the radiocapitellar joint line, and 24.3 mm (95% CI, 22.4-26.1) distal to the ulnohumeral joint line. The mean length of the annular ligament was 14.1 mm (95% CI, 11.8-16.3). The most distal point of the annular ligament footprint was 11.2 mm (95% CI, 7.1-15.2; posterior, 1.1 mm [95% CI, –0.9-3.1]; proximal, 10.3 mm [95% CI, 6.3-14.3]; lateral, –1.9 mm [95% CI, –3.5 to –0.3]) from the supinator tubercle, 11.9 mm (95% CI, 9.6-14.1) from the radiocapitellar joint line, and 6.7 mm (95% CI, 5.3-8.2) from the ulnohumeral joint line. The center of the annular ligament was 17.3 mm proximal to the supinator tubercle. An illustration based on quantitative findings is demonstrated in Figure 4.

Bony Anatomy. On the humerus, the epicondylar ridge was a mean length of 68.6 mm (95% CI, 58.7-78.6). The lateral epicondyle was 20.8 mm (95% CI, 18.8-22.8) from the radiocapitellar joint line with the elbow in full extension. On the ulna, the length of the supinator crest was, on average, 42.2 mm (95% CI, 35.7-48.8). The supinator tubercle was found to be 26.8 mm (95% CI, 23.2-30.3) from the radiocapitellar joint line and 27.1 mm (95% CI, 22.9-31.3) from the ulnohumeral joint line.

DISCUSSION

The most important finding of this study is the quantitative distances from the anatomic origin and insertions of the lateral elbow ligamentous complex components to clinically relevant bony landmarks, which may help in achieving more anatomic reconstruction of the LUCL and/or RCL. It was observed that with the elbow in full extension, the LUCL humeral footprint was 7.1 mm anterior and 9.8 mm distal to the lateral epicondyle and 8.6 mm proximal to the radiocapitellar joint line, while the RCL humeral footprint was 6.6 mm anterior and 5.6 mm distal to the lateral

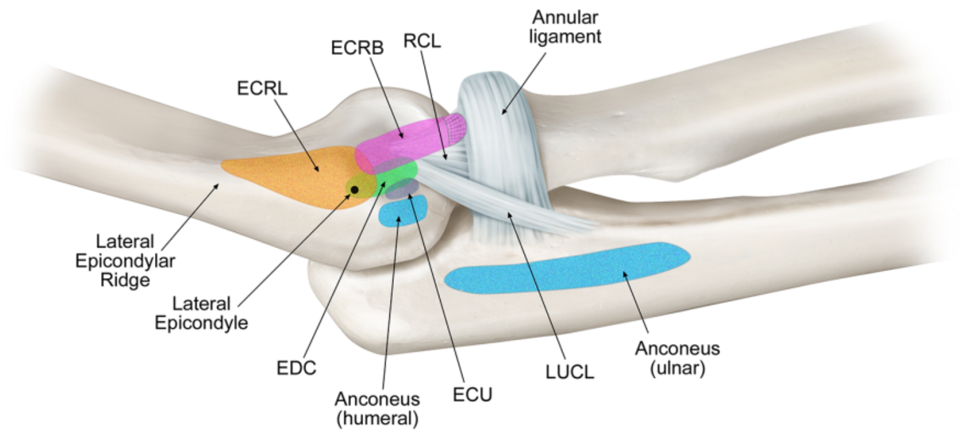

Figure 3. Illustration of extensor lateral elbow muscular origins and attachment sites based on quantitative findings. ECRB, extensor carpi radialis brevis; ECRL, extensor carpi radialis longus; ECU, extensor carpi ulnaris; EDC, extensor digitorum communis; LUCL, lateral ulnar collateral ligament; RCL, radial collateral ligament.

TABLE 3
Areas and Distances for LUCL and RCL Humeral Footprints[a]

	LUCL	RCL
Area, mm^2	16.6 (13.1 to 20.2)	44.3 (34.1 to 54.4)
Distance from lateral epicondyle, mm		
Total	13.2 (12.0 to 14.3)	9.2 (7.8 to 10.7)
Anterior	7.1 (4.7 to 9.4)	6.6 (5.5 to 7.8)
Distal	9.8 (8.4 to 11.2)	5.6 (4.0 to 7.2)
Lateral	–2.4 (–4.2 to –0.6)	–1.6 (–2.8 to –0.3)
Distance from radiocapitellar joint line, mm		
Total	9.2 (8.0 to 10.3)	13.5 (12.1 to 14.8)
Anterior	–2.1 (–0.8 to –3.4)	–2.8 (–1.1 to –4.6)
Proximal	8.6 (7.5 to 9.7)	12.7 (11.4 to 14.0)
Lateral	0.4 (–0.6 to 1.3)	1.1 (–0.1 to 2.3)

[a]Data are shown as mean (95% CI). LUCL, lateral ulnar collateral ligament; RCL, radial collateral ligament.

epicondyle and 12.7 mm proximal to the radiocapitellar joint line. The center of the ulnar attachment of the LUCL was found 1.4 mm anterior and 2.4 mm proximal to the supinator tubercle and 24.4 mm distal to the radiocapitellar joint line. Likewise, the center of the annular ligament was found to be 17.3 mm proximal to the supinator tubercle. The supinator tubercle was identified as a small bony prominence near the proximal end of the supinator crest in this study. Another study has demonstrated that there is variability in this bony landmark.[2] As such, we found it important to provide distances for annular ligament and LUCL ulnar attachment sites that are referenced from the radiocapitellar joint line. The radiocapitellar joint line can be easily identified intraoperatively using a spinal needle, and the reported distances of ligament attachment sites distal to the radiocapitellar joint line, coupled with the anterior/posterior distance from the supinator tubercle/crest, can result in a reproducible method to find the anatomic insertion sites of these ligaments. Referencing from the apex of the supinator crest, radial notch, or other bony landmarks may be difficult clinically because of both the limited surgical access with the radial head reduced in its anatomic location and the previously mentioned variability that exists with more accessible bony landmarks.[2] It should be noted that the attachment site measurements that are presented in this study are calculated mean values and do have associated standard deviations; thus, the measured distances that we provide are not universal for all patients and may vary based on patient size.

The current study also provides the first quantitative anatomic report on the attachment sites of the origins of all common extensor tendons. Cohen et al[6] previously provided qualitative and quantitative descriptions of the ECRB tendon attachment and similarly found that, although the EDC and ECRB tendons do coalesce proximally near the radiocapitellar joint line, the tendons are identifiable and can continue to be traced proximally. While they also reported that the ECRB tendon could be isolated away from the capsule, to which it is attached near the radiocapitellar joint line, we considered this part of its tendinous insertion. As such, we reported the ECRB attachment site had 20.4% of its

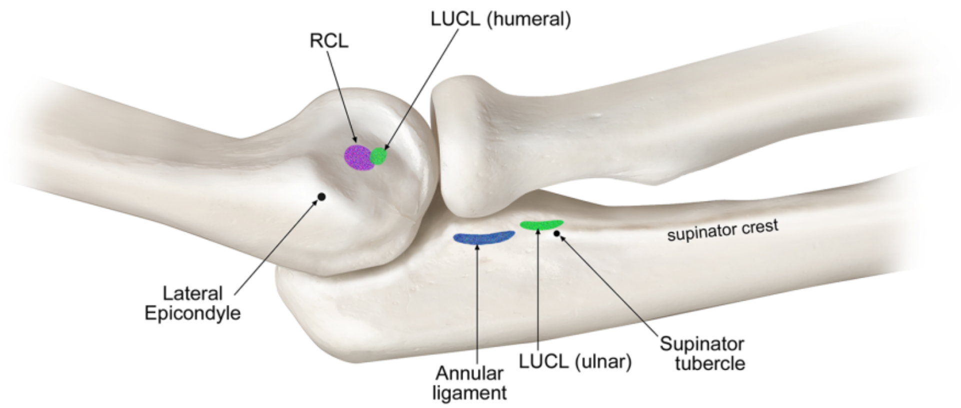

Figure 4. Illustration of extensor lateral elbow humeral and ulnar ligamentous attachment sites based on quantitative findings. LUCL, lateral ulnar collateral ligament; RCL, radial collateral ligament.

muscle belly distal to the radiocapitellar joint line. This difference in the definition of the ECRB attachment may explain the differences between reported ECRB attachment site dimensions and areas in the current study and that of Cohen et al.[6] We believe that the capsular attachment portion of the ECRB is of clinical significance to surgeons when considering either injections or surgical debridement of the ECRB tendon in the setting of lateral epicondylitis. A previous cadaveric study has discussed safe zones for arthroscopic debridement of lateral epicondylitis, reporting that 100% of the ECRB and 90% of the EDC origin sites can be debrided arthroscopically without damaging the LUCL.[17] It should be noted that the elbow was in 90° of flexion when defining safe zones in their study, whereas our study presents findings with the elbow in extension.[17] The position of elbow flexion should be carefully considered when both interpreting the present results and applying these findings and previously reported safe zone findings to surgical approach.

This study does include limitations. The variability of the lateral ligamentous complex of the elbow has been well-documented.[3,6] Because of our relatively small sample size of 10 specimens, the present study is unable to add to the conversation regarding normal anatomic variants of the lateral ligamentous complex. However, this was not the aim of this study, as we set out to provide more generalizable information that could be utilized regardless of possible variations in the individual components of the ligamentous complex. This study is also limited in that the distances provided were measured using only male cadaveric specimens without known heights for individual participants. Therefore, the distances presented may vary based on sex and stature, which could not be assessed in this study. The utilized methodology is similar to that used in other anatomic studies that have been published previously, with quantitative measurements of ligamentous anatomy presented in which all male cadaveric specimens were used or no sex of cadaveric specimens was reported and no correction for size was provided.[8,11]

CONCLUSION

The current study provides measured distances of LUCL and RCL attachments in reference to clinically relevant landmarks, which can potentially aid surgeons in performing more anatomic reconstruction or repair of the lateral ligamentous complex of the elbow. The common extensor tendons originated at the lateral aspect of the distal humerus, with the ECRB having a robust capsular attachment that extended distal to the radiocapitellar joint line.

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