RESEARCH ARTICLE

Radiographic Description of Soft Tissue Attachments around the Elbow

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Abstract

Objectives: Quantitatively define the radiographic locations of the major soft-tissue attachments about the elbow.

Methods: In 10 cadaveric elbows, the attachments of the medial ulnar collateral ligament, lateral ulnar collateral ligament, annular ligament, triceps, and biceps were marked with radiopaque spheres. Measurements were made on calibrated AP and lateral fluoroscopic images from known osseous landmarks.

Results: On AP radiographs; the anterior bundle of the MUCL (aMUCL) measured 28.6mm (95% CI, 27. 5-29.8mm) from the humeral attachment to the midpoint of the MUCL ridge on the ulna and 14.3mm, (95% CI 13.0-15.5) to the olecranon. The LUCL was 39.9mm (95% CI, 38.6 – 41.1mm) from the humeral attachment to the supinator crest attachment and 8.9mm (95% CI, 8.1-9.8mm) to the lateral epicondyle. On the lateral radiographs, the humeral attachment of the aMUCL to the medial coronoid was 27.1mm (95% CI, 25.9-28.2mm) and 9.3mm (95%CI, 17.5 - 21.2mm) to the tip. The LUCL humeral attachment to the supinator crest was 45.4mm (95%CI, 44.1-46.8mm). The LUCL humeral attachment was located 8.9mm (95%CI, 8.0-9.7mm) posterior from the anterior humeral line.

Conclusion: The soft-tissue attachments about the elbow were reproducibly demonstrated on radiographs in relation to osseous landmarks and radiographic lines. The radiographic relationships will allow for improved identification of the ligament and tendon attachment sites of the elbow for intraoperative assessment and postoperative evaluation following reconstruction.

Level of evidence: V

Keywords: Elbow, Ligament, Reconstruction, Tendon, Xray

Introduction

The elbow is a complex joint that allows for both flexion-extension, as well as forearm rotation. In addition to fractures, injuries to ligaments and tendons around the elbow are commonly encountered.[1-6] The medial ulnar collateral ligament (MUCL) is the main medial stabilizer of the ulno-humeral joint to valgus stress in the midranges of the elbow flexion.[7-10] Additionally, the lateral ulnar collateral ligament (LUCL) is the principal soft tissue restraint to posterolateral rotatory instability of the elbow.[11-13] The annular ligament is the primary stabilizer of the radioulnar articulation and allows for forearm rotation. Its attachments are on the radial side of the ulna.[14,15] the biceps and triceps are the two tendinous structures that attach to the radius and ulna, respectively, and their attachment sites have not been quantified radiographically, to the authors' knowledge.

Several preceding studies have anatomically described the attachments of the MUCL, lateral collateral ligament complex, triceps, and biceps tendons based on gross anatomic description.[16-31] with an improved understanding of elbow biomechanics and anatomy, the prevalence of ligamentous reconstruction has increased. Specifically, reconstruction of the anterior bundle of the MUCL (aMUCL) has seen the most growth in recent years. The epidemiological trends of ulnar collateral ligament reconstruction (UCLR) in New York demonstrate a 193%

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increase from 2002 to 2011, with the fastest growth in adolescent patients.[1,32,33] While the outcomes of such surgical procedures are improving, a better understanding of both the gross and radiographic anatomy is vital for the surgical treatment of these elbow injuries.[6,34-38]

There are limited radiographic descriptions of elbow anatomy in the published literature.[29,39] Understanding the gross anatomical and radiographic relationships of structures commonly treated surgically is important. Additionally, identifying anatomy during chronic and revision surgical elbow treatment can be challenging. Understanding the radiographic relationships of the soft tissue attachments about the elbow can assist with identifying their attachment sites under fluoroscopy. Lastly, radiographic anatomy can be used to assess the anatomic accuracy of operative reconstruction and repair of these injured structures through post-operative radiographic evaluation.

We, therefore, developed a study and asked the following question: 1) Can we quantitatively and consistently define the radiographic locations of the MUCL, LUCL, annular ligament, triceps, and biceps attachments about the elbow?

Materials and Methods

Specimen Preparation

Ten fresh-frozen, unpaired cadaveric elbows from donors with no evidence of previous ligament or bony abnormality were obtained for the current study. All specimens were superficially dissected, removing the skin and subcutaneous tissue. The underlying periarticular soft tissue structures were carefully exposed, and all muscle was removed. The capsular, ligamentous, and tendinous attachments were left intact. The attachments of the anterior and posterior bundles of the MUCL (aMUCL and pMUCL), lateral collateral ligament complex (LUCL and annular ligament, precluding the radial collateral ligament), triceps, and biceps were identified [Figures 1 and 2]. After identification of the LUCL complex, the radial collateral ligament attachment was found to blend into the annular ligament and have no specific bony attachment. Therefore, it was not marked in the study.

The footprints of each ligament and tendinous attachment point were identified and agreed upon by two sports-medicine fellowship-trained orthopedic surgeons, a senior and a junior resident. After identification of the footprint, the ligamentous or tendinous structure was removed to reveal the bony insertion. The dimensions (length and width) of the attachment were measured with a caliper, and the center was then determined. Then a 1.7 mm hole was drilled into the subchondral bone, and subsequently, a 2-mm stainless steel sphere (Small Parts, Miami Lakes, Florida) was press-fit into the bone utilizing a bone tamp. The bone tamp, being wider than the stainless steel sphere and drilled hole, ensuring that each sphere was placed into the bone at similar depths.

Data Collection

Utilizing a mini fluoroscopy C-arm with an image intensifier, standard anteroposterior (AP) and lateral radiographs were obtained for each specimen. A 25.4mm radiopaque marker was included on all radiographs to correct any magnification disparity between specimens. The radiopaque marker was positioned in the imaging field using a secure device [Figures 3 and 4].

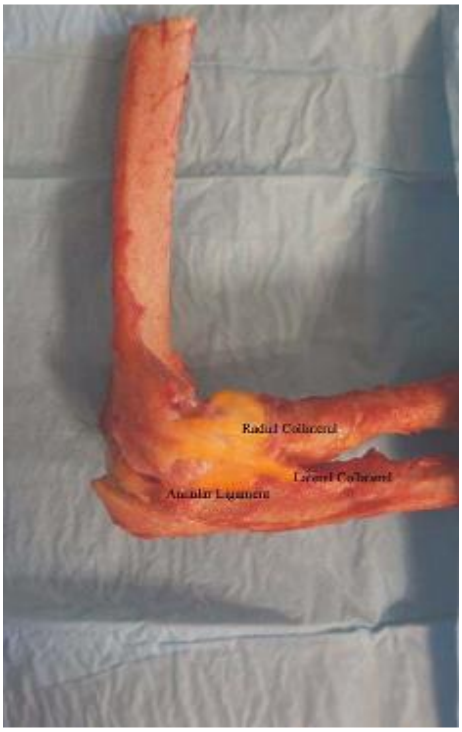

Figure 1. Lateral ulnar collateral ligament complex dissection image

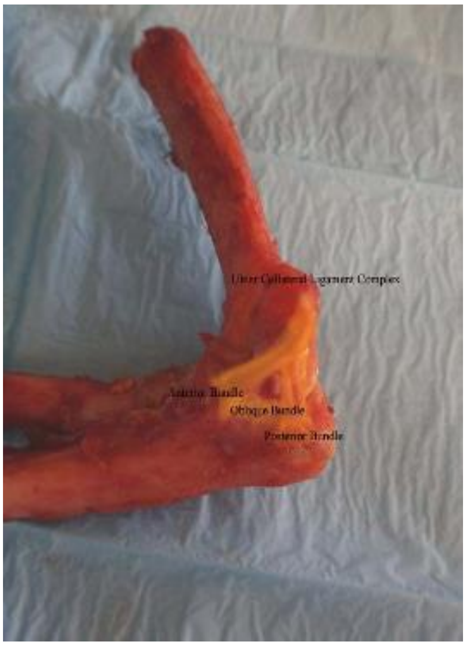

Figure 2. Medial ulnar collateral ligament complex dissection image

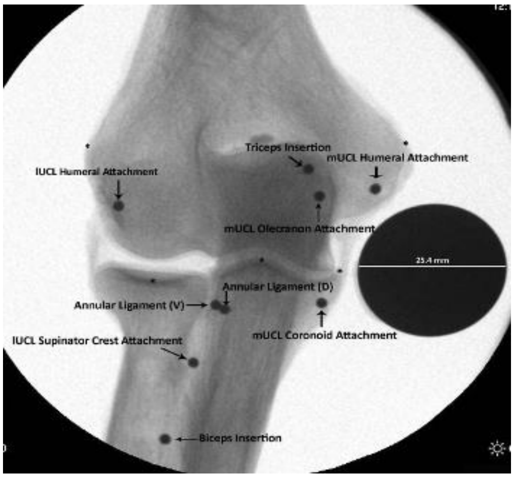

Figure 3. AP radiograph image demonstrating the radiographic attachment sites with stainless steel sphere and attachment sites of interest: medial epicondyle, lateral epicondyle, coronoid tip, the center of the radial head, and medial margin of the coronoid process (asterisks). D: dorsal attachment; V: volar attachment; MUCL: medial ulnar collateral ligament; LUCL: lateral ulnar collateral ligament

Figure 4. Lateral radiograph image demonstrating the radiographic attachment sites with stainless steel sphere and attachment sites of interest: coronoid tip, the center of the radial head, olecranon tip (asterisks). D: dorsal attachment; V: volar attachment; MUCL: medial ulnar collateral ligament; LUCL: lateral ulnar collateral ligament

Measurements

Digital images were saved and uploaded for analysis using Image J software (National Institutes of Health, Bethesda, MD, USA). Image J software allows for the measurement of calibrated images and has been utilized in similar cadaveric studies.[40-42] Images were calibrated utilizing the 25.4mm radiopaque marker in the field of view. Measurements that describe the spatial relationships among ligamentous and tendinous attachments, as well as easily identifiable osseous landmarks, were collected in a spreadsheet (Microsoft Excel, Redmond, WA).

For AP radiographs, absolute measurements were made between two attachment sites of interest, a radiographic line or an easily visible osseous landmark [Figure 5]. Lateral radiograph measurements were made similarly [Figure 6].

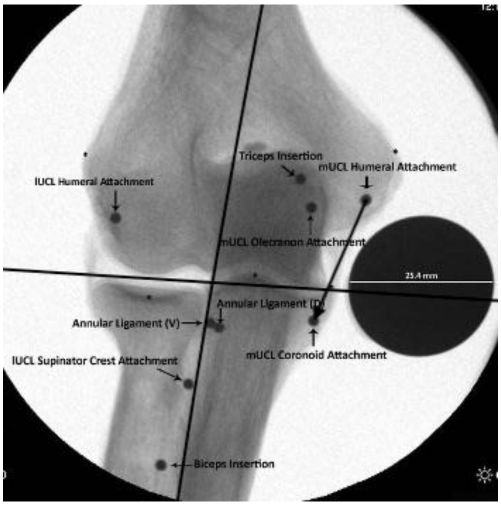

Figure 5. AP radiograph image demonstrating example measurement. The lateral ulnar line and a line parallel to the joint are present. Asterisks denote osseous landmarks: medial epicondyle, lateral epicondyle, coronoid tip, the center of the radial head, and medial margin of the coronoid process. D: dorsal attachment; V: volar attachment; MUCL: medial ulnar collateral ligament; LUCL: lateral ulnar collateral ligament

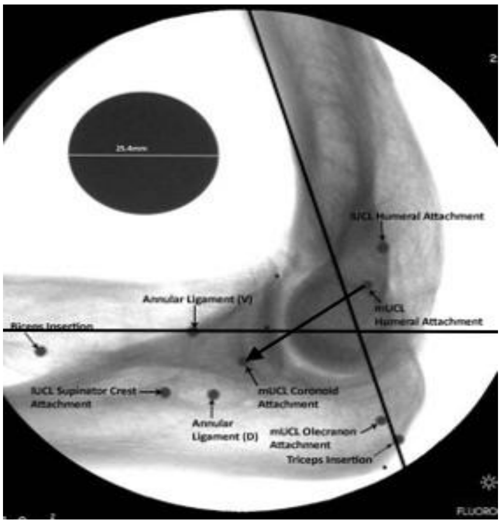

Figure 6. Lateral radiograph image demonstrating example measurement. The anterior humeral line and the mid-axial radial line are present. Asterisks denote osseous landmarks: coronoid tip, the center of the radial head, and olecranon tip. D: dorsal attachment; V: volar attachment; MUCL: medial ulnar collateral ligament; LUCL: lateral ulnar collateral ligament

The landmarks used on the AP radiographs included the medial epicondyle, lateral epicondyle, coronoid tip, center of the radial head, and medial margin of the coronoid process. The transverse joint line was determined as an approximately perpendicular line drawn on the medial border of the ulna. The landmarks used on the lateral radiographs included the coronoid tip, center of the radial head, and olecranon tip. The anterior humeral and radial axis lines were used as radiographic lines of interest.

All distances were measured by two independent examiners blinded to the other reviewers' measurements. The measurements were repeated after an interval of two weeks to limit recall bias and allow for intra and inter-observer calculations.

Statistical Analysis

Absolute measurements between two attachment sites or an attachment site and an osseous landmark were reported as means and standard deviations. Statistical analysis was performed with SPSS software.

Results

There were ten specimens included for analysis in this study. There were four female and six male cadaveric specimens available for analysis. The average age was 68 (range 58 - 85). There was no evidence of prior ligamentous damage or bony deformity. No specimens were excluded from the analysis. The anatomic relationships of the soft-tissue attachments around the elbow, as seen on anteroposterior radiographs, can be seen in [Table 1]. The anatomic relationships of the soft-tissue attachments around the elbow, as seen on lateral radiographs, can be seen in [Table 2].

Intra-observer intra-class correlation coefficients were 0.98 and 0.95 for examiner one and two, respectively. The combined intra-observer intra-class correlation coefficient was 0.97, demonstrating high intra-observer reliability. Inter-observer reliability was assessed between each examiner in the first and second trials, as well as for both trials combined. The overall inter-observer intra-class correlation coefficient for the combined trial was 0.95. This indicates high inter-observer reliability.

Table 1. AP radiographic results

Quantitative Relationships of Elbow Anatomic Structures to Landmarks and Reference Lines on Elbow Anteroposterior Radiographs

Structure Relationship	Distance ± standard deviation (mm)
Humeral Attachment of MUCL to:	
Coronoid attachment (anterior bundle)	28.6 ± 3.8
Olecranon attachment (posterior bundle)	14.3 ± 4.0
Superior aspect of medial epicondyle	11.7 ± 2.3
Transverse joint line	20.3 ± 3.7
Ulna Attachment of MUCL to:	
Olecranon attachment (posterior bundle)	20.1 ± 3.3
Medial aspect of coronoid	5.9 ± 2.1
Transverse joint line	6.3± 2.0
Olecranon Attachment of MUCL to:	
Medial aspect of coronoid	18.03 ± 3.9
Transverse joint line	15.8 ± 4.1
Humeral Attachment of LUCL to:	
Supinator crest attachment	39.9 ± 4.0
Superior aspect of lateral epicondyle	8.9 ± 2.7
Transverse joint line	14.6 ± 3.2

Table 1. Continued

Supinator Crest Attachment of LUCL to:	
Transverse joint line	20.2 ± 2.8
Annular Ligament Dorsal Attachment to:	
Annular ligament volar attachment	9.2 ± 4.2
Tip of coronoid process	14.9 ± 6.4
Transverse joint line	9.5 ± 3.8
Annular Ligament Volar Attachment to:	
Tip of coronoid process	12.3 ± 2.9
Transverse joint line	11.4 ± 3.6
Biceps Insertion to:	
Center of radial head	32.1 ± 3.7
Transverse joint line	33.3 ± 4.9
Triceps Insertion to:	
Center of olecranon	7.6 ± 3.7
Transverse joint line	19.2 ± 3.6

Table 2. Lateral Radiograph Results

Quantitative Relationships of Elbow Anatomic Structures to Landmarks and Reference Lines on Elbow Lateral Radiographs

Structure Relationship	Distance ± standard deviation (mm)
Humeral Attachment of UCL to:	
Coronoid attachment (anterior bundle)	27.1 ± 3.7
Olecranon attachment (posterior bundle)	23.4 ± 4.0
Anterior humeral line	9.1 ± 2.0
Ulna Attachment of UCL to:	
Tip of coronoid	19.3 ± 6.0
Radial axis line	12.5 ± 3.5
Olecranon Attachment of UCL to:	
Ulna attachment (transverse bundle)	25.0 ± 3.6
Radial axis line	21.8 ± 5.6
Humeral Attachment of LUCL to:	

Table 2. Continued	
Supinator crest attachment	45.4 ± 4.3
Anterior humeral line	8.9 ± 2.7
Supinator Crest Attachment of LUCL to:	
Radial axis line	14.4 ± 2.2
Annular Ligament Dorsal Attachment to:	
Annular ligament volar attachment	11.7 ± 2.1
Tip of coronoid process	23.5 ± 2.4
Radial axis line	15.1 ± 2.4
Annular Ligament Volar Attachment to:	
Tip of coronoid process	16.7 ± 4.9
Radial axis line	6.2 ± 3.3
Biceps Insertion to:	
Center of radial head	34.1 ± 4.4
Radial axis line	6.5 ± 2.4
Triceps Insertion to:	
Tip of olecranon	6.1 ± 1.7
Radial axis line	22.9 ± 5.5

Discussion

Successful anatomic reconstruction and repair of the ligament and tendons of the elbow rely on precise anatomic identification of their attachment sites. Several anatomic studies have attempted to describe the attachment sites of the ligamentous and tendinous structures about the elbow; however, to date, only limited radiographic data has been reported.[20,26-29,39] This study has clearly defined the soft tissue attachments about the elbow utilizing easily identifiable osseous landmarks as well as radiographic lines and subsequently provides a detailed analysis of potential reconstruction tunnels.

Numerous studies have described the cadaveric attachments of both the medial and lateral soft tissue structures about the elbow.[16, 19, 25-27, 30, 42] Farrow et al.[26] used computed tomography and ten cadaveric specimens to detail the footprint of the aMUCL. The authors reported the mean length of the ulnar soft tissue footprint to be approximately 29.2 mm, with a long ulnar attachment on the sublime tubercle that continued along the MUCL ridge. These findings were dissimilar to Fuss,[25] who found a long ulnar attachment in only 1 of 20 cadaveric specimens. In the current study, we identified the midpoint of the attachment site for the aMUCL in all specimens, and it was a mean of 5.9 mm from the medial aspect of the coronoid process. Capo et al.[28] reported a mean distance of 10 mm of the aMUCL to the coronoid margin with 3-dimensional mapping technology. The reported distances are valuable during aMUCL reconstruction to determine accurate tunnel locations.[8,43]

Traditionally, the pMUCL has been identified as a secondary constraint with little effect on stability; however, more recent literature has detailed the potential importance of the pMUCL in unstable elbow injuries.[45-48] Shukla et al.[47] demonstrated that an intact pMUCL can prevent elbow dislocation and limit subluxation to 6.6 mm after an aMUCL transection under external rotation and valgus forces in a cadaveric study. The authors found the results significant at both 30 and 60 degrees of elbow flexion. They even raised the possibility of pMUCL reconstruction in the inherently unstable elbow after lateral stabilization. Furthermore, Golan et al.[49] used nine cadaveric specimens to demonstrate that even with the aMUCL intact, sectioning the pMUCL results in significant torsion and gapping of the ulnohumeral joint. Identification of the radiographic attachments of the pMUCL becomes vital in these situations if pMUCL reconstruction is warranted.

Whereas the MUCL has been of interest due to injuries in overhead athletes, the lateral collateral ligament complex is commonly involved in traumatic elbow dislocations and unstable elbow injuries. In these instances, anatomic attachment identification is difficult, and knowledge of the radiographic attachment sites becomes more important. Berg and DeHoll[29] dissected the lateral elbow ligaments in fresh frozen cadavers and then painted the LUCL and annular ligament with a radiopaque mixture to qualitatively identify both these structures on radiographs. Their AP and lateral radiographs appear similar to the attachment points identified by the current study. These values allow for precise bone tunnel placement with intra-operative fluoroscopy in the setting of LUCL reconstruction, especially in individuals without a palpable supinator crest.[50] In cases of LUCL reconstruction, surgeons typically strive for tunnel placement at the humeral isometric point.[51, 52] This may be more difficult than perceived, and Alaia et al.[51] reported that no perfect isometric point exists after they analyzed 13 cadaver limbs. They suggest surgeons use the humeral center of the rotation. The authors found that differing humeral tunnel placement dramatically affected graft elongation, but ulnar placement had a minimal effect. This makes the anatomical distances obtained for the LUCL humeral attachment pivotal and suggests that the ulnar attachment may not be as important. Kim et al.[53] mirrored these findings, who created posterolateral instability in 7 cadaveric elbows and then made five different ulnar tunnels for ligament reconstruction. The authors reported no significant gapping at the posterolateral ulnohumeral joint regardless of where the ulnar tunnels were placed.

We also identified the anatomic distal attachment sites of the biceps and triceps tendons. These bony attachment sites are perhaps easier to identify intraoperatively than the medial and lateral elbow ligamentous complexes due to the easily identifiable radial tuberosity and olecranon process. For example, in biceps repair, it can be significantly difficult to get enough fixation distally and ulnar-based aspect of the radial tuberosity. Intra-operative and certainly post-operative radiographs can be used to verify true anatomic repair.

Furthermore, we feel the osseous landmarks used in this study may be unconventional regarding elbow reconstruction. However, they were determined by the ease with which they are identifiable on fluoroscopic images. Intraoperatively, these radiographic projections are quick and easy to find, which could aid in surgical reconstruction.

There were several limitations to this study. The radial collateral ligament extends from the lateral epicondyle with fibers that blend from the lateral collateral ligament and then blend into the annular ligament. No clear distal attachment was identified when marking the attachment site to the annular ligament. In previous cadaveric studies, this also proved difficult to identify.[29] this was also true for the anterior and posterior bundles of the medial collateral ligament at the humeral attachment site. The fibers for the humeral attachment were blended into one footprint on the medial epicondyle, and the transverse bundle blended into both the anterior and posterior bundle attachments. For the radiopaque steel sphere placement, we drilled holes into the subchondral bone and inserted the 2mm stainless steel spheres into the center of the attachment sites. Even though this was done uniformly by a single research team member, the depth and drill hole was not standardized, which could lead to potential measurement errors. The biceps and triceps tendon distal insertions are broad attachments on the proximal radius and olecranon, respectively.[22,54] A 2-mm radiopaque marker may not be sufficient for characterizing the nature of their attachments.

Additionally, we found that the elbows became unstable after dissecting the soft tissue off the elbow (except for the ligamentous and capsular structures). Acquisition of the radiographs was obtained with a reviewer stabilizing the elbows firmly. However, this, too, was not standardized and may lead to small errors in the radiographs. The osseous landmarks used in this study may be unconventional regarding elbow reconstruction. However, they were determined by the ease with which they are identifiable on fluoroscopic images. Intraoperatively, these radiographic projections are quick and easy to find, which aids in surgical reconstruction.

Conclusion

We have quantitatively defined radiographic landmarks of the medial and lateral collateral ligaments, triceps, and biceps tendon attachments about the elbow. The results of this study demonstrate that ligamentous attachments about the elbow are reproducibly identified on radiographs with respect to known osseous landmarks and radiographic lines. These radiographic relationships will allow for improved identification of the ligament and tendon attachment sites of the elbow for intraoperative assessment and postoperative evaluation of these reconstructed structures.

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