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Three-dimensional analysis of elbow soft tissue footprints and anatomy

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Background: Tendinous and ligamentous injuries commonly occur in the elbow. This study characterized the location, surface areas, and origin and insertional footprints of major elbow capsuloligamentous and tendinous structures in relation to bony landmarks with the use of a precision 3-dimensional modeling system.
Methods: Nine unpaired cadaveric elbow specimens were dissected and mounted on a custom jig. Mapping of the medial collateral ligament (MCL), lateral ulnar collateral ligament (LUCL), triceps, biceps, brachialis, and capsular reflections was then performed with 3-dimensional digitizing technology. The location, surface areas, and footprints of the soft tissues were calculated.
Results: The MCL had a mean origin (humeral) footprint of 216 mm^2, insertional footprint of 154 mm^2, and surface area of 421 mm^2. The LUCL had a mean origin footprint of 136 mm^2, an insertional footprint of 142 mm^2, and a surface area of 532 mm^2. Of the tendons, the triceps maintained the largest insertional footprint, followed by the brachialis and the biceps ($P < .001$–.03). The MCL, LUCL, and biceps footprint locations were consistent, with little variability. The surface areas of the anterior (1251 mm^2) and posterior (1147 mm^2) capsular reflections were similar ($P = .82$), and the anterior capsule extended farther proximally.
Conclusion: Restoring the normal anatomy of key elbow capsuloligamentous and tendinous structures is crucial for effective reconstruction after bony or soft tissue trauma. This study provides the upper extremity surgeon with information that may aid in restoring elbow biomechanics and preserving range of motion in these patients.
Level of evidence: Basic Science, Anatomy.

Keywords: Elbow; anatomy; three-dimensional; ligament; tendon; footprint; surface area

The elbow is an inherently stable joint complex, owing to its bony anatomy and soft tissue reinforcement.[21] Nevertheless, elbow dislocations occur with an incidence of 5.21/100,000 person-years, often with accompanying avulsion of bone and resulting disruption of tendinous or ligamentous attachments.[22] Traumatic rupture of the soft

Investigational Review Board approval was not required for this cadaveric study.

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tissue restraints can also occur, most frequently in the overhead-throwing athlete.[7] To restore upper extremity function, reconstruction of the anatomy should proceed with the goal of restoring the normal anatomy of the bony and soft tissues.

The area of attachment of a ligament or tendon to a bony surface, termed the "footprint," has been identified and described for the rotator cuff.[3-5] Beginning with Minagawa et al[19] in 1998, the widths of the supraspinatus and infraspinatus tendon footprints were assessed. Volk and Vangsness[23] later quantified the supraspinatus tendon length. Dugas et al[6] contributed the first comprehensive evaluation of the rotator cuff footprint, with information on all of the tendinous components collectively, which was later confirmed in a cadaveric study by Curtis et al.[4]

To date, however, the complete analogous anatomy has not been defined for the stabilizing soft tissue structures of the elbow. Farrow et al[9] described the ulnar attachment length, but not the area, of the medial collateral ligament (MCL). Mazzocca et al[18] examined the insertional anatomy of the distal biceps tendon, and Jarrett et al[11] further defined this region into the short and long heads. In addition, Keener et al[13] mapped the insertional footprint of the triceps. Ma and Chang[16] also quantified the brachialis insertion on the coronoid. To the best of our knowledge, however, several periarticular elbow soft tissues, including the lateral ulnar collateral ligament (LUCL) footprints and the surface areas of key capsuloligamentous structures, have not yet been studied. Moreover, previous investigations into the footprint of various tendons and ligaments about the elbow have not considered the structures collectively, and most have used digital or vernier calipers, which provide only coarse and rudimentary measurements.[9,11,13,18,19]

The purpose of our study was to accurately characterize the major elbow capsuloligamentous and tendinous structure anatomic surface areas and origin and insertional footprints relative to the bony landmarks of the elbow with the use of a precision 3-dimensional mapping system. In doing so, we further sought to compare these measurements among the various soft tissue structures.

Materials and methods

The study evaluated 9 fresh frozen unpaired human cadaveric elbow specimens. Each specimen consisted of an upper extremity extending from the midhumerus to the fingertips. The specimens were from male donors who were a mean age of 69 years (range, 64–72 years). All specimens were stored at −4°C until evaluation and were thawed to room temperature before dissection. A superficial dissection of skin and subcutaneous tissue from the midhumerus to the midforearm was performed, followed by a deeper dissection to expose the underlying periarticular soft tissue elbow structures. All capsular, ligamentous, and tendinous attachments were preserved and left intact at this point. None of the specimens had evidence of prior injury or surgery to the elbow. To provide a fixed reference point for the digital mapping system, the specimens were rigidly mounted on a custom jig with fixation of the humerus and ulnar shaft with the elbow in 90° of flexion.

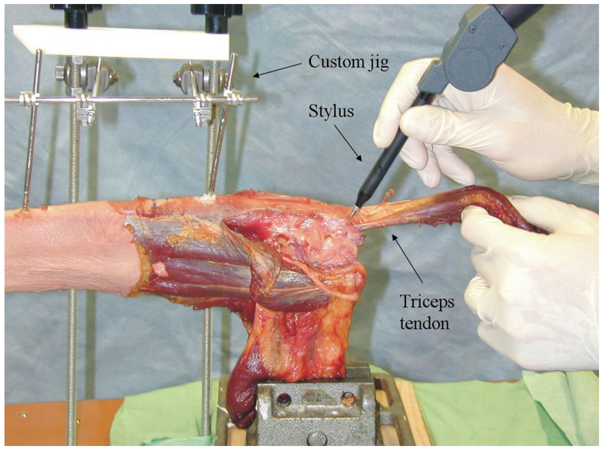

Figure 1 Elbow fixed on custom jig with digitizing stylus (MicroScribe G2X; Immersion Corp, San Jose, CA, USA) mapping triceps tendon insertion.

The attachments and areas of numerous important ligaments, tendons, and bony landmarks about the elbow, including the MCL, LUCL, triceps, biceps, brachialis, and the anterior and posterior capsular reflections, were characterized using the MicroScribe G2X (Immersion Corp, San Jose, CA, USA) digitizing system and the Optotrak Certus system (Northern Digital Inc, Waterloo, ON, Canada). The MicroScribe G2X has a resolution of 0.23 mm and uses a mechanical tracking system to generate 3-dimensional models of physical objects and structures. Specifically, a pen-like stylus extending from a counter-balanced articulated arm unit was used to outline a region or area of interest (Fig. 1). The Optotrak Certus system functions similarly, with a resolution of 0.1 mm, using a hand-held probe.

Mapping was carefully performed for all major elbow soft tissues and bony prominences. The individual ligaments were dissected out, and the surface area of each was calculated. A large portion of the footprints could be mapped in this position, but for the complete footprint to be characterized, the proximal muscle belly (for tendons) and midportion of the ligaments were sectioned to allow retraction of the soft tissue structure to accurately map the underside of the footprint. With the elbow rigidly fixed proximally and distally, no elbow subluxation was permitted, even after ligamentous sectioning. Each measurement was performed 4 times by the same investigator.

A host computer calculated the position of the stylus in space, and input from the digitizers was analyzed using Rhinoceros 3.0 nonuniform rational basis spline modeling software (McNeel & Assoc, Seattle, WA, USA). A digital image of each elbow specimen was generated, and dimensional features (eg, surface area, length, origin and insertional footprint, and position of footprint relative to bony landmarks) of various structures were calculated from this data. A representative 3-dimensional model is illustrated in Figure 2.

Statistical analyses were performed with SPSS 16.0.1 software (SPSS Inc, Chicago, IL, USA). Mean differences and 95% confidence intervals were calculated, and all comparisons were made with the Mann-Whitney U test. All P values are 2-tailed, with $P < .05$ indicating significance.