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Reinvestigation of the Morphological Characteristics of the Lateral Ulnar Collateral Ligament in Humans

By

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Summary: To clarify the cause of posterolateral rotatory instability after damage to the lateral ulnar collateral ligament (LUCL), the morphological characteristics of the LUCL were reinvestigated and three-dimensional (3D) image of the ligament was reconstructed using 35 human elbows. The results were as follows: 1) the insertion point of the LUCL on the humerus was almost at the center of the capitellum, and its width was 2.61 ± 1.02 mm. The insertion point of the LUCL on the ulna was located from the lesser sigmoid notch to the supinator crest and had a width of 9.0 ± 2.8 mm. The proximal insertion of the LUCL on the ulna was 7.0 ± 3.0 mm, and the distal part was on the articular surface of the radial head. 2) Three-dimensional imaging of the LUCL revealed an anterior curved shape that covered the radial head. Based on these results, it was clear that both the supinator crest and the lesser sigmoid notch could be useful as osseous landmarks. We think that these anatomical results are useful for surgeons performing LUCL reconstruction.

Introduction

Based on textbooks and other reports in the literature, the lateral collateral ligament (LCL) complex of the elbow joint consists of four components: the lateral ulnar collateral ligament (LUCL), annular ligament (AL), radial collateral ligament (RCL), and accessory collateral ligament (ACL)[1)]. The primary functions of the complex are to restrain varus and rotational articulations[2)] and to stabilize the structure between ulnohumeral and radiocapitellar articulations[3, 4)]. The LUCL adheres to both the lateral epicondyle of the humerus (blending with the fibers of the AL) and the supinator crest of the ulna[5)], and it plays a major role in providing restraint to control posterolateral stability[5, 6)].

Disruption of the LCL complex often results from elbow dislocation, some mechanism that induces axial compressive valgus, or supination forces of the elbow joint[1, 6)]. It has also been reported that injuries to the entire LCL complex can cause varus-valgus laxity and rotational instability, which allows the proximal radius and ulna to rotate externally and posterior to the distal humerus[1, 7, 8)]. In particular, the LUCL is considered to play the primary role against posterolateral rotatory instability (PLRI), which was first described by O'Driscoll et al.[6)]. Although PLRI is related to injury of the LCL complex, it has not been treated effectively; therefore, surgical treatment for PLRI seems appropriate[2)]. Recently, various surgical techniques for repair, reattachment, or reconstruction for severe PLRI have been reported[9–11)]. On the other hand, several studies have shown that reconstruction of the LUCL, such as using tunnels placed in the lateral humeral condyle and the supinator crest of the ulna with tendon grafting, is considerably effective for restoring its stability[2, 9, 12)]. Moreover, biomechanical studies have also indicated that there are no perfectly isometric points along the humerus or ulna for LUCL reconstruction[13–15)].

With respect to the appropriate clinical treatment for PLRI, we think that clarifying the anatomical characteristics of the LUCL is useful for determining successful surgical reconstructions. Thus, the attachment parts of the LUCL and its running routes were reinvestigated, and the related osseous landmarks were reproduced with three-di-

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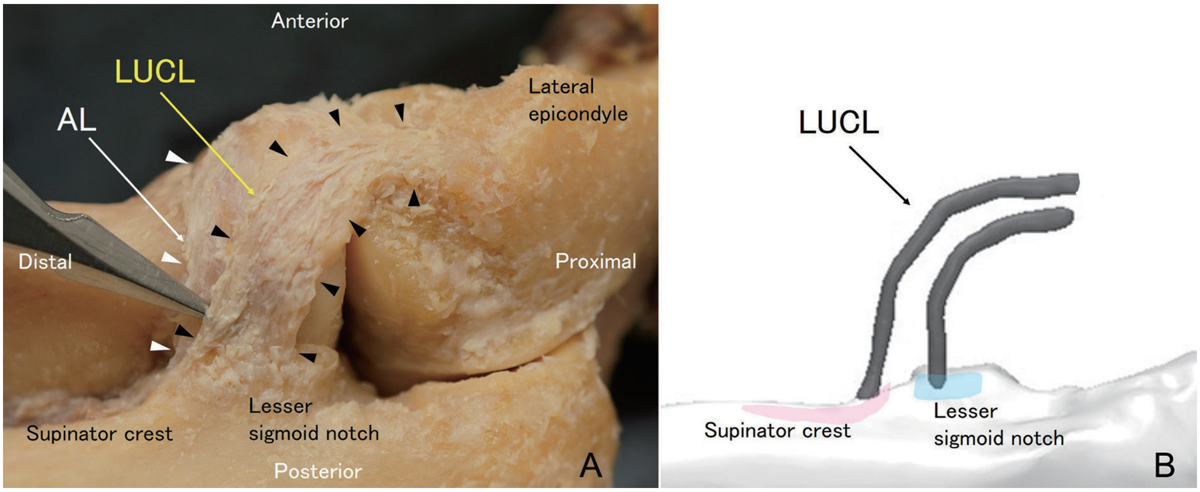

Fig. 1. Macroscopic findings on the posterolateral view of the left elbow showing the insertions and running route of the lateral ulnar collateral ligament (LUCL). A: The LUCL (yellow long arrow) originates from the anterior edge of the lateral epicondyle and inserts to the ulna. The black arrow heads show the outline of the LUCL, and the white arrow heads show the distal edge of the annular ligament (white long arrow), which is separated from the LUCL. B: Three-dimensional imaging on the posterolateral view of the elbow showing the LUCL outlined by soft steel wires. On the ulna, the insertion of the distal edge of the LUCL is located on the supinator crest (pink color area), and the proximal edge is located on the lesser sigmoid notch (blue color area).

mensional (3D) imaging.

Materials and Methods

For this investigation, 35 upper limbs from human cadavers were used (from 18 men and 17 women; their ages ranged from 60 to 97 years). All specimens were fixed with 10% formalin and had been preserved in 50% alcohol for 6 months. These cadavers were donated to our institute for education and research purposes, and this study was approved by the ethics committee of Iwate Medical University (No: H27-106).

With the gross dissection method, the skin and subcutaneous tissues of the elbow were removed to expose the extensor muscle groups on the lateral epicondyle, and the dissection focus was the differences in ulnar insertion between the LUCL and the AL. After removing the extensor muscle groups and supinator, the joint capsule and LCL complex were exposed. The joint capsule was carefully separated from the LCL fibers through the supinator crest to the lateral epicondyle, and the outlines of the LUCL were observed. The LUCL was blended to the AL at the ulnar side and to the RCL at the humeral side. The LUCL was distinguished from the AL to confirm its insertion. As shown in Fig. 1, the insertion of the LUCL at the ulna was more superficial and proximal than that of the AL, and it was clear that the LUCL could be recognized based on the fibers running from the ulna to the lateral epicondyle.

After dissection, the elbow joints were then flexed at 45°, an intermediate position in supination/pronation. The outlines of the LUCL were carefully marked with soft stainless wire with a diameter of 0.3 mm using adhesive.

3D visualization and measurements

The elbows were scanned with the joint flexed at 45° and in a neutral position using a 16-row multislice computed tomography scanner (ECLOS; Hitachi Medical Corporation, Tokyo, Japan). Axial plane imaging with 0.5-mm slices were obtained and saved as DICOM (Digital Imaging and Communications in Medicine) data. All digital imaging data were transferred to a dedicated software program (Mimics version 15.0 and MedCAD module; Materialise N.V., Belgium), and 3D images of the LUCL were created. The LUCL and its related osseous landmarks were analyzed using the 3D imaging. By using the imaging with the above-mentioned software, the insertions and running routes of the LUCL were observed and calculated as follows (values are given as mean ± standard deviation):

Measurements of the LUCL insertion at the humerus

The center of the humeral insertion of the LUCL was defined as the mid-point between the proximal and distal ends of the LUCL and was measured on the true lateral view (Fig. 2). With the dedicated software in transparent mode (MODE: Toggle Transparency), the 3D images were set so that the axis of rotation of the lateral condyle and the medial condyle would fully coincide. These images were projected onto a two-dimensional view, and a true lateral view was created. The coordinates of

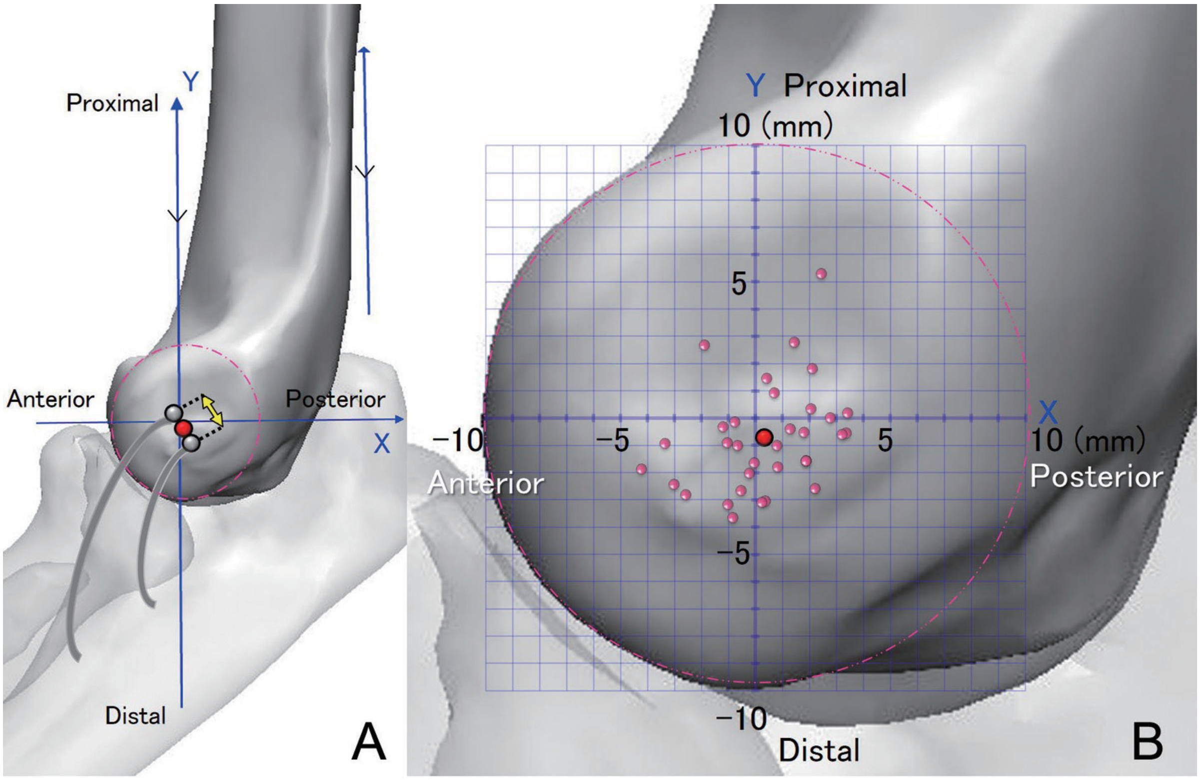

Fig. 2. Three-dimensional imaging of a true lateral view of the left elbow showing a marked outline of the lateral ulnar collateral ligament (LUCL). A: The center of the humeral insertion of the LUCL is defined as the mid-point (indicated by the red point) between the proximal and distal ends of the LUCL (indicated by the gray points). The yellow arrow indicates the width of the ulnar insertion of the LUCL. B: The origin of the coordinates is set at the center of the circle. The Y-axis (the proximal-distal line) is set parallel to the long axis of the humerus. The centers of the humeral insertion of the LUCL are plotted, and the red dot indicates the mean position.

the center of the humeral insertion of the LUCL were plotted in a circle in the true lateral view. The widths of the LUCL insertions at the humerus were also measured.

Measurements of the running route of the LUCL at the radial head

The true horizontal view was defined as the plane vertical to the true lateral view and horizontal to the articular surface of the radial head (Fig. 3). The locations of the LUCL attachment to the AL were measured on the true horizontal plane at the radial head border. In this plane, the radial head could be considered as a circle; each proximal and distal soft steel wire was shown as two points. These two points, which indicated the locations of the running route of the LUCL at the radial head border, were calculated as angles.

Measurements of the LUCL insertion at the ulna and its related structures

On the true lateral view, the widths of the LUCL insertions at the ulna were measured (Fig. 3). The distance between the LUCL insertion at the ulna and the radial head border was also measured.

The accuracy of the length and area measurements was < 0.1 mm and 0.1 mm^2, respectively. When comparing the accuracy of the 3D models generated from computed tomography data with the optical scan, the average error was 0.2 ± 0.31 mm or around one-third of the pixel size[16].

Results

Macroscopic findings

The LUCL was clearly identified in 33 of the 35 elbows (appearance rate: 94.3%) (Fig. 1, 2 and 3). The LUCL originated from the anterior edge of the lateral epicondyle and inserted from the lesser sigmoid notch to the supinator crest with increasing width. On the other hand, the lateral epicondyle, the radial head, and supinator crest were easily palpable as osseous landmarks in all elbows.

Three-dimensional visualization and measurements

The LUCL formed an anteriorly curved shape and covered the radial head like a hammock in the 3D images

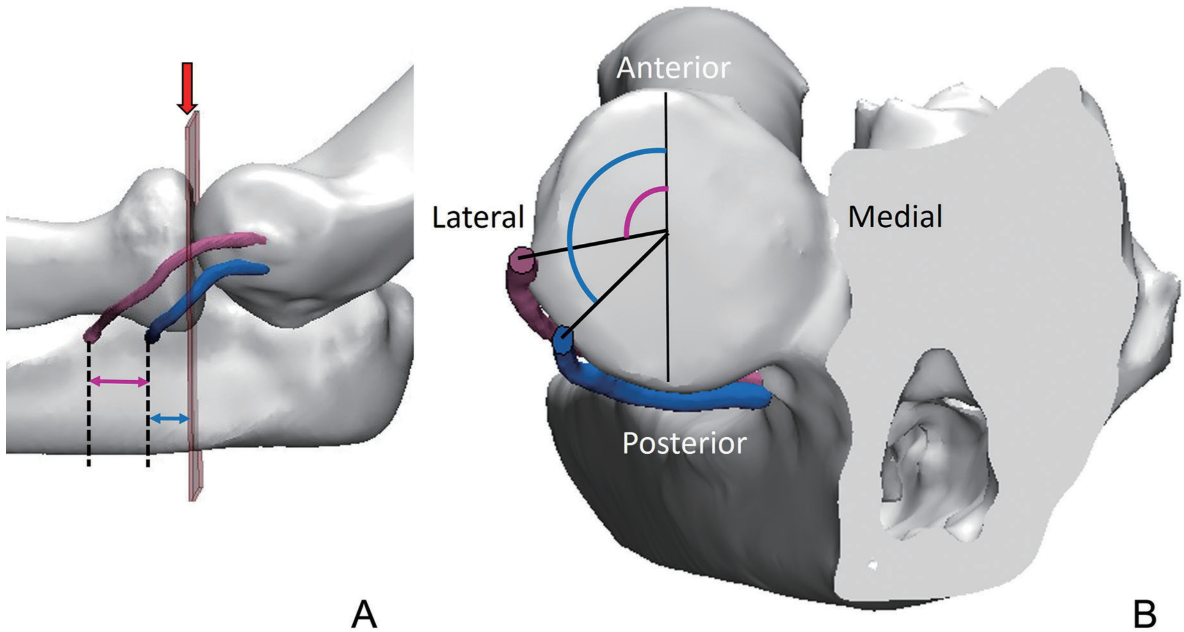

Fig. 3. Three-dimensional imaging showing the insertion of the lateral ulnar collateral ligament (LUCL) on the ulna. A: The left elbow on a true lateral view. The LUCL is outlined by the soft steel wire. The longer pink arrow indicates the width of the LUCL insertion at the ulna, whereas the blue arrow indicates the distance between the proximal end of the LUCL insertion at the ulna and the radial head border. B: The radial head border on the true horizontal view at the level of the red arrow in A. It is clear that the anterior edge of the LUCL is at the 9 o'clock position and the posterior edge is at the 8 o'clock position. The arches indicate the angles of the location of each proximal and distal edge of the LUCL at the radial head border.

(Fig. 3). In the ulna, the distal part of the LUCL insertion was located on the supinator crest, and the proximal part of the LUCL was located on the lesser sigmoid notch that consisted of the radioulnar joint (Fig. 1). The radial head and supinator crest were easily identified; however, the apex of the lateral epicondyle was not clearly identified because it was ridge-shaped in the 3D images. The shapes of the lesser sigmoid notch were varied because of spur formation and the individual differences among elbows.

(1) Measurements of the LUCL insertion at the humerus

The center of the insertion of the LUCL at the humerus was 0.37 ± 2.33 mm (range: −4.22 to 3.4 mm) posterior and 0.75 ± 2.21 mm (−3.65 to 5.29 mm) distal from the center of the capitellum (Fig. 2). The width of the LUCL insertion at the humerus was 2.61 ± 1.02 mm (0.78 to 4.61 mm).

(2) Measurements of the running route of the LUCL at the radial head

In the horizontal plane, the LUCL was located on the radial head at 99.5 ± 10.3° (80.7–122.1°) to 126.1 ± 12.4° (99.0–151.1°) (Fig. 3B).

(3) Measurements of the LUCL insertion at the ulna and its related structures

The width of the LUCL at the ulnar insertion was 9.0 ± 2.8 mm (4.2–15.1 mm). The proximal end of the LUCL insertion at the ulna was 7.0 ± 3.0 mm (1.6–13.4 mm) distal to the articular surface of the radial head border (Fig. 3A).

Discussion

There are various descriptions regarding LUCL insertions. Morrey et al. have mentioned that the axis of elbow motion passes though the center of the capitellum using the biomechanical method[17]. It was also mentioned that the humeral insertion should be located at the center of the capitellum for LUCL reconstruction[11, 13]. The current study revealed that the humerus insertion of the LUCL was located at nearly the center of the capitellum on 3D imaging, and these findings are agreement with those of previous studies and reports on LUCL reconstruction[11, 13].

The insertion on the radius in the present study showed that the LUCL ran along the radial head and attached to the AL at approximately 99° to 126° and had approximately an 8 to 9 o'clock position at the radial head. O'Driscoll et al. reported that the LUCL arches over the AL and the radial head to reach the ulna[5]. Using magnetic resonance imaging, Schaeffeler et al. showed that the running route of the LUCL forms a sling for the radial head on the coronal view[18]. However, in the present study, the positional relationship between the LUCL and the radial head were clear with 3D imaging. Because the LUCL was attached to the AL, it could be thought the LUCL protects the radial head like a hammock, and thus the radial head and the ulna to prevent its subluxation; it is considered to be the principal constraint of the elbow joint against PLRI[6, 17, 19, 20].

In the literature on the insertion on the ulna, numerous studies have reported that the insertion of the LUCL was located at the supinator crest[5, 17]; however, a few studies pointed out that the relationship between the LUCL and the lesser sigmoid notch were also important[3, 19]. In this study, the LUCL insertion at the ulna was found to be attached from the lesser sigmoid notch to the supinator crest, and the proximal end of the LUCL insertion was located approximately 7.0 mm distal to the radial head border, showing that both the supinator crest and the lesser sigmoid notch could be useful as osseous landmarks.

For reconstruction of the LUCL, single- or double-bone tunnel techniques are usually performed at the ulna. In biomechanical studies, the tunnel should be placed 16–20 mm distal to the radial head[1, 2, 10, 14, 19, 21–24]. On the other hand, Cohen et al. suggested that the two bone tunnels should be placed at the proximal margin of the radial head and 15–20 mm distal to it[25]. The present study described detailed anatomical data of the size of the LUCL insertion firstly, and showed that the LUCL was inserted at a width of 9 mm at the ulna. Therefore, we believe that if it is difficult to use the single-tunnel technique to cover all of the insertion, then the double-tunnel technique would be a more appropriate procedure. On this point, the present findings are very useful for surgeons in the reconstruction of the LUCL[23].

Conclusion

1. The morphological characteristics of the LUCL were reinvestigated using anatomical methods and three-dimensional imaging.
2. The related osseous landmarks to be used for the reconstruction of the LUCL were provided based on the details of our anatomical data.

Acknowledgments

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