Diagn Interv Radiol 2019; 25:473–479

MUSCULOSKELETAL IMAGING

ORIGINAL ARTICLE

The radial and ulnar collateral ligaments of the wrist are true ligaments

Tolga Türker
Joseph E. Sheppard
Andrea S. Klauser
Stephen S. Johnston
Helen Amerongen
Mihra S. Taljanovic

PURPOSE
Our hypothesis in this study is that the radial and ulnar collateral ligaments of the wrist exist and are true ligaments which can be visualized by high-resolution ultrasonography (US).

METHODS
High-resolution US examination of the radial and ulnar collateral ligaments of the wrist was performed on 56 fresh cadaveric wrists. The visibility of these ligaments was assessed by four observers who classified the ligaments in consensus as well seen, adequately seen, or not seen. Surgical dissections of 12 radial collateral ligaments and 12 ulnar collateral ligaments were then performed and the ligaments were classified as present or absent. The US and dissection results were then compared. To confirm that the dissected structures represent true ligaments a histologic examination of the ligaments was performed.

RESULTS
All examined radial and ulnar collateral ligaments were seen on the US examination. The radial collateral ligament was seen between the radial styloid and radial aspect of the scaphoid. The ulnar collateral ligament was seen between ulnar styloid process and the triquetrum. On all surgical dissections, the radial collateral ligament was present at the floor of the first extensor compartment and the ulnar collateral ligament was at the floor of the sixth extensor compartment. Both ligaments were proven to be true capsular ligaments on both dissection and histologic examinations.

CONCLUSION
The radial and ulnar collateral ligaments of the wrist are true ligaments and can be seen at the floor of the first and the sixth extensor compartments, respectively, using high-resolution US. Based on their anatomic location, they most likely provide static stability to the wrist joint.

From the Departments of Orthopedics (T.T. ✉ *drtolgaturker@gmail.com*, J.E.S.) and Cellular and Molecular Medicine (H.A.) and Medical Imaging (M.S.T.), Arizona University School of Medicine, AZ, USA; Department of Radiology (A.S.K.), Division of Rheumatology and Sports Imaging, Medical University Innsbruck, Innsbruck, Austria; Consultant Radiologist (S.S.J.), Arizona State Radiology, AZ, USA.

Received 22 January 2019; revision requested 23 February 2019; last revision received 19 March 2019; accepted 30 March 2019.

Published online 19 September 2019.

DOI 10.5152/dir.2019.19036

The wrist has several ligaments that are mainly responsible for guiding and constraining the joint (1). It is commonly agreed that wrist ligaments can be classified as either intrinsic ligaments, which bind the carpal bones within the joint while allowing them to move in a complex motion, or extrinsic ligaments, which are mainly placed within or in very close relation to the joint capsule and provide more structural support (1–3). The extrinsic wrist ligaments originate from the distal radius, ulna, or triangular fibrocartilage complex.

Even though the classic anatomy textbooks mention the radial collateral ligament (RCL) and ulnar collateral ligament (UCL), there is still disagreement regarding existence of some extrinsic ligaments such as the RCL and especially the UCL (4–8). Berger mentioned that according to Taleisnik, the ligamentous anatomy does not change, only our descriptions of anatomy change (1). Hence, we hypothesized that the RCL and UCL exist and are true ligaments and represent the floor of the first extensor compartment for the RCL and the floor of the sixth extensor compartment for the UCL. In this study, we investigate origins and attachments of both collateral ligaments of the wrist in cadaveric dissections, their histologic properties, and their appearance on high-resolution ultrasonography (US) examination.

You may cite this article as: Türker T, Sheppard JE, Klauser AS, Johnston SS, Amerongen H, Taljanovic MS. The radial and ulnar collateral ligaments of the wrist are true ligaments. Diagn Interv Radiol 2019; 25:473–479.

Methods

This research was conducted according to the principles of the World Medical Association Declaration of Helsinki "Ethical Principles for Medical Research Involving Human Subjects", (amended in October 2013). RCL and UCL were evaluated in 56 wrists of 28 adult fresh frozen cadavers with US studies. No information about specimens such as age of donors, soft tissue disorder or trauma history was available.

Ultrasonography

High-resolution US examination was performed on a General Electric Logiq 9 US machine using a 9–12 MHz linear hockey stick transducer by a fellowship trained musculoskeletal radiologist with over 15 years of experience in musculoskeletal US. To accommodate the depth, a copious amount of US gel was applied on both the radial and ulnar aspect of all 56 examined wrist joints (28 right and 28 left). The RCL was scanned with the wrist in pronation with or without ulnar deviation from the first compartment (Fig. 1). The UCL was scanned with the wrist in pronation with or without radial deviation using the extensor carpi ulnaris (ECU) tendon as an acoustic window via the sixth compartment (Fig 2). Radial deviation may improve the visualization of the UCL by stretching it. Similarly, ulnar deviation of the wrist frequently improves the visualization of the RCL. Both ligaments were examined primarily in their longitudinal axes and the representative images were recorded. The visibility of these ligaments was assessed by the examiner and three additional observers (senior surgery resident, chief ultrasound technologist, and a medical student) in consensus. All observers were present for the real-time US examination at which time the visibility of the ligaments was assessed simultaneously. The ligaments were considered to exist if they were seen as echogenic bands and/or fibrillar structures on US images (9, 10). On the US images the ligaments were classified as: well seen (with excellent visualization of their fibers); adequately seen (with clear visualization of their fibers but no superb images obtained, mainly due to rigidity of cadaveric specimens); or not seen (with non-visualization of their fibers).

Main points

- Radial and ulnar collateral ligaments of the wrist are true ligaments.
- The ligaments could be visualized with a high-resolution ultrasound, therefore their pathologies could be identified.
- Based on the ligaments locations, they could provide stability to the wrist joint.

Anatomical dissections

After US studies were performed, a random set of 12 out of 56 wrists wrists (12 RCLs and 12 UCLs) with their surrounding relationships were dissected by a hand sur-

Figure 1. All ligaments in cadavers were evaluated using 9-12 MHz linear hockey stick transducer. Different higher frequency linear transducer of 8-18 MHz was used in a volunteer to demonstrate ultrasound probe placement for imaging of the radial collateral ligament.

Figure 2. All ligaments in cadavers were evaluated using 9-12 MHz linear hockey stick transducer. Different higher frequency linear transducer of 8-18 MHz was used in a volunteer to demonstrate ultrasound probe placement for imaging of the ulnar collateral ligament.

geon who was blinded to the US findings. Dorsal incisions were performed and the extensor tendons were removed from the second, third, fourth, and fifth compartments. The first and the sixth compartment extensor tendons were kept intact. Meticulous dissections were performed at both radial and ulnar aspects of the wrist joints. First, the RCL and UCL structures were cataloged as present or absent.

After all dissections were performed, one RCL and one UCL samples were removed *en bloc* with surrounding tendinous structures and transferred to the histology lab for light microscope studies.

Data obtained from the surgical specimens were compared with the data obtained by US study.

Histologic study

Cadaver #18 was used for histology study. RCL and UCL tissues were harvested and washed with phosphate-buffered saline then placed in 10% neutral-buffered formalin for 24 hours for fixation. Immediately after fixation the specimens were dehydrated by placing in 25%, 50%, and 70% ethanol solutions for two hours each. Following dehydration, the specimens were cut in half and taken to histology for routine paraffin embedding and sectioning. Sections were stained with hematoxylin and eosin (H&E), Verhoeff's-Van Gieson (VVG) stain for elastic fibers, or mouse anti-Type I collagen visualized with fluorescein-tagged goat anti-mouse secondary antibody. A negative control was run in parallel by omitting the primary antibody. The ulnotriquetral ligament served as a positive control for all three types of staining. Within the VVG-stained sections, staining of elastic structures at the expected locations within blood vessels served as a positive internal control for elastic fiber staining.

Results

On US images all RCLs were seen in their anatomic locations between the radial styloid and radial aspect of the scaphoid, dorsal to the radial artery and deep and somewhat dorsal to the first extensor compartment. All RCLs had an echogenic fibrillar appearance (Fig. 3). All UCLs had an appearance of a thick echogenic and sometimes fibrillar band and were seen between the ulnar styloid process and triquetrum abutting the deep aspect of the sixth extensor compartment (Fig. 4). In 9 cadavers, 18 right and left RCLs were well seen and in the remaining 19 cadavers they were adequately seen. In 8 cadavers, 16 right and left UCLs were well seen and in the remaining 20 cadavers they were adequately seen.

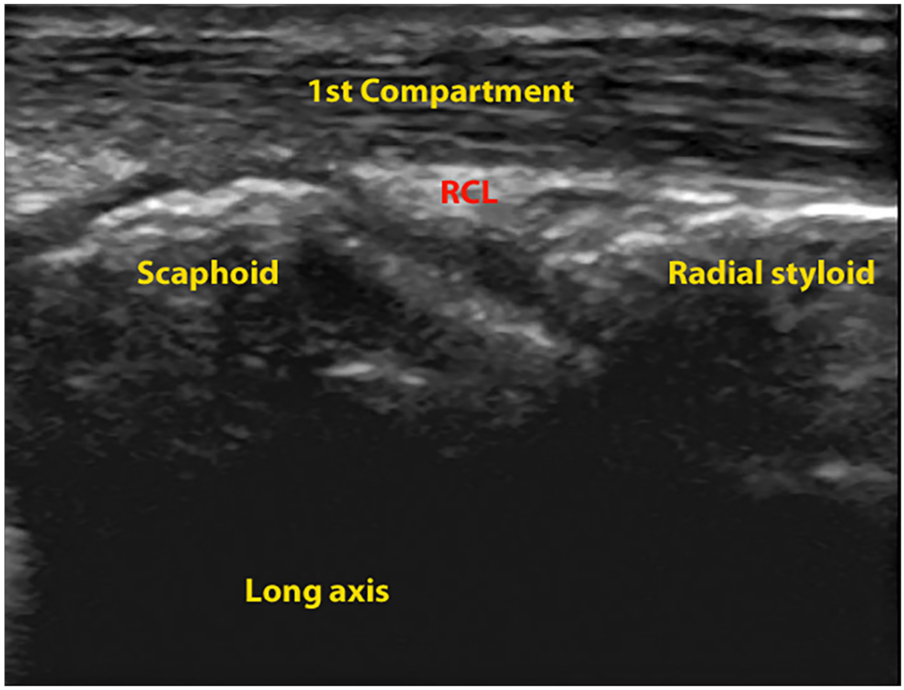

Figure 3. Longitudinal axis of US image of the right radial collateral ligament (RCL), which has fibrillar echogenic appearance. This ligament is seen connecting the radial styloid and scaphoid, deep to the first extensor compartment tendons.

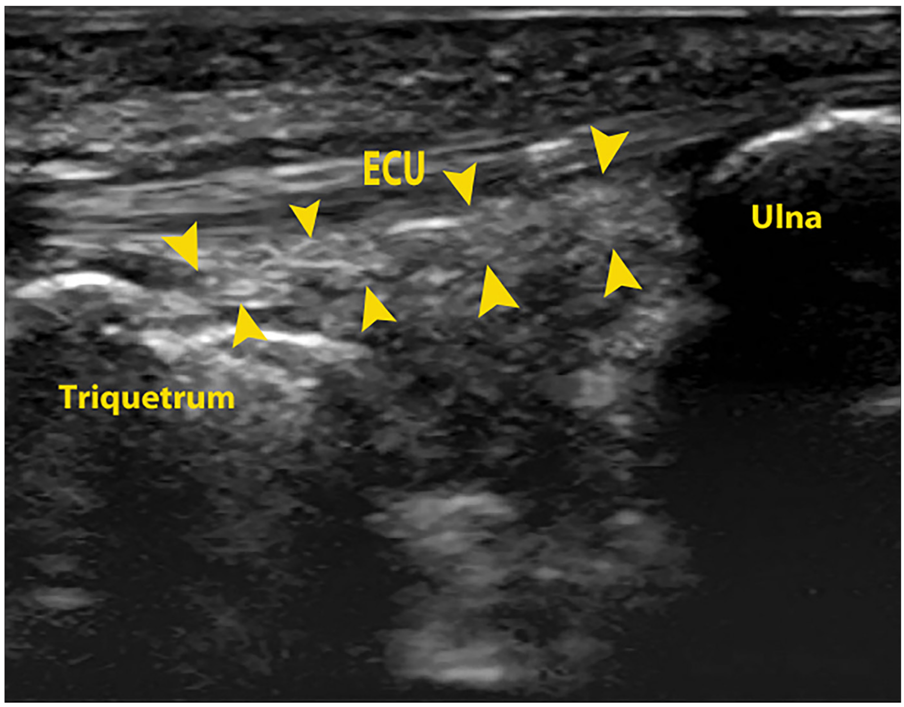

Figure 4. Longitudinal axis of US image of the left ulnar collateral ligament of the wrist. The *arrowheads* are pointing to the superficial and deep borders of the ligament which has the appearance of an echogenic and somewhat fibrillar band. This ligament is seen between the ulnar styloid and triquetrum, deep to the sixth extensor compartment. ECU, extensor carpi ulnaris tendon.

Both the RCL and UCL were shown in the dissections in all specimens. The RCL was a fan-shaped structure and it was found at the floor of the first extensor compartment underneath the abductor pollicis longus (APL)

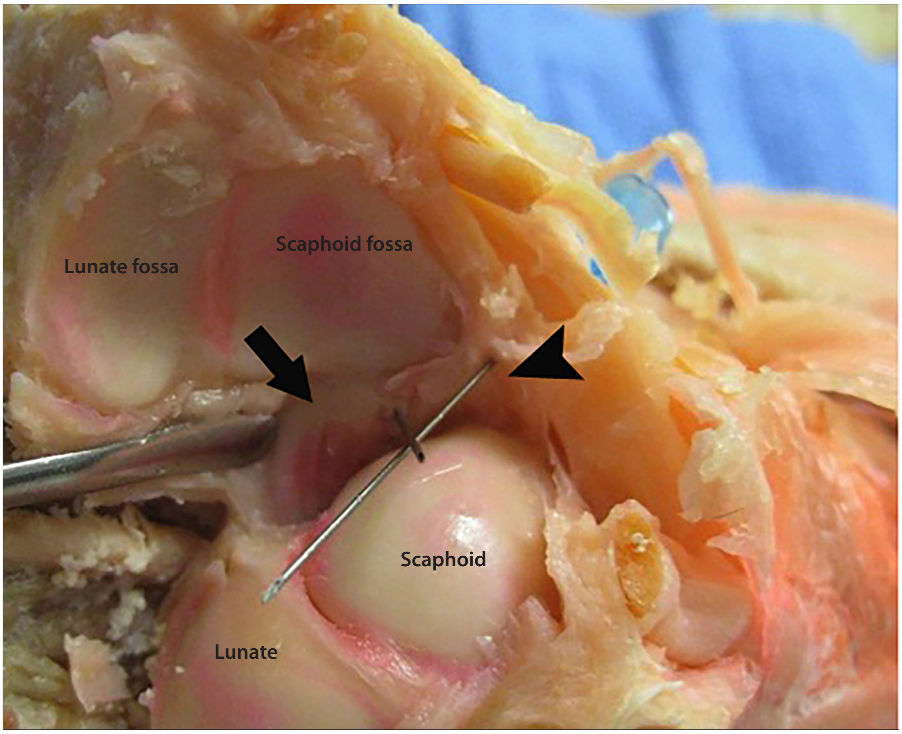

Figure 5. Cadaveric dissection of the radial collateral ligament *(arrowhead)*. Please note that the needle on the right, next to the *arrowhead* pierces the ligament. The *arrow* points the radioscaphocapitate ligament which was pierced by the needle on the left.

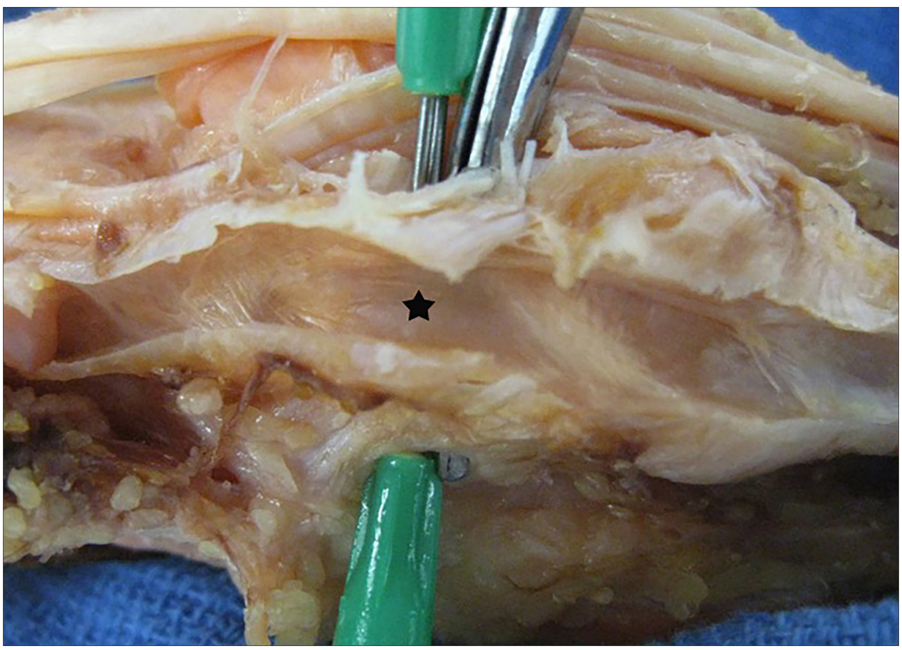

Figure 6. Cadaveric dissection of the ulnar collateral ligament *(star)*. Please note that the extensor carpi ulnaris tendon was removed.

and extensor pollicis brevis (EPB) tendons (Fig. 5). The UCL was found at the floor of the sixth extensor compartment below the ECU tendon (Fig. 6). Both, the RCL and UCL were within the joint capsule, therefore, they are classified as extrinsic wrist ligaments.

H&E and VVG stained sections of the presumptive RCLs and UCLs showed the presence of dense fibrous structures composed primarily of collagen fiber bundles (Fig. 7). Immunohistochemical staining of both RCL and UCL was positive for Type I collagen thus confirming ligamentous structures by this method. VVG stained sections revealed sparse elastic fibers distributed among collagen fiber bundles.

Organization of the radial and ulnar collateral ligamentous tissue is varied. In both structures, the predominant impression was of densely-packed undulating collagen fibers aligned in parallel within major bundles. Both ligaments also included areas of more loosely-packed interlaced collagen fiber bundles, and these looser areas carried more prominent vasculature. In both ligaments synovial membrane was apparent along at least one surface.

Discussion

Understanding the anatomy and function of the complex ligamentous structures of the wrist joint is important to treat traumatic and pathologic conditions. The current literature is inconsistent in the description of the RCL and UCL of the wrist and some authors even question their existence (5–8). Our study, based on cadaveric dissections, demonstrated that both the radial and the ulnar collateral ligaments of the wrist are true anatomical structures and their ligamentous composition is also demonstrated histologically. Both ligaments can be visualized at the floor of the first and sixth extensor compartments respectively on US examination.

A ligament can be considered as such based on either its mechanical assets or histologic organization or both (1). A ligament is a connection between two skeletal structures; therefore any substance that connects two structures can be called a ligament (1). On the other hand, a ligament can also be identified through its histologic organization. A ligament consists of relatively parallel groups of densely packed and highly organized collagen fibers, organized into bundles or fascicles. Fascicles are surrounded by poorly organized connective tissue, the perifascicular space. A capsular ligament has two surfaces: a) superficial surface, capsular side and b) deep surface, articular side. The superficial surface has flat sheets of collagen organized as "stacked" from the fibrous stratum of the epiligamentous sheath. On the deep part, the epiligamentous sheath is lined with one or two layers of cuboidal cells, the synoviocytes. If a ligament is a true intra-articular structure, it is completely covered with synovium, whereas capsular ligaments have synovi-

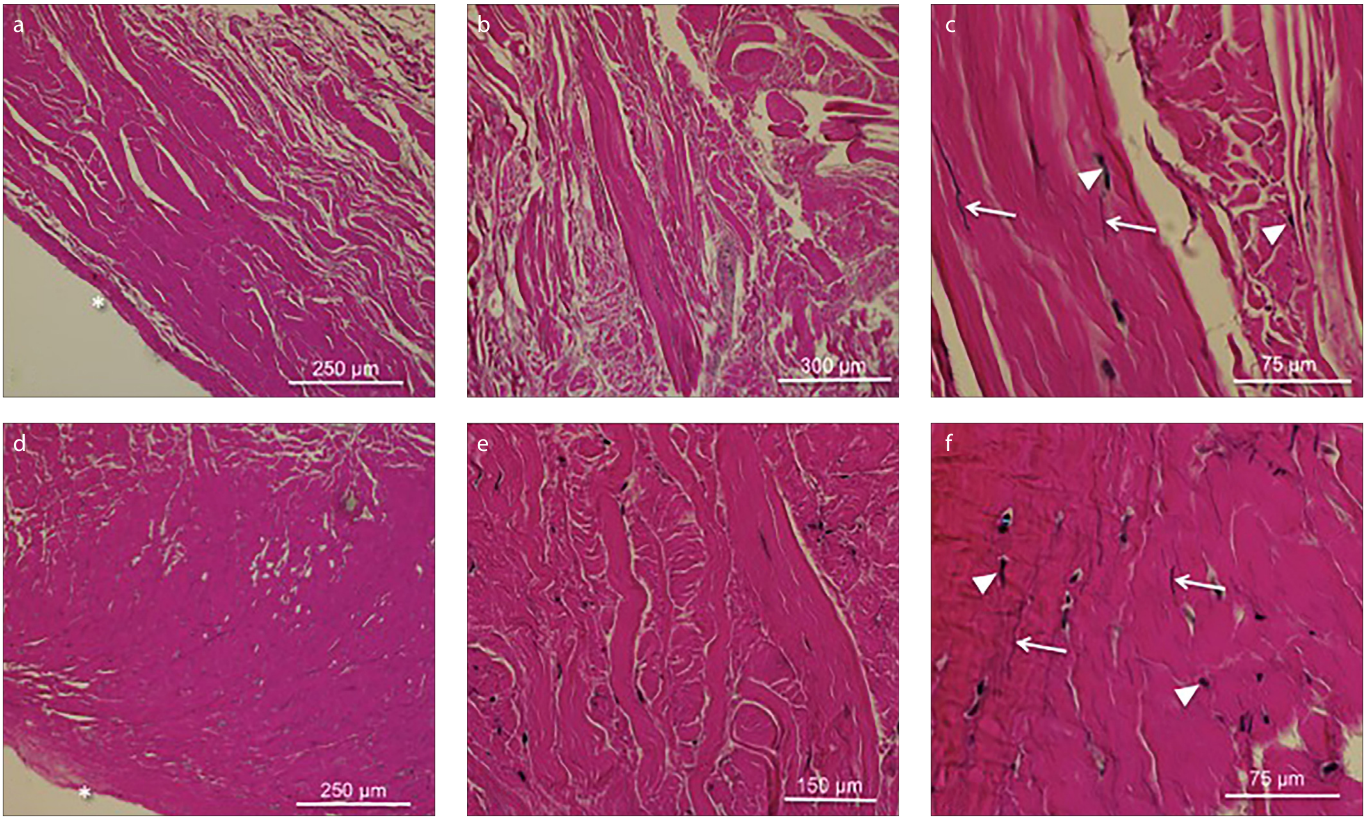

Figure 7. a–f. Histologic sections of the ligament in H&E stain: **(a–c)**, ulnar collateral ligament; **(d–f)**, radial collateral ligament. Synovium *(asterisk)*, fibrocyte/fibroblast nucleus *(arrowhead)*, and elastic fiber *(arrow)* are shown.

um on their joint surface only (11). Our histology specimens in both UCLs and RCLs showed flat collagen sheets on the superficial side and collagen bundles on the deep side covered by synovial lining, therefore both histology samples support that these structures are true capsular ligaments.

There is still some disagreement about the existence of the RCL of the wrist, and even if it does exist, there is argument about the location of its origin, its distal attachment, and also its distinctiveness (1, 8, 12, 13). In their magnetic resonance imaging (MRI) study in 15 cadaveric wrists and 15 wrists of patients, Totterman et al. (2) described the collateral ligament which originates from the radial styloid to the scaphoid bone as the radioscaphocapitate (RSC) ligament. Zumstein et al. (8), in their cadaveric study, pointed out that the RSC ligament has a broad origin at the dorsal aspect of the radial styloid to the volar radial corner of the distal radius, therefore, their dissection did not reveal a separate RCL. In fact, as they described it, the RSC ligament emerges from the place where the RCL is supposed to originate in our study. Additionally, in their cadaveric study, Viegas et al. (14) did not describe the RCL, and showed the RSC ligament on the volar radial rim of the radius. Interestingly, in contrast to Zumstein's study (8), the tip of the radial styloid is shown unoccupied in Viegas's work. Boutry et al. (15) performed US evaluation of the normal intrinsic and extrinsic wrist ligaments in 30 volunteers using 12 MHz linear–array transducers in 15 asymptomatic volunteers. In this study, the RCLs were completely visible only in 12% and partially visible in 18% of subjects, with an average thickness of 2.2 mm. However, the RSC ligament was seen in 100% of subjects, with an average thickness of 2.5 mm. It could be argued that since the authors were able to show the RSC on US studies in all subjects, but incompletely visualize the RCLs, the RCL may be part of the radial side of the RSC. Kleinman (16) mentions the RCL in one of the illustrations in his review article about the distal radioulnar joint. However, there is no reference that substantiates the existence of the RCL in this article. Feipel and Rooze's cadaveric dissections also did not reveal the presence of a RCL; however, the authors described the radioscaphoid ligament as a fan-shaped ligament that originates from the radial styloid to the scaphoid (6). North et al. (17), in their cadaveric study, concluded that the RCL, which is called radioscaphoid ligament, is not a true ligament but extends from the palmar aspect of the radial styloid to the scaphoid. Despite all the skeptics, in their MRI study, Ringler et al. (18) visualized the collateral ligaments of the wrist and described the RCL as a thin low signal intensity linear structure running from the radial styloid to the radial side of the scaphoid. Mayfield et al. (19), in their cadaveric study of 28 wrists, revealed that each wrist had the RCL. Berger (1, 5, 20, 21), who performed the comprehensive anatomical studies of the wrist joint, used the name "radial collateral ligament" but described it as one of the three major components of the RSC: radial collateral, radioscaphoid, and radiocapitate ligaments. Magnetic resonance arthrogram study of 22 fresh human cadaveric wrists by Theumann et al. (22) and US study of both wrists in 18 healthy volunteers with mangnetic resonance arthrography correlation in 10 subjects by Lacelli et al. (23) showed clearly that the RCL of the wrist exists, and extends from the radial side of the radial styloid to the scaphoid. However, unlike in Berger's study, in these two studies, the RCL was described as a separate anatomical structure (22, 23). Mizuseki and Ikuta (24), in their cadaveric study, reveal that the RCL is a broad ligament that starts from the radial side of the dorsal radiocarpal ligament and blends with the scaphotriquetrum ligament. These authors claim that there is a distinctive margin between the RSC ligament and the RCL (24). In light of the discussion above and our previous work by Taljanovic et al. (25, 26) on wrist ligaments using high-resolution US and 3 Tesla MRI, the RCL should be considered a different ligament than the RSC. Our study confirmed that the RCL ligament of the wrist, which originates at the radial tip of the radial styloid, spans the radiocarpal joint as a fan-shaped structure, and attaches to the radial aspect of the scaphoid bone, is a separate structure from the RSC ligament. In this study, we showed that the RCL exists at the floor of the first dorsal extensor compartment and can be visualized through this window using high-resolutionUS.

There is still some disagreement in the literature about the existence of the UCL of the wrist (5–7). In our study, US images of this ligament correlated with dissections and histologic examination and showed that the UCL is a true ligament. This ligament originates from the tip of the ulnar styloid process and extends to the ulnar side of the triquetrum.

Three ulnocarpal ligaments have been described (1). The palmar ulnolunate and ulnotriquetral ligaments which extend from the volar radioulnar ligament to carpal bones, and the ulnocapitate ligament which extends from the volar aspect of the ulnar head to capitate (1). Besides these ligaments, the ulnomeniscal homolog, which has densely packed collagen fibers, is described in this region between the ulnar styloid and the triquetrum (18). In his study, Berger described only the ulnotriquetral ligament spanning from the distal ulna to the proximal triquetrum. The UCL of the wrist is not mentioned in his study. The ulnocapitate ligament was described as the ulnar anchor of the wrist. The ulnolunate and ulnotriquetral ligaments form the anterior and ulnar aspects of the ulnocarpal joint capsule (1, 20). In his review article, Kleinman (16) also did not mention the UCL of the wrist, but one of the illustrations showed the ligament as originating from the tip of the ulnar styloid process; however the distal attachment was not shown. In the high-resolution US study by Lacelli et al. (23) the UCL was never visualized. Theumann et al. (22) in their magnetic resonance arthrogram study did not show the UCLs of the wrist, but the ulnotriquetral ligaments were seen on the palmar ulnar aspect of the wrist joint. North et al. (17), in their study on 13 cadaveric wrist specimens, concluded that there is a capsular attachment from the distal tip of the styloid process of the ulna to the triquetrum next to the ulnotriquetral ligament. This capsular attachment makes the floor of the ECU tendon. Mizuseki and Ikuta (24), in their cadaveric study, even with careful dissection did not reveal the presence of the UCL of the wrist . This ligament was also not seen in the US study by Boutry et al. (15). Therefore, the authors suggested that the UCL could be considered the ulnar capsular thickening (15). We would expect that if the UCL is only the capsular thickening, it should be seen as a hyperechogenic capsular thickening on the US studies. However, in our study, all UCLs of the wrist were seen as thick echogenic and sometimes fibrillar bands on US examinations and were confirmed to represent true ligaments on surgical dissections and with histologic examination.

Taleisnik (12) described the UCL of the wrist as poorly developed and not more than a capsular thickening between the base of the ulnar styloid process and the triquetrum. One should not confuse the ulnotriquetral ligament with the UCL of the wrist because the ulnotriquetral ligament originates from the volar radioulnar ligament and extends to the triquetrum (1), while the UCL is described as originating from the tip of the ulnar styloid and extending to the ulnar side of the triquetrum. Mayfield et al. (19), in their cadaveric study on 28 wrists, revealed that each subject had UCL, which extends from the ulnar styloid process to the triquetrum. Viegas et al. (14), in their cadaveric study, mention the ulnocarpal ligament, which is described as exactly like the UCL in our study further reflecting the extent of the confusion.

According to our previous experience, the UCL is frequently seen on MRI and US studies and has an appearance of ulnar capsular thickening between the ulnar styloid and triquetrum (25). Based on the results of our study, the UCL is a true ligament which extends from the ulnar styloid process to the triquetrum rather than a capsular thickening and is located deep to the ECU and the sixth dorsal extensor compartment. This finding reminded us of Kauer (27) who stated that the forearm fascia has two layers, superficial and deep. The superficial layer loops around the tendons except the ECU tendon. The deep layer of the fascia strongly attaches to the ulnar styloid making the floor of the ECU tendon and extends to the fifth metacarpal base with significant connections with triangular fibrocartilage complex (27). We believe that the mentioned deep layer of the forearm fascia structure is the UCL. This ligament can also be seen through the sixth extensor compartment and any US detectable traumatic and pathologic conditions can be seen using high-resolution US. There is a similar debate in structure of medial patellofemoral ligament (MPFL). Even though there are some disagreements about the layers of MPFL, its deepest layer is considered to be a part of the joint capsule. We believe that UCL-fascia relation is similar to MPFL-joint capsule relation (28).

Kauer (27) states that the APL with the EPB in the first extensor compartment limit ulnar deviation while the ECU in the sixth extensor compartment limits radial deviation of the wrist. Therefore, they act as dynamic collateral ligaments for the wrist joint. In addition to these dynamic structures, both UCL and RCL of the wrist have densely-packed undulating collagen fibers aligned in parallel within major bundles. Both ligaments have synovial membrane apparent along their undersurface as extrinsic ligaments. They are also located at the radial and ulnar side of the wrist joint at zones of isometry, and gain additional stability from the APL, EPB and ECU tendons. Therefore, one can speculate that since these ligaments are located on each side of the wrist joint with dense parallel collagen fibers, both UCL and RCL may limit excessive radial deviation and ulnar deviation respectively. This study could be supported with a biomechanical study that may better explain their function.

Our study has some limitations. First, although we believe that we performed enough surgical dissections, we did not obtain detailed measurements of the ligaments. We focused on whether the ligaments exist; therefore, we ended the dissection as soon as the ligaments were identified. Second, we could have done more histology sections from each dissected wrist; however, since all the ligamentous structures looked the same macroscopically, we decided that one section from each ligament would be enough to show if the structures were true ligaments. Third, this study could have utilized magnetic resonance images. We decided to use US as an imaging technique for two reasons: a) US has a higher spatial resolution in superficial anatomical structures using a hockey stick probe as we demonstrated in our study, and b) US can be used even in clinical settings with minimal preparation, therefore any injury in the wrist collateral ligaments can be diagnosed in a fast and cost-effective manner. Fourth, because we used cadaver arms to perform this study, soft tissue rigidity might have an effect on the US images. Last, as we mentioned earlier, a biomechanical analysis could be added to the study.

In conclusion, our study demonstrates that the radial and the ulnar collateral ligaments are true ligaments of the wrist joint. These ligaments may have important roles in joint stabilization, especially in radial and ulnar deviations. An US study might be helpful to visualize the ligaments and could be used to rule out injuries in these ligaments after a trauma.

Conflict of interest disclosure

The authors declared no conflicts of interest.

References

1. Berger RA. The anatomy of the ligaments of the wrist and distal radioulnar joints. Clin Orthop Relat R 2001;32–40. [CrossRef]
2. Totterman SM, Miller R, Wasserman B, Blebea JS, Rubens DJ. Intrinsic and extrinsic carpal ligaments: evaluation by three-dimensional Fourier transform MR imaging. AJR Am J Roentgenol 1993; 160:117–123. [CrossRef]
3. Rominger MB, Bernreuter WK, Kenney PJ, Lee DH. MR imaging of anatomy and tears of wrist ligaments. Radiographics 1993; 13:1233–1246. [CrossRef]
4. Platzer W. Color Atlas and Textbook of human Anatomy. Volume 1 Locomotor system. New York: Georg Thieme Verlag Stuttgart; 1992.
5. Berger RA, Landsmeer JM. The palmar radiocarpal ligaments: a study of adult and fetal human wrist joints. J Hand Surg Am 1990; 15:847–854. [CrossRef]
6. Feipel V, Rooze M. The capsular ligaments of the wrist. Eu J Morphol 1997; 35:87–94. [CrossRef]
7. Chen YR, Xie RG, Tang JB. In vivo changes in the lengths of carpal ligaments after mild dorsal angulation of distal radius fractures. J Hand Surg Eur Vol 2015; 40:494–501. [CrossRef]
8. Zumstein MA, Hasan AP, McGuire DT, Eng K, Bain GI. Distal radius attachments of the radiocarpal ligaments: an anatomical study. J Wrist Surg 2013; 2:346–350. [CrossRef]
9. Lee JC, Healy JC. Normal sonographic anatomy of the wrist and hand. Radiographics 2005; 25:1577–1590. [CrossRef]
10. Renoux J, Zeitoun-Eiss D, Brasseur JL. Ultrasonographic study of wrist ligaments: review and new perspectives. Semin Musculoskelet Radiol 2009; 13:55–65. [CrossRef]
11. Canovas F, Ledoux D, Bonnel F. Biometry of the capsular ligaments of the wrist. Chir Main 1998; 17:207–214. [CrossRef]
12. Taleisnik J. The ligaments of the wrist. J Hand Surg Am 1976; 1:110–118. [CrossRef]
13. Siegel DB, Gelberman RH. Radial styloidectomy: an anatomical study with special reference to radiocarpal intracapsular ligamentous morphology. J Hand Surg Am 1991; 16:40–44. [CrossRef]
14. Viegas SF, Patterson RM, Ward K. Extrinsic wrist ligaments in the pathomechanics of ulnar translation instability. J Hand Surg Am 1995; 20:312–318. [CrossRef]
15. Boutry N, Lapegue F, Masi L, Claret A, Demondion X, Cotten A. Ultrasonographic evaluation of normal extrinsic and intrinsic carpal ligaments: preliminary experience. Skeletal Radiol 2005; 34:513–521. [CrossRef]
16. Kleinman WB. Stability of the distal radioulna joint: biomechanics, pathophysiology, physical diagnosis, and restoration of function what we have learned in 25 years. J Hand Surg Am 2007; 32:1086–1106. [CrossRef]
17. North ER, Thomas S. An anatomic guide for arthroscopic visualization of the wrist capsular ligaments. J Hand Surg Am 1988; 13:815–822. [CrossRef]
18. Ringler MD. MRI of wrist ligaments J Hand Surg Am 2013; 38:2034–2046. [CrossRef]
19. Mayfield JK, Johnson RP, Kilcoyne RF. The ligaments of the human wrist and their functional significance. Anat Rec 1976; 186:417–428. [CrossRef]
20. Berger RA. The ligaments of the wrist. A current overview of anatomy with considerations of their potential functions. Hand Clin 1997; 13:63–82.
21. Berger RA, Blair WF. The radioscapholunate ligament: a gross and histologic description. Anat Rec 1984; 210:393–405. [CrossRef]
22. Theumann NH, Pfirrmann CW, Antonio GE, et al. Extrinsic carpal ligaments: normal MR arthrographic appearance in cadavers. Radiology 2003; 226:171–179. [CrossRef]
23. Lacelli F, Muda A, Sconfienza LM, Schettini D, Garlaschi G, Silvestri E. High-resolution ultrasound anatomy of extrinsic carpal ligaments. Radiol Med 2008; 113:504–516. [CrossRef]
24. Mizuseki T, Ikuta Y. The dorsal carpal ligaments: Their anatomy and function. J Hand Surg Br 1989; 14:91–98. [CrossRef]
25. Taljanovic MS, Malan JJ, Sheppard JE. Normal anatomy of the extrinsic capsular wrist ligaments by 3-T MRI and high-resolution ultrasonography. Semin Musculoskelet Radiol 2012; 16:104–114. [CrossRef]
26. Taljanovic MS, Goldberg MR, Sheppard JE, Rogers LF. US of the intrinsic and extrinsic wrist ligaments and triangular fibrocartilage complex--normal anatomy and imaging technique. Radiographics 2011; 31:e44. [CrossRef]
27. Kauer JM. Functional anatomy of the wrist. Clin Orthop Relat R 1980; 149:9–20. [CrossRef]
28. De Maeseneer MI, Marcelis S, Boulet C, et al. Ultrasound of the knee with emphasis on the detailed anatomy of anterior, medial, and lateral structures. Skeletal Radiol 2014; 43:1025–1039. [CrossRef]