Thumb Carpometacarpal Ligaments Inside and Out: A Comparative Study of Arthroscopic and Gross Anatomy from the Robert A. Chase Hand and Upper Limb Center at Stanford University

Andrew Y. Zhang, MD¹ Sarah Van Nortwick, BA¹ Elisabet Hagert, MD^{1,2} Amy L. Ladd, MD¹

¹Stanford, University, Palo Alto, California

²Karolinska Institutet, Solna, Sweden

Address for correspondence Amy L. Ladd, MD, Robert A. Chase Hand Center at Stanford, 770 Welch Road, Suite 400, Palo Alto, CA 94304 (e-mail: alad@stanford.edu).

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Abstract

Purpose We propose to identify and correlate arthroscopic internal ligaments with external ligaments, providing an accurate roadmap for arthroscopic ligament and joint anatomy. Ligamentous laxity is considered an important risk factor in developing the common basilar arthritis of the thumb. Controversy exists as to the precise ligamentous anatomy of the thumb carpometacarpal (CMC) joint (CMC-I); description of the internal arthroscopic anatomy is limited.

Methods We performed CMC-I joint arthroscopy using the 1-Ulnar (1U) and thenar portals in five cadavers, seeking to identify the following seven ligaments arthroscopically: the superficial anterior oblique ligament (sAOL), deep anterior oblique ligament (dAOL), ulnar collateral ligament (UCL), dorsal trapeziometacarpal ligament (DTM-1), posterior oblique ligament (POL), dorsal central ligament (DCL), and dorsal radial ligament (DRL). After grading articular changes of the trapezium, we passed Kirschner wires (K-wires) (0.028) outside-in to mark the arthroscopic insertion of each ligament on the trapezium. Gross dissection was performed to confirm the wire placement; the anatomic identity and position of joint stabilizing ligaments, and the location of frequently used portals.

Results The volar ligaments—the sAOL, dAOL, and UCL—were highly variable in their arthroscopic appearance and precise location. The sAOL is a thin veil of membranous tissue that variably drapes across the anterior joint capsule. The reported dAOL and UCL, in our study, correlated to a thickened portion of this veil around the volar beak and was not consistently identified with gross dissection. In contrast, the arthroscopic appearance and location of the dorsal ligaments—DTM-I, POL, DCL, and DRL—were consistent in all specimens.

Conclusion Our study further defines and correlates the arthroscopic and external ligamentous anatomy of the CMC-I joint.

Keywords

- arthroscopy
- gross anatomy
- ligament anatomy
- thumb CMC
- arthroscopy
- thumb CMC arthritis

Thumb carpometacarpal (CMC) joint (CMC-I) arthritis affects one in four women in the United States over age 55 as well as a significant number of men.^{1,2} Surgical treatment is controversial: trapezial excision, with its many modifications, is the most common procedure performed for advanced arthritis

(radiographic Eaton stage 2–4).^{3–5} Arthroscopic treatment, first described by Menon and Berger in the late 1990s, includes debridement, synovectomy, thermal capsular shrinkage, and partial trapeziectomy, with or without interposition, and it offers a potential alternative to nonoperative

treatment for less advanced disease.^{6–9} Laxity of joint stabilizing ligaments has been implicated as a contributor to arthritis in anatomic studies.^{10–13}

Understanding the complex bony and enveloping soft tissue anatomy of the CMC-I enhances evaluation and treatment of arthritis. The literature contains only two detailed descriptions of the arthroscopic appearance of the joint stabilizing ligaments of the CMC-I joint^{14,15}; the comparative descriptions are inconsistent and lack consensus. The study of Bettinger and Berger (hereafter “Bettinger”) describes the visualized arthroscopic ligaments using the nomenclature from open dissection techniques, but it does not describe the methodology used to define these arthroscopically. The number of cadavers used was not specified in this study.¹⁴ In a previous study by Bettinger et al, 37 cadaver arms were dissected and formed the basis for their nomenclature.¹⁰ Orellana and Chow (hereafter “Orellana”) document the arthroscopic appearance of several ligaments in a technique paper introducing the radial portal.¹⁵ Orellana utilized six cadavers of unspecified sex. These two citations provide several conflicting accounts of the arthroscopic anatomy. The location and presence of the intermetacarpal ligament (IML) is debated as between intracapsular and arthroscopically visualized (Orellana) or extracapsular and not visualized (Bettinger). Bettinger describes the ulnar collateral ligament (UCL) as having vertical fibers; Orellana identifies the UCL as an oblique structure.

The inconsistent anatomy described in these reports suggests that the arthroscopic view of the intra-articular ligaments may vary. To address this discrepancy, we identified the ligaments arthroscopically, and verified their presence and location by gross dissection.

We secondarily investigated the articular surface topography to provide preliminary means of grading clinically relevant arthritis.

Materials and Methods

Specimens

Five⁵ cadaveric hand and forearm specimens were studied. Specimens comprised four male and one female Caucasian. All were right hands; average age 69.2 (range 50–93 years). Approval for this project was granted through the local institutional review board, and the handling of human remains adhered to ethical and practical protocols. One specimen had a known history of osteoarthritis; arthritic history was otherwise unknown. No specimens were excluded.

Arthroscopy Technique

The technique of CMC-I joint arthroscopy utilized two portals: the 1-Ulnar (1U) as described by Berger and the thenar portal as described by Walsh and colleagues.^{16,17} These two portals were chosen given our clinical preference for suitable triangulation and visualization of the joint. An arthroscopy traction towel was used (Linvatec, Largo, FL), with 10–15 lbs of traction. Two penetrating towel clamps were clamped through the interosseous membrane and tied to the table using twine. Fingertraps applied to the middle and index

fingers were used for distal traction. Surface landmarks of extensor pollicis longus (EPL), extensor pollicis brevis (EPB), and abductor pollicis longus (APL) tendons were identified. The CMC-I joint was palpated and insufflated with 2–3 mL of saline. The 1U portal just ulnar to the EPB at the level of the joint was established. A 2.7mm small joint 30-degree arthroscope was employed (Smith & Nephew, Memphis, TN). The thenar eminence was illuminated and an 18-gauge needle was placed in the thenar portal in the bulk of the thenar muscle at the level of the CMC I joint, ~90° from the 1U portal. The synovium was shaved (2.9-mm INCISOR power shaver, Smith & Nephew, Memphis, TN) within the CMC-I joint. Starting at the volar beak of the metacarpal, we systematically examined the joint in a clockwise fashion.

Using a probe, we palpated and identified any structure around the joint with longitudinal groupings of collagen fibers, indicating sufficient substance consistent with a ligament. Based on published gross and arthroscopic illustrations and descriptions of Bettinger, Pellegrini, Lee, and Ladd, we provisionally named the visualized ligaments.^{10,13,14,18,19}

We marked each ligament position on the trapezium with a drilled 0.028 K-wire, passing the wire in an external-to-internal direction, verifying its position arthroscopically. We similarly passed a K-wire through the sites for the 1R and an additional dorsal distal portal (D2) described by Slutsky to define their location with respect to the ligaments.²⁰ Each K-wire was externally tagged with a unique color tape for easy identification during the gross dissection.

The following ligaments were provisionally identified arthroscopically: superficial and deep AOL (sAOL and dAOL), UCL, dorsal trapeziometacarpal ligament (DTM-I), posterior oblique ligament (POL), dorsal central ligament (DCL), and dorsal radial ligament (DRL).^{10,13,14,18,19} We additionally identified thenar musculature visualized beyond the volar capsule, and volar radial tendinous slips consistent with accessory APL fibers, not previously described arthroscopically.

Arthroscopic Assessment of the Joint Surfaces

We divided the trapezium and metacarpal surfaces into four quadrants as defined by Xu in gross dissections²¹; the patterns of cartilage wear were staged using a modified Outerbridge scale²² (–Fig. 1). A probe was used to estimate the depth of cartilage lesions. The results were recorded and correlated with gross dissection findings.

Dissection Techniques and Measurements

Gross dissections were performed to confirm the identity of the marked ligaments. The dissections were performed using loupe magnification and standard hand surgical instruments. All nonligament soft tissues were excised over the first and second metacarpals (MC-I–II), first and second carpometacarpal (CMC-I–II) joints and scaphotrapeziotrapezoid (STT) joint. The extensor carpi radialis longus (ECRL) and brevis (ECRB), the flexor carpi radialis (FCR), and the flexor pollicis longus (FPL) tendons were excised at their insertions, leaving APL, EPL, and EPB tendons attached to the MC I. The thenar muscles were elevated in a proximal–distal direction to reveal

Fig. 1 Four quadrants of the trapezium defined and modified from Xu can be identified arthroscopically to provide cartilage wear pattern information. An imaginary line from the 1U portal to the trapezial surface articulating with the volar beak of the metacarpal establishes the dorsal/volar axis. A perpendicular line to this, from the prominent ulnar trapezial ridge to the APL, establishes the radial/ulnar axis. Using a modified Outerbridge scale,²² degeneration is described as follows: stage 1, normal cartilage; stage 2, cartilage with minor defects; stage 3, progressively degenerated cartilage including deep surface pits, clefts, and exposed bone; and stage 4, eburnated bone. The corresponding quadrants of the metacarpal articular surface are shown but not readily visualized with arthroscopy.

the underlying joint capsule. At the level of the CMC-I joint capsule, meticulous dissection according to the technique of Berger revealed the ligaments marked by the K-wires.^{18,19,23,24}

Results

We identified and compared seven arthroscopic and dissected ligaments. The volar ligaments—sAOL, dAOL, and UCL—varied in their location and caliber, whereas the dorsal ligaments—DTM-I, POL, DCL, and DRL—were highly consistent (►Figs. 2, 3).

The Anterior Oblique Ligaments (sAOL and dAOL)

The metacarpal volar beak provided volar arthroscopic orientation (►Fig. 4). The anterior oblique ligaments were

encountered directly opposite the 1U portal surrounding the volar beak as a veil of vertical membranous fibers. The broader sAOL was encountered radial to and at the volar beak articulation (►Figs. 2, 3). The purported dAOL was perceived as a thickened ulnar portion of this anterior complex and not discretely identified. Probing these ulnar, vertically oriented fibers, however, artificially created a discrete separation suggestive of a ligament.

The Ulnar Collateral Ligament

The arthroscopic ligamentous structure ulnar to the AOL was found to be the UCL on gross dissection, with one exception. In that specimen, the perceived arthroscopic UCL was found to be thickened joint capsule of the AOL complex, potentially representing a capsular thickening, or perhaps the deep AOL as defined by Bettinger as an intracapsular ligament.^{10,14} On

Fig. 2 Artistic representation of the arthroscopic cross-sectional ligamentous anatomy and portal positions. The variability and presence of the dAOL and sAOL are represented by a continuum denoted in red.

gross dissection the UCL is readily identified as more obliquely oriented fibers ulnar to the AOL (►Figs. 2–5). The dissected UCL was confirmed as an extracapsular ligament, with intra-articular extensions spanning the capsule.^{14,15} These arthroscopic extensions blended with the AOL in all specimens.

Thenar Muscle and APL Accessory Slips

Thenar muscle was readily visualized arthroscopically superficial to the volar capsule and radial to the AOL complex (►Fig. 4). Vertical, radial ligamentous-appearing structures in the volar radial quadrant region were verified upon gross dissection as accessory APL tendinous slips, extending across the joint and inserting on the thenar muscles.

The Ulnar Recess

The ulnar recess was consistently visualized from the thenar portal and complements the ulnar tubercle of the trapezium.¹⁶ The ulnar tubercle is defined as the tapered peak on the

ulnar aspect of the trapezium, it resembles the pommel of a saddle. The ulnar tubercle is straddled by UCL and DTM-1 (►Fig. 5).

The DTM-1

The DTM-1 is an oblique dorsal ligament, best visualized from the thenar portal and located just dorsal and radial to the ulnar recess. Its obliquity makes it easily distinguishable (►Fig. 6).

The POL, DCL, and DRL Complex

The 1U portal consistently pierces between the POL and the DCL (►Figs. 2, 3). The POL is ulnar and adjacent to the portal. The DCL is radial to the 1U portal and grossly lies directly deep to the EPB tendon. The DRL is radial to the DCL. By gross dissection, the DRL is found to be slightly dorsal-ulnar to the APL. When the 1R portal is utilized, the DRL is ulnar to the portal but not readily visualized arthroscopically (►Figs. 2, 3, 6).

Cartilage Wear

Arthroscopic quadrant designations of cartilage wear patterns corresponded to gross findings. The dorsal radial quadrant was difficult to visualize with the 1U and thenar portal combination (►Fig. 7a–b).

Discussion

Current arthroscopic techniques focus on treatment for early-stage CMC-I arthritis.^{7,9,25,26} Improved characterization of the pathoanatomy potentially broadens the surgical utility of arthroscopy.

Our study expands upon existing literature by validating arthroscopic findings with subsequent gross dissection of the CMC-I.^{14,15,19} We have identified the four previously described access portals in relation to the location of internal supporting ligaments and provide an “open-book” reference of CMC-I ligamentous anatomy.

Fig. 3 Open-book illustration of the ligamentous anatomy of the CMC I joint including all ligaments readily identified arthroscopically. The origin and insertion of each ligament is shown. Asterisk represents the volar beak and its articulating location on the trapezium. The brown articular stainings represent drill passes.

Fig. 4 Arthroscopic ligamentous anatomy of the anterior ligaments of three representative subjects visualized through the 1U portal. Corresponding gross dissection is shown at bottom right. The asterisk marks the location of the volar beak, the most proximal prominence parallel to the trapezial surface. The thenar muscles are visible in subject 1 between the sparse AOL and UCL; this is a common clinical finding, and their close relationship was confirmed with gross dissection.

Fig. 5 Photo showing the ulnar border of the right thumb CMC joint; volar is to the right of the photo and dorsal is to the left. The ulnar recess, as seen bordered by the UCL and DTM-I, represents an area devoid of ligamentous tissue under both arthroscopic and gross examination and forms a checkrein ligamentous complex.

The volar ligament variability supports the controversial location and nature of these structures.^{10,14,15,17-19,27-29} The AOL complex is difficult to define precisely both arthroscopically and grossly; given the inconsistencies of the sAOL and dAOL, we have designated these as a collective *volar* or *AOL complex*.¹⁹ Although the AOL complex appears stout under arthroscopic magnification, probing revealed thin, membranous tissue intimal with the thenar muscles. Gross dissection confirmed its diaphanous and collective nature in all five specimens (►Fig. 4). Two previous studies have reported the existence of a superficial and a deep AOL^{10,17}; we sought to identify these, but did not find clear evidence that these were present as two distinct structures. Our arthroscopic study supports a recent open dissection study that found the existence of an intracapsular structure deep to the UCL, possibly denoting a deep AOL, in only 3 of 30 specimens.¹⁹

In contrast, the ulnar and dorsal ligaments were geographically consistent and stout on both gross and arthroscopic examination. These findings support recent anatomical descriptions^{18,19,30} and differ from the previous limited arthroscopic literature in the following ways: (1) The UCL is a complementary, volar counterpart of the DTM-I, and (2) the most oblique dorsal ligament, previously identified as the POL,^{14,15} was in fact DTM-I, as described with open dissection methodology, which refines commonly used nomenclature.¹⁹

These two ligaments straddle the ulnar trapezial ridge, spanning the ulnar recess seen arthroscopically, and occupy the ulnar side of the CMC-I joint. The more volar ligament is the UCL/VTM-I, originating on the volar ulnar ridge of the

Fig. 6 Arthroscopic ligamentous anatomy of the posterior ligaments of three representative subjects visualized through the thenar portal. Corresponding gross dissection is shown at bottom right.

Fig. 7a,b (a) Arthroscopic view through the thenar portal (b) and open-book dissected view of the trapeziometacarpal articulation demonstrating cartilage wear by quadrant. This specimen demonstrates preferential volar and dorsal radial wear. VU, volar ulnar, DU, dorsal ulnar, VR, volar radial, and DR, dorsal radial.

trapezium. It courses in an oblique direction to insert onto the volar ulnar edge of the first metacarpal. Its dorsal counterpart, the DTM-I, originates from the dorsal ulnar edge of the trapezium and courses obliquely to insert on the ulnar edge of the first metacarpal. These ligaments serve as the ulnar checkrein ligaments of the CMC-I joint.^{5,14} Given that the UCL is the volar equivalent of the DTM-I in anatomy and function, we propose replacing the term *UCL* with the more accurate term *volar trapeziometacarpal ligament (VTM-I)*.¹⁹

Three dorsal ligaments were identified with arthroscopic and gross dissection. The POL originates from the dorsal tubercle of the trapezium, along with the DCL and DRL, fanning from the tubercle onto the metacarpal to form a deltoid-shaped ligament complex, as recently described^{18,19} (►Fig. 6). Previ-

ous reports of this dorsal complex emanating from the tubercle describe this as two ligaments (DRL and POL).^{10,14,15,27-29,31}

The biomechanical significance of the thick, stout dorsal ligaments in contrast to the thin, variable volar ligaments was not established in our study. A recent in vivo investigation of six normal subjects, however, measured the change of length in computationally determined CMC ligaments using serial computed tomography (CT) images in positions of thumb flexion, abduction, and opposition. This study demonstrated significant lengthening of the posterior ligaments—dorsoradial, posterior oblique, intermetacarpal, and dorsal intermetacarpal—and the authors proposed the important role these stout ligaments play with joint stability. Furthermore, they demonstrated compensatory shortening of the deep anterior

oblique in these postures.³⁰ We believe that the dorsal ligaments are pivotal as restraints to posterior shear, translation, and dislocation, and that the AOL serves as a thin, complementary tension band to support this phenomenon. Both arthroscopic visualization and gross dissection confirmed thenar muscle fibers spanning the CMC joint in close proximity to AOL ligaments. We further propose that the thenar muscles play a critical supportive role in volar stabilization, analogous to the rotator cuff stability of the glenohumeral joint. The importance of thenar strengthening in hand therapy in arthritis rehabilitation supports this concept.³²

Accessory slips of the APL tendon located radial to the AOL complex were often seen arthroscopically. Zancolli has previously suggested that APL may act as a deforming force in the pathogenesis of CMC arthritis¹²; the role the APL and these slips play in joint stability, however, has not been tested biomechanically.

Limitations of this study include a relatively small sample size, only one female specimen, and suboptimal visualization of the dorsal radial quadrant of the CMC joint. Despite the sample size, however, we observed high variability among the volar ligaments and absolute consistency of the dorsal ligaments. Histology was not performed on these specimens to confirm the capsular versus ligamentous nature of the ligaments. Our gross findings of thin volar ligaments and stout dorsal ligaments, however, support recent histomorphometric and immunofluorescent analyses^{18,19} that determine the volar structures to be more consistent with capsular tissue than with ligament.¹⁹ Male subjects were preferentially chosen, given larger joints and ease of performing arthroscopy. All of our subjects had osteoarthritis and were of older age (range 50–93 years); this introduces the possibility that the ligamentous structures may be abnormal or insufficient, and thus not characteristic of normal anatomy. Yet our subjects demonstrated relative early stages of arthritis, with a retained saddle shape of the trapeziometacarpal surface, suggesting the ligamentous anatomy lies on the normal end of the spectrum. Our choice of 1U and thenar portals was based on surgeon preference for easy triangulation and better visualization of the joint; however, the dorsal radial quadrant and metacarpal were imperfectly visualized. Conveniently, the metacarpal is relatively preserved even in advanced arthritis, and the dorsal radial quadrant of the trapezium is thought to be the least affected by disease.^{3,17,21} We believe arthroscopy's potential benefit outweighs these limitations.

In summary, our comparative study addresses the location, bulk, and fiber orientation of the CMC-1 ligaments, demonstrating the highly variable nature of the volar ligaments and consistency of the dorsal ligaments. This refined characterization may provide means to enhance arthroscopic and open treatment for this challenging disease.

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