

Magnetic resonance imaging technology in evaluating the presence and integrity of the anterior oblique ligament of the thumb

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Abstract

This investigation examines the reliability and reproducibility of magnetic resonance imaging (MRI) technology in evaluating the anterior oblique ligament (AOL) of the trapeziometacarpal joint (TMC) of the thumb, in order to establish an effective imaging protocol to use in the early identification of conditions leading to degenerative arthritis. We used cadaver specimens, three hand surgeons independently rated from X-rays each specimen. The specimens were then scanned in a General Electric MRI machine with a standard wrist coil. An effort was made to reproduce the image of the AOL - with a unique technique to obtain images of the obliquely oriented thumb and its ligaments. Following the MRI, the specimens were dissected to expose the AOL and visualize the TMC joint. A standard MRI fiducial was sewn to the proximal and distal extent of the volar side of the AOL. The soft tissues were replaced and the skin was closed. They were then rescanned following the same protocol, and pre and post-dissection ligament-labeled specimens were compared. Following dissection and tagging of the AOL ligament, a repeat MRI confirmed its location and validated the protocol in all cases. The open dissection and ligament tagging confirmed that what was visualized was in fact the structure of interest. This investigation demonstrated that with an appropriate MRI protocol it is feasible to guide the scanner to catch appropriate images of a ligament that is closely correlated with degenerative arthritis.

Introduction

The anterior oblique ligament and degenerative arthritis

The basilar joint of the thumb frequently develops osteoarthritis, particularly in postmenopausal women. One in 4 women and 1 in 12 men ultimately develop X-ray evidence of basilar joint degeneration.¹ Unique anatomy and exposure to complex axial loading, flexion-

extension, rotational, and shear forces make the trapeziometacarpal joint (TMC) especially vulnerable. This joint's anatomy, development, kinematics, and pathophysiology have been well described in the literature.²⁻¹⁰

The endpoint of degenerative osteoarthritis of the thumb carpometacarpal (CMC) joint is often debilitating pain and dysfunction, particularly with lateral pinch and opposition.⁴⁻⁶ Non-operative options for patients reaching this stage of joint deterioration include the acceptance of pain, modification of exacerbating activities, splints to support the joint externally, steroid injections, and oral anti-inflammatories.¹¹ Operative options include arthrodesis, osteotomy, hemi- or total trapeziectomy, implant arthroplasty, single or double interposition arthroplasty, suspension-plasty, or ligament reconstruction with tendon interposition arthroplasty (LRTI).^{2,3,12-23} These are all procedures with varying degrees of morbidity. The common goal of any treatment for painful arthritis at this vulnerable joint is to reduce pain and restore function to the thumb.

The surgical procedures mentioned earlier have been successful, particularly LRTI. Though, they are reconstructive not restorative procedures. If a patient's propensity towards osteoarthrosis of the basilar joint could be assessed, early intervention could decrease their likelihood of developing arthritis.

Identification of vulnerable trapeziometacarpal joints

Precise evaluation of joint stability is critical to the early diagnosis of a vulnerable thumb TMC joint. Existing literature has well established that the integrity of the anterior oblique ligament (volar beak ligament) is strongly correlated with joint stability and joint congruency, as well as joint degradation (Figures 1 and 2).⁴⁻¹⁰

The major static stabilizer of the TMC joint during lateral pinch is the intracapsular palmar beak ligament.⁶⁻⁸

Pellegrini *et al.* analyzed joint congruency and contact pressures with Fuji film. Using cadaver limbs with tendons attached, common thumb and hand movements were reproduced while joint reaction force at the TMC joint was measured. The anterior oblique ligament (AOL) was also intentionally divided and the movements were repeated. Results showed a significant dorsal translation of the metacarpal and an increase in articular pressure in the volar compartment.⁶ Preferential loading of the volar surfaces in this experimental model correlates well with the *in vivo* pattern of joint degradation in which the unstable joint subluxates dorsally and preferentially wears out the volar surface of the joint.^{6,8,9,16}

Unfortunately, there is currently no reliable, reproducible way to evaluate the AOL's structural integrity by physical examination and X-

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ray. Several physical exam maneuvers to test for laxity in the thumb basilar joint have been described, but they tend to be subjective and non-specific. If a patient is globally lax, the interpretation of a positive physical exam is even less informative.

The purpose of this study was to test the reliability and reproducibility of magnetic resonance imaging (MRI) technology in the examination of the AOL in cadaver specimens. By dissecting and tagging the ligament and then repeating the MRI, the location of the AOL was confirmed and the validity of an effective imaging technique protocol was established.

Materials and Methods

Specimens and unique imaging protocol

Six freshly frozen cadaver specimens from the mid-forearm level to the fingertips were obtained. There were two right-handed female specimens, two right-handed male specimens, one left-handed male specimen and one left-handed female specimen with ages ranging from 25 to 60 years. Anterior posterior, lateral, and oblique X-rays of the TMC joint were taken. Three hand surgeons experienced with the revised Eaton and Littler classification of basilar joint arthritis independently rated each specimen from X-rays.^{16,24}

The specimens were subsequently scanned in a MRI machine (GE Horizon LX Echospeed, 1.5 Tesla, 9.0 software). A standard wrist coil

was used to enhance detail (MRI Devices Corp., Model HRW Wrist Array Coil for GE Signa, 1.5/1.0 Tesla). The specimens were placed in the scanner in a supinated position. And the same MRI technician ran all scans.

As in other instances, when MR imaging of a specific ligament is the goal of the study, the most valuable images are those that include the origin and insertion of the ligament. Based on this premise, we sought to reproduce images of the AOL that included its origin from the articular margins of the volar trapezium to its insertion on the volar thumb metacarpal. Because the ligament spans the thumb TMC joint volarly, the best image is a slice oriented sagittally to the thumb and centered on the joint. This was challenging, as the thumb is oblique to the wrist and digits in all three planes (Figures 3-5). Standard wrist MRI protocols are oriented along the longitudinal axis of the forearm and fingers. This forced us to devise a unique technique to get appropriate images of the obliquely oriented thumb and its ligaments.

Several initial scans were run to adjust the imaging protocol (Figures 6 and 7). Eventually a standardized imaging protocol was delineated and used on subsequent specimens (Table 1).

Table 1. The imaging protocol.

Run initial scan as a 3-plane localizer. This gives us coronal, axial, and sagittal images relative to the scanner.

Run series of oblique sagittal images (to scanner), but along the thumb MC axis.

Run series of axial images (to thumb axis).

Run series of coronal images through plane of ligament (*i.e.* coronal to thumb axis).

Run series of sagittal images with slight proximal radial to distal ulnar, centered on the joint.

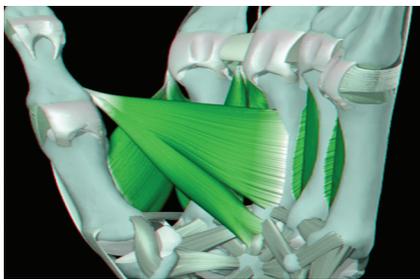


Figure 1. The anatomy of the anterior oblique ligament to the thumb, attachments and insertions.

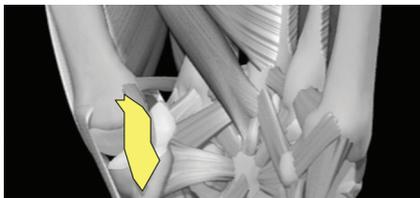


Figure 2. The outlined anatomy of the anterior oblique ligament.



Figure 3. Coronal posterior anterior view of the imaging plane.



Figure 4. Oblique view of thumb oriented in a different plane.



Figure 5. Oblique view of thumb oriented in a different plane.

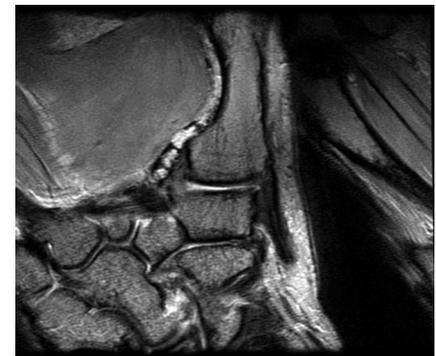


Figure 6. The T1-weighted image of a cadaver carpometacarpal joint of the thumb, coronal view.

Identifying the trapeziometacarpal joint and marking the anterior oblique ligament

Once the MRIs were completed, 6 specimens were carefully dissected in a minimally invasive way to expose the AOL. A 3-centimeter longitudinal incision was made in line with the flexor pollicis longus (FPL) tendon, centered over the TMC joint. Sharp dissection was carried down to the FPL tendon, while the abductor pollicis muscle was retracted dorsally and the flexor pollicis brevis muscle volarly. The FPL was then exposed and retracted volarly, and the volar TMC joint was visualized.

A standard MRI fiducial was sewn to the proximal and distal extent of the volar side of the AOL. Fiducials (Multi Modality Radiographic Markers, MM 3002) are small lifesaver shaped adhesive-backed tags used on the skin to localize areas of interest (such as highlighting a tumor). The fiducials show up as moderate to high signals on T2-weighted scans. Since ligaments are low signal on T2's, these provide effective contrast to the ligament.

After the fiducials were attached to the ligament, the soft tissues were gently replaced and the skin was closed. The specimens were then run through the MRI scanner under the identical protocol to compare and contrast the pre-dissection and post dissection, ligament-labeled specimens (Figure 8).

Results

In all 6 cases, the ligament was successfully identified using the new imaging protocol. In order to confirm that the investigators were

visualizing the structure of interest, the open dissection and ligament tagging was used to confirm the findings.

Subluxation was evident in three of the specimens - 5.0 mm in a right-handed female, 4.0 mm in a right-handed female, and 2.5 mm in a left-handed male. A small cyst was evident in a right-handed male specimen. Two small and one medium osteophyte was found in three specimens - small in a left-handed male and a left-handed female, and medium in a right-handed male. The joint space recorded for each was: 3.0 mm, right-handed female; 1.5 mm, right-handed female; 2.0 mm, right-handed male; 1.5 mm, left-handed male; <1.0 mm, right-handed male; and 2.5 mm, left-handed female (Table 2).

Discussion

The role of the anterior oblique ligament in determining joint degeneration

The anterior oblique ligament is critical to

stability and normal motion of the TMC joint. Bettinger *et al.* performed thorough anatomic dissections on 37 hands, explicitly detailing the ligamentous anatomy of the trapezium and trapeziometacarpal joint.⁷ Two layers to the volar capsular complex were noted. The superficial AOL was confluent with the volar capsule, while the deep AOL was shorter, more discrete and intra-articular. The deep AOL originated from the volar central apex of the trapezium and inserted just ulnar to the volar styloid process at the base of the first metacarpal (beak) - serving as a pivot point for the pronation. The d-AOL average size in Bettinger's series was 8.37 mm long by 5.45 mm wide by 1.17 mm thick.⁷ Pellegrini suggested that as the thumb CMC joint evolved into its unique orientation - permitting the thumb's essential and specialized function - it forsakes bony stability in order to increase mobility.⁹ The periarticular soft tissues then offset the strain by coalescing in a multitude of intra and extra-articular ligaments. These structures work harmoniously with dynamic musculotendinous attachments and the bicon-

Table 2. X-ray findings.

Spec. # Serial #	Hand/Gender	X-ray Sublux.	Findings Cysts	Osteophytes	Joint Space
1 - 41810	R/F	5.0 mm	none	none	3.0 mm
2 - 41814	R/F	4.0 mm	none	none	1.5 mm
3 - 41819	R/M	0.0 mm	none	none	2.0 mm
4 - 41819	L/M	2.5 mm	none	(+) small	1.5 mm
5 - 41823	R/M	0.0 mm	(+) small	(+) medium	<1.0 mm
6 - 41824	L/F	0.0 mm	none	(+) small	2.5 mm



Figures 7. Images of the anterior oblique ligament before surgery and insertion marker - oblique views.

Figure 8. Oblique view of the anterior oblique ligament showing the marker placed against the ligament.

cave, saddle-shaped articulation in order to provide a diversity of motion - both for power grip and pinch, as well as delicate pulp-to-pulp activities.⁷ A disturbance in this balance leads to an increase in joint reactive and shear forces. These forces are concentrated on the volar compartment corresponding to the same area eburation is first noted in earlier stages of the disease.⁶ Correspondingly, any joint with mild to moderate degeneration will also have attritional changes and histopathologic changes in the AOL.^{6,8}

When a joint prematurely experiences these stresses, particularly in a repetitive, chronic fashion, a painful synovitis ensues, ultimately leading to cartilage degradation and osteoarthritis.¹⁰

Previous findings of anterior oblique ligament correlation

Of all the joint stabilizers, the AOL is most closely correlated with degenerative arthritis - as evidenced in biomechanical cadaver studies, in which the joint loading patterns were most distinctly altered after sectioning the AOL.⁶

Eaton and Littler reconstructed the volar ligament in patients with painful hypermobility. Their greatest success involved patients presenting with basilar thumb pain and no evidence of arthritis - or, those presenting with only mild changes (Eaton stages I and II).^{2,3} They presented short-term and long-term results,^{2,3} in which patients achieved a 95% rate of good or excellent results at 7 years. They also looked for evidence of joint degeneration after ligament reconstruction. They found that all of the stage I patients and 82% of the stage II patients remained arthritis-free. Drs. Eaton and Littler concluded that volar ligament reconstruction for painful hypermobility without advanced arthritis (stages III and IV) would restore stability, reduce pain and possibly slow joint degeneration.² Freedman *et al.* carried this work further. They presented results of 24 thumbs after volar ligament reconstruction for persistent, painful laxity without advanced arthritis. The average follow up was 15 years. Twenty-three of 24 thumbs were stage I.

At 15 years follow-up, 15 thumbs remained stage I, 7 were stage II, and 2 were stage III. Only 8% progressed to advanced arthritis - compared to an arthritic deterioration rate of 17 (33%) in the general population. The authors concluded that by reconstructing the volar ligament and restoring thumb CMC stability, arthritis could potentially be delayed or prevented.²² Lane and Henley looked at 35 of their volar ligament reconstructions for painful laxity without arthritis.

At a 5.2-year follow-up, they recorded a 97% rate of good and excellent results. One hun-

dred percent of their patients had stable thumbs and increased pinch strength. None of the 35 patients had clinical or X-ray evidence of arthritis at 5.2 year follow-ups.²³

The need for and development of new, reliable magnetic resonance imaging protocol

The challenge is determining either surgical indications for a ligament reconstruction or conservative treatment to manage thumb pain. Many of these joints develop severe arthritic changes on X-ray, yet are minimally symptomatic. Historically, little else is done beyond determining whether the lax joint should be stabilized in order to prevent arthritic change, or treated as painful instability that may or may not develop arthritis.

Traditionally, mid-aged adult patients presenting with activity-related pain at the base of the thumb and normal X-rays are assessed for common diagnoses on the differential. Once the physician is convinced that the TMC joint is the source of pain, they assess for hypermobility. If it is decided that the joint is lax, initiating treatment with a supportive splint, activity modification, and nonsteroidal anti-inflammatory drugs is reasonable. But, if the patient fails to respond to conservative treatment and returns in 6 months with a lax joint despite X-rays indicating normal articulations, another course of action must be pursued.

Because clinical examination of the AOL integrity is highly subjective and variable, we felt that magnetic resonance images of the AOL could potentially evaluate the structural integrity of the ligament and subsequently support one treatment over another. An appropriate MR image could reveal a periarticular detachment of the AOL, or the presence of a volar metacarpal synovial recess. Both of these findings would suggest early ligament failure and prompt a reconstruction, potentially preventing the early onset of arthritis and joint degeneration. Conversely, if the ligament appeared stout, without edema, and firmly attached, we would be inclined to stay the course and continue supportive treatment only.

The anterior oblique ligament is key to preventing degenerative arthritis

Support for this rationale comes from the work of Doerschuk *et al.* Their study, published in 1999, histologically examined the AOL in cadaver specimens and correlated the pathology of the ligament with the condition of the articular surfaces. Doerschuk *et al.* found that ligament degeneration initiates at its distal insertion on the metacarpal beak. A pathologic sequence of degeneration of the beak ligament

correlates with progressive palmar TMC articular wear.⁸ Specifically, they found microscopic disruption of the ligament from its insertional fibrocartilage at the palmar metacarpal margin of the joint to be correlated with stage I disease (minimal articular wear). As further attenuation of the ligament occurs, a palmar metacarpal synovial recess develops as the insertion site migrates distally. This recess formation was seen with localized volar compartment eburation as evidenced in stage II. And, finally, loss of beak ligament integrity coincides with complete eburation of both joint surfaces of the trapezium and metacarpal.⁸ Through this study and by more precisely identifying the condition of the AOL - particularly the integrity of its distal metacarpal attachment - we could better predict the potential for joint degradation and thereby institute more selective treatment.

Role of magnetic resonance imaging in assessing small ligaments and joints: now and the future

Numerous studies support the use of MRI to evaluate the small ligaments and joints of the hand, wrist, and forearm.²⁵⁻³¹ The majority of these have focused on the ulnar collateral ligament of the thumb's metacarpophalangeal joint. Most of these studies have concluded that MRI is an excellent tool to differentiate displaced tears of the ulnar collateral ligament from non-displaced tears. Another study used MRI successfully to examine the interosseous membrane in a prospective cadaver study in which the IOM was surgically divided.³¹ To date, no study has specifically used MRI in order to evaluate the structural integrity of the deep AOL of the thumb TMC. Based on the success of MRI to image other small ligaments of the hand, we felt capturing the AOL would be possible with a reasonable and reproducible imaging protocol.

The present study demonstrated that while technically tricky it is nonetheless feasible to guide the scanner to catch appropriate images of this essential ligament.

Some may argue, that if a patient has basilar thumb pain and clinical laxity, the state of the AOL is irrelevant. Numerous studies show favorable outcomes when volar ligament reconstruction is used to treat painful, unstable, non-arthritic thumbs.^{2-3,12,22,23} However, all of these studies lack control group. The study populations were never randomly selected for volar ligament reconstruction *versus* a control group without such treatment. The condition of the AOL in these patients prior to their reconstructions is unknown.

One variable worth considering for future studies is the MRI assessment of the AOL in both symptomatic and asymptomatic patients.

Establishing a reliable imaging protocol allows future studies to focus on imaging the stabilizing ligaments of the TMC joint. This information could influence treatment protocols and surgical planning. Our goal was to establish a precedent for imaging this critical ligament in a reproducible fashion. Subsequent studies may look at using higher Tesla magnets to increase detail and specificity.

Additionally, an MRI classification in the prediction of future ligament function - further dictating both effective and preventative treatment pathways - would be valuable for the physician and patient alike.

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