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Association of Lunate Morphology, Sex, and Lunotriquetral Interosseous Ligament Injury with Radiologic Measurement of the Capitate-Triquetrum Joint

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Abstract

Objective—Radiologic presentation of carpal instability at the radial side of the carpus, e.g. scapholunate diastasis following scapholunate interosseous ligament injury, has been studied extensively. By comparison, presentation at the ulnar-sided carpus has not. The purpose of this study was to assess the effects of lunate morphology, sex, and lunotriquetral interosseous ligament (LTIL) status on the radiologic measurement of the capitate-triquetrum joint (C-T distance). Further, we sought to evaluate the diagnostic accuracy of C-T distance for assessing LTIL injuries.

Materials & Methods—We retrospectively identified 223 wrists with wrist radiographs and MR arthrograms with contrast injection. Data collected included sex, lunate morphology and LTIL status from MR arthrography, and C-T distance from radiography. The effects of lunate morphology, sex, and LTIL injury status on C-T distance were evaluated using generalized linear models. Diagnostic performance of C-T distance was assessed by the area under receiver-operator characteristic curve (AUROC).

Results and conclusion—Lunate morphology, sex, and LTIL injury status all had significant effects on C-T distance; wrists with type II lunates, men, and wrists with LTIL injuries had greater C-T distances than wrists with type I lunates, women, and wrists without LTIL injuries, respectively ($p<0.01$). The diagnostic value of the C-T distance was sufficient for women with type I (AUROC=0.67) and type II lunates (0.60) and good for men with type I (0.72) and type II lunates (0.77). The demonstrated influence of LTIL status on C-T distance supports the use of C-T distance as a tool for assessing full-thickness LTIL tears.

Keywords

wrist injuries; carpal bones; sex characteristics; ligaments; radiography; diagnostic techniques and procedures

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CONFLICT OF INTEREST
The authors declare that they have no conflict of interest.

INTRODUCTION

The lunotriquetral interosseous ligament (LTIL) is considered one of two primary intrinsic ligaments responsible for supporting the proximal carpal row and ensuring proper carpal kinematics [1, 2]. When LTIL integrity is compromised, commonly due to a tear, the lunate may experience greater flexion [3-5]. Disruption of the LTIL may therefore introduce dysfunctions in carpal kinematics and changes in static carpal alignment beyond the proximal carpal row. Early detection of LTIL disruption, a common cause of ulnar-sided wrist pain, is essential for optimal treatment; chronic injury can potentially lead to volar intercalated segmental instability, at which point more complicated surgical interventions may become necessary [6-8].

Lunate bones are anatomically classified into two types – type I and type II – based on the absence and presence of an additional articular facet on the lunate, respectively [9]. Conventional radiographs have limited reliability for visually classifying lunate morphology, so the shortest distance between the capitate and triquetrum (C-T distance) on posteroanterior wrist radiographs has been employed in the classification [10-12]. Nakamura et al. [10] found that, on average, wrists with type II lunates had a greater C-T distance than those with type I lunates. This increase in C-T distance has been attributed to hamate movement through the capitate-triquetrum joint to articulate with the lunate [10, 13]. Prior research also suggests that there are sex-specific differences in carpal structure and kinematics [14-17]. However, there is a lack of data regarding how C-T distance varies for each sex. There is also limited research concerning how C-T distance varies with LTIL injury for each lunate morphology and for each sex. Given that the lunate demonstrates increased flexion after LTIL sectioning, LTIL injury might increase C-T distance via increased lunate flexion into the capitate-triquetrum joint [3, 5].

Our first objective is to evaluate the association of lunate morphology, sex, and LTIL injury with C-T distance. Our second objective is to determine the diagnostic accuracy of C-T distance as a biomarker for full-thickness LTIL tears.

METHODS & MATERIALS

Patient selection

Our study received local Institutional Review Board approval and the requirement for informed consent was waived because it was done retrospectively and without collecting patient identifiers. Patients were identified from our Department of Radiology Picture Archiving and Communication System database by running a search using keywords ‘wrist’ and ‘MR arthrogram’ for individuals of both sexes in the 18 to 45-year age range who had posteroanterior wrist radiographs. The 18 to 45-year age range was selected to reduce potential confounding by age-related wrist disorders. Other inclusion criteria included availability of MR arthrograms and neutral unilateral posteroanterior wrist radiographs acquired after pain onset or injury and in less than 30 days before the MR arthrogram. The neutral wrist position on radiography was defined as less than a 20-degree angle between the axes of the radius and third metacarpal bone. MR arthrography was considered our reference standard for classifying lunate morphology because its accuracy for this purpose is comparable with anatomic dissection [18]. Due to sex-specific data regarding C-T distance being unavailable before we started the study, we were unable to determine sample sizes *a priori*. Two-hundred twenty-three (N(wrists)=223, N(participants)=220) wrist scans from 2004 through 2017 were sequentially identified and selected for the study (see Fig 1 for patient selection flowchart; see Table 1 for age distributions). Demographic data collected from each participant included sex and age at the time of MR arthrogram acquisition. Images were evaluated by a radiology researcher (observer 1) and a fellowship trained, board certified musculoskeletal radiologist with 20 years of experience (observer 2).

Lunate morphology

Observer 1 classified lunate morphology as type I or type II based on the absence or presence of an additional articular facet seen on MR arthrography, respectively (Fig 2).

To assess the inter-observer (observers 1 and 2) and intra-observer (observer 1) agreements for lunate classification from MR arthrography, a preliminary set of 33 randomly chosen wrist MR arthrograms was used. To assess agreement for classifications of lunate morphology derived from MR arthrograms versus conventional radiographs, observer 1 re-assessed lunate morphology using only conventional radiographs for a randomly selected set of 40 participants (20 type I lunates and 20 type II lunates) three months after the initial data collection.

LTIL status

Both observers identified LTILs as having a full-thickness defect or ‘torn’ when contrast injected into the radiocarpal compartment extravasated into the midcarpal compartment or contrast injected into the midcarpal compartment extravasated into the radiocarpal compartment via the lunotriquetral interval; observers classified all other LTILs as ‘not torn’ [19]. LTIL injury status was evaluated using static fluoroscopic images and MR arthrograms (see Figs 3, 4, 5, and 6 for examples of full-thickness LTIL tears). Cine fluoroscopy was also evaluated to definitively identify the path of contrast passage between the midcarpal and radiocarpal joints for cases with concurrent scapholunate interosseous ligament tears and when available for all other subjects (see Fig 7 and 8 for examples). Diagnostic discrepancies between observers were resolved by consensus upon rigorous re-evaluation of all available scans prior to statistical analysis. Given that subregions of the LTIL lie oblique to the axial plane and that, at our institution, MR arthrograms are routinely acquired in the standard axial plane, we did not feel we could reliably localize the portion(s) of the LTIL that were torn [19].

C-T distance

On neutral posteroanterior wrist radiographs, observer 1 measured the C-T distance in millimeters as the shortest distance between the dorsal surfaces of the capitate and triquetrum bones (Fig 9) [10]. C-T distance was measured before LTIL condition was evaluated to minimize bias.

To determine the reproducibility of the C-T distance measurement, observer 1 re-assessed C-T distance for a randomly selected set of 40 participants (20 type I lunates and 20 type II lunates) three months after the initial data collection.

Lunate facet

We measured the width of the additional articular facet on the lunate for all wrists with type II lunates. The lunate facet width for each wrist was measured in millimeters as a line connecting the two ends of the facet seen on the same wrist radiographs used to measure C-T distance.

Statistical analysis

Statistical analyses were performed using R version 3.3.1 (R Foundation for Statistical Computing, Vienna, Austria) and the 'Epi' package. Inter-observer, intra-observer, and inter-modality agreement for lunate morphology classifications were determined using Cohen's kappa coefficients. The intra-observer reliability of the C-T distance measurement was determined using an intraclass correlation coefficient.

A generalized linear model was used to determine the association of lunate morphology, sex, and LTIL injury with C-T distance. P-values below 0.05 were considered for statistical significance. The medians and 95-percent confidence intervals of C-T distance for each group of subjects with the same lunate morphology, sex, and LTIL status were calculated.

Diagnostic performance of C-T distance for assessing LTIL status was evaluated by determining the area under receiver-operator characteristic curve (AUROC) for each group of participants with the same lunate morphology and sex. AUROC values were used to label the biomarker as not useful (<0.5), bad (0.5-0.6), sufficient (0.6-0.7), good (0.7-0.8), very good (0.8-0.9), or excellent (0.9-1.0) for each group. The optimal C-T distance cutoff point and accompanying sensitivity and specificity values for each group of participants were also determined. The relationship between the width of the additional articular lunate facet in wrists with type II lunates and C-T distance was evaluated using a Pearson's correlation coefficient. Associations of sex and LTIL injury with lunate facet width were determined using a generalized linear model.

RESULTS

Inter- and intra-observer agreement

Inter-observer and intra-observer agreements for lunate classification from MR arthrograms were moderate (Cohen's kappa=0.76) and strong (Cohen's kappa=0.85), respectively. The intra-observer reproducibility of the C-T distance measurement was excellent (ICC=0.99).

Inter-modality agreement

Agreement for lunate classification from MR arthrograms versus conventional radiographs was moderate (Cohen's kappa=0.65).

C-T distance

Using the generalized linear model, we found that sex, lunate morphology, and LTIL injury status all had significant effects on C-T distance (p<0.01). With sexes grouped, wrists with type II lunates had greater C-T distances than wrists with type I lunates for all LTIL statuses (Table 2). Men had greater C-T distances than women for all lunate types and LTIL statuses. Wrists with full-thickness tears of the LTIL had greater C-T distances than wrists without full-thickness tears within each sex and with sexes grouped.

Diagnostic accuracy

The diagnostic accuracy of C-T distance for identifying full-thickness LTIL tears was sufficient for women with type I (AUROC=0.67) and type II lunates (0.60). Diagnostic accuracy was good for men with type I (0.72) and type II lunates (0.77). Optimal cutoff values can be found in Table 3.

Lunate facet

There was a strong, positive correlation between lunate facet width and C-T distance in wrists with type II lunates (r=0.68). We also found that LTIL injury status had a significant association on lunate facet width (p<0.001), while sex did not. Further, the positive correlation between lunate facet width and C-T distance was stronger for wrists with full-thickness LTIL tears (r=0.85) compared to wrists without LTIL tears (r=0.55).

DISCUSSION

Our data demonstrated a relationship between lunate morphology, sex, LTIL injury, and C-T distance. In agreement with prior studies [10, 12], we found that wrists with type II lunates had greater C-T distances than wrists with type I lunates. We observed greater C-T distances in men compared to women, independent of lunate morphology and LTIL injury status. For each combination of sex and lunate morphology, LTIL injury was associated with greater C-T distances. The diagnostic performance of C-T distance for detecting full-thickness LTIL tears indicated its potential value as a biomarker and warrants further study. We also explored the relationship between width of the additional articular facet in wrists with type II lunates and C-T distance and found a stronger positive correlation between them for wrists with LTIL injury, perhaps a result of increased lunate-hamate articulation permitted by a widened C-T distance. With further research, the static carpal alignment changes we observed following LTIL injury could support the use of C-T distance as a clinical assessment tool. Quantitative measurements from conventional radiographs have been used in the clinical setting to identify patterns of static carpal instability caused by scapholunate ligament disruption and substantiate the need for further study [20-22]. While the scapholunate ligament is one intrinsic source of support for the proximal carpal row, static carpal stability also depends on LTIL integrity [23]. Disruption of the LTIL – a common cause of ulnar-sided wrist pain – has predominantly been investigated using arthroscopy, arthrography, or MR arthrography because presentation on conventional radiographs was thought to be limited to subtle changes within the proximal carpal row [6]. Our data demonstrate that C-T distance may be used in preliminary clinical assessment to justify the use of a ‘gold standard’ imaging modality when investigating suspicion of LTIL injury with ulnar-sided wrist pain. Given that conventional radiographs are widely available and non-invasive, biomarkers such as C-T distance that take advantage of this modality are practicable in the clinical setting. C-T distance might offer an advantage in assessing suspected LTIL tears over existing measures of sagittal lunate tilt due to the ease of differentiating carpal bones on posteroanterior radiographs compared to lateral radiographs [24].

We observed a greater increase in C-T distance with LTIL injury in men compared to women. Craigen and Stanley [16] noted that women were more likely to have ‘column’ wrists with a large amount of flexion/extension movement within the proximal carpal row, while men predominantly had ‘row’ wrists with movement along the path of radial/ulnar deviation. It is possible that baseline flexion of the lunate in female wrists obviates the effect of LTIL injury and consequent increased lunate flexion on C-T distance [3, 5]. Similarly, it is possible that male wrists experience less lunate flexion within the normal range of carpal kinematics, resulting in a pronounced increase in C-T distance following LTIL tear. Garcia-Elias et al. [17] observed greater wrist laxity in female wrists and increased scaphoid flexion in more lax wrists; our findings would support the idea that the greater laxity of female over male wrists allows for greater baseline lunate flexion and decreased change in C-T distance after LTIL tear. Considering our explanation that LTIL disruption would affect C-T distance via increased flexion of the lunate into the capitate-triquetrum joint space for all wrists, the differential effect of ligament tear on C-T distance based on sex supported by our data indicates sexual dimorphism in carpal kinematics as opposed to scaling differences.

The methods used in our study do present some limitations. The use of C-T distance as a biomarker might be limited by the need to identify lunate morphology via conventional radiography instead of MR arthrography, given that we found only moderate agreement between the two modalities for the classification of lunate morphology. Future studies might benefit from the use of other descriptors of lunate morphology such as lunate height, diameter, or appearance of the proximal articular surface on posteroanterior radiograph [25]. Availability of ligamentous injury diagnoses from other ‘gold standard’ procedures such as arthroscopy or availability of surgical correlations might also yield more accurate classifications of LTIL injuries by severity and functional subregion (i.e. dorsal, proximal, and volar subregions) [1, 23]. We were unable to evaluate pre-dynamic and dynamic patterns of carpal instability given the lack of radiographic stress views and dynamic imaging in our selected cohort; further, it is unlikely that C-T distance would be affected in these cases given that static changes in carpal alignment tend to reflect more severe cases of carpal instability [1]. A prospective study might also benefit from patient data which might differentiate between degenerative and traumatic ligament injuries. While our study did not account for wrists with multiple ligamentous injuries, we believe this would be an interesting area for future studies. We were unable to account for whether subjects had their dominant or non-dominant wrist examined, though there is no reason to believe this would affect our results [12]. We were also unable to control for aspects of wrist positioning, like the extent of flexion-extension and pronation-supination, at the time of image acquisition due to the retrospective nature of our study. A prospective study with a longitudinal component would best clarify the sex-related differences in C-T distance with LTIL injury and indicate whether an increased C-T distance in men is indicative of injury or predisposition to injury.

To acknowledge the contribution of the scapholunate interosseous ligament to maintaining proximal carpal row stability, we incorporated scapholunate interosseous ligament condition into the generalized linear model used during early data analysis. We did not see a significant association between full-thickness scapholunate interosseous ligament tear and C-T distance, so given our limited sample size and statistical power and the lack of a relationship between scapholunate interosseous ligament tear and C-T distance, scapholunate interosseous ligament injury was not considered in our final statistical analyses.

Our study confirmed the relationship between C-T distance and lunate morphology, and investigated the associations between C-T distance, lunate morphology, sex, and LTIL injury. We demonstrated that individuals with type II lunates had greater C-T distances than individuals with type I lunates. Furthermore, we found that C-T distance was greater in men than women and in wrists with a full-thickness LTIL tear versus without. The C-T distance has potential as a complementary tool for assessing LTIL status using conventional radiographs.

Acknowledgments

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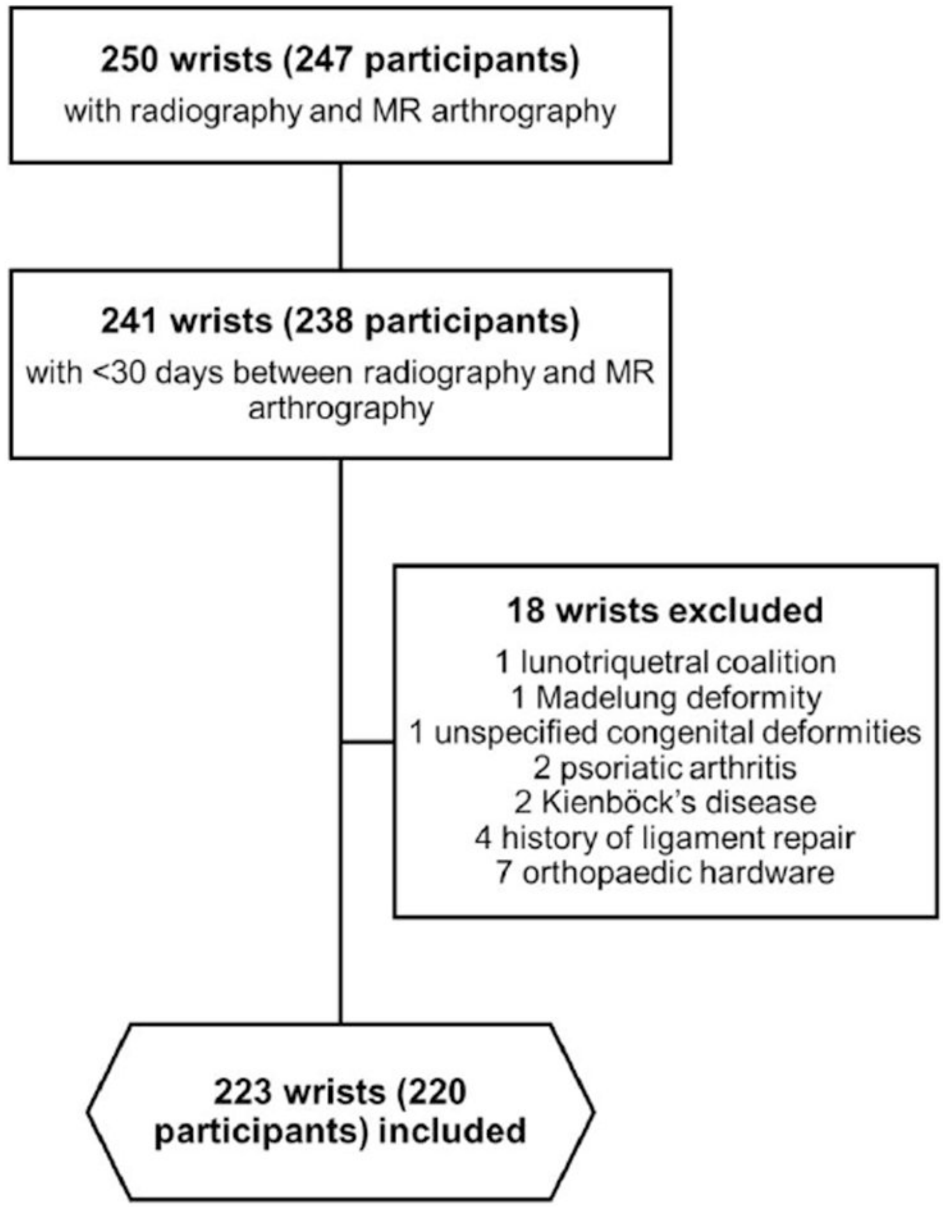


Fig 1.
Flowchart of patient selection

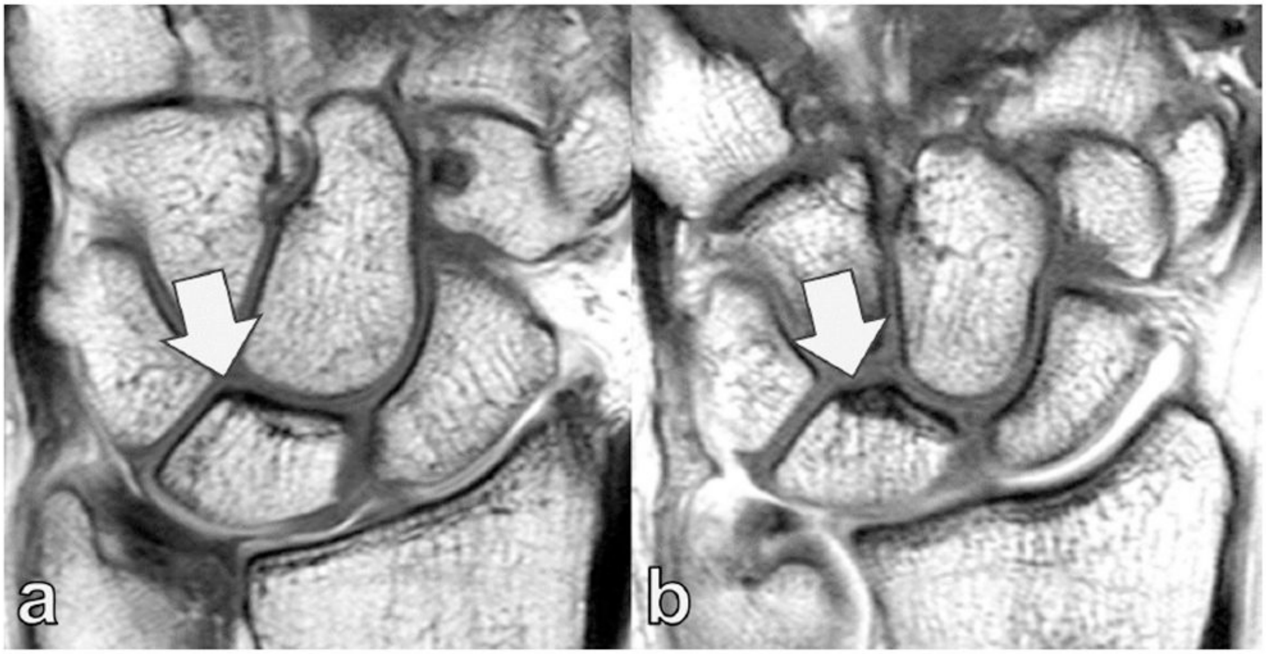


Fig 2.

Examples of type I (**a**) and type II (**b**) lunates as seen on coronal T1-weighted MR arthrogram; arrows point to the absence and presence of an additional articular facet on the lunate, respectively

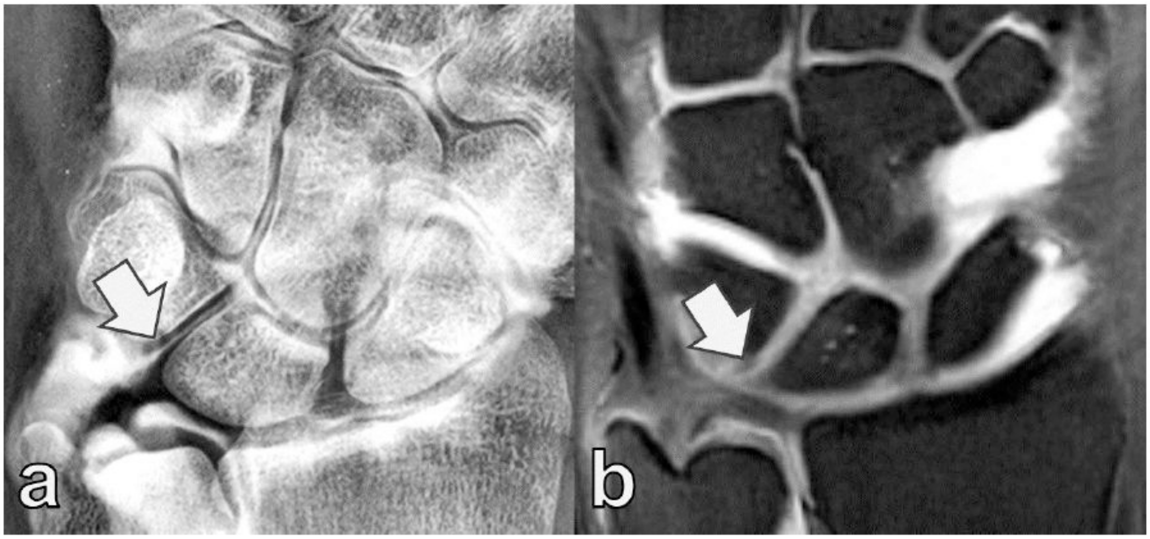


Fig 3.

Thirty-two-year-old man with full-thickness LTIL tear indicated by arrows on (**a**) arthrogram and (**b**) coronal fat-suppressed T1-weighted MR arthrogram

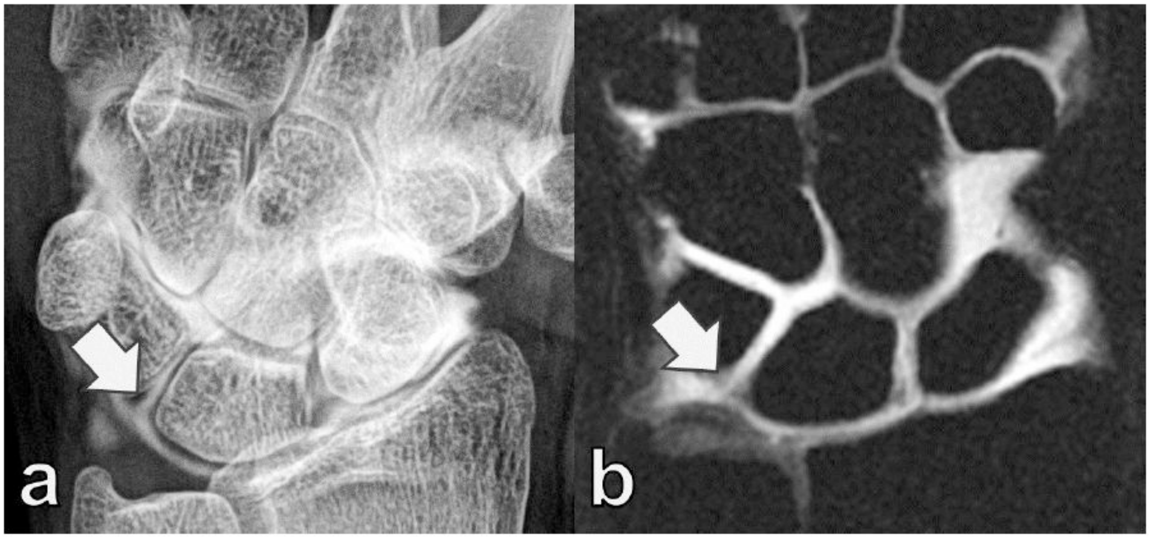


Fig 4.

Twenty-year-old woman with full-thickness LTIL tear indicated by arrows on (**a**) arthrogram and (**b**) coronal fat-suppressed T1-weighted MR arthrogram

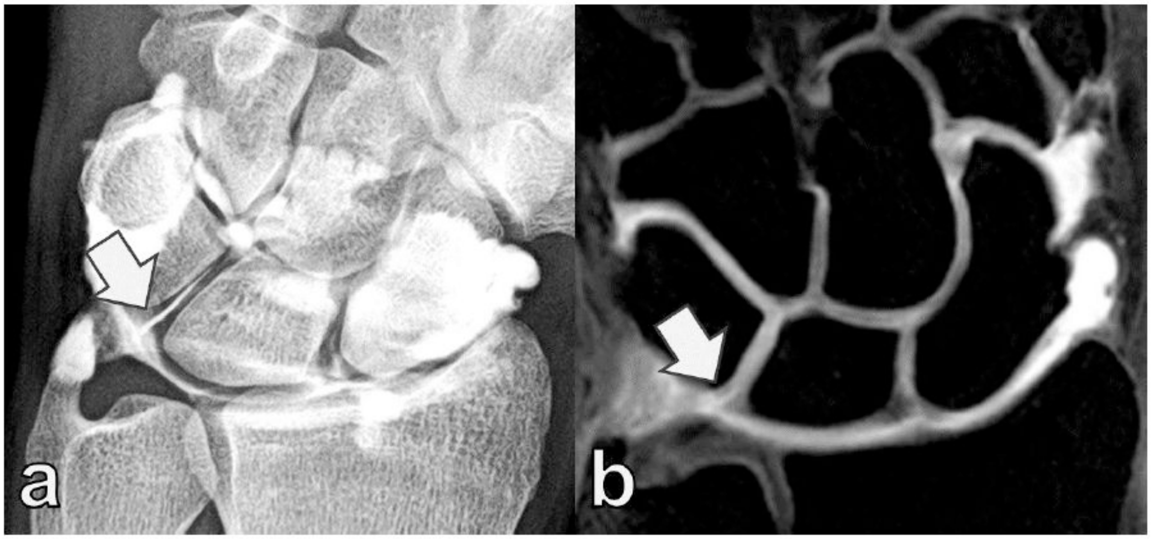
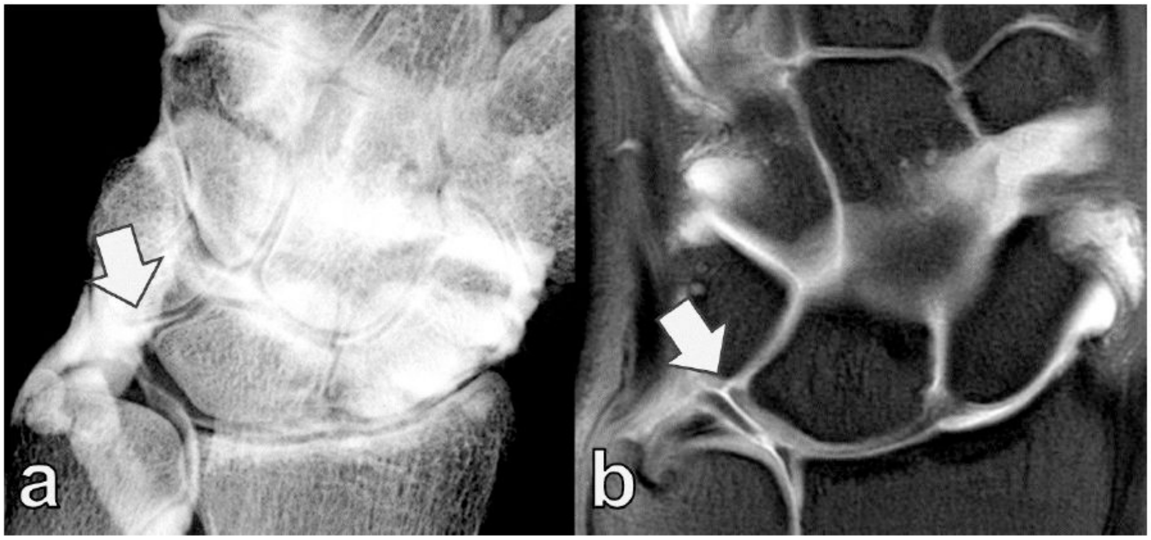


Fig 5.

Twenty-one-year-old man with full-thickness LTIL tear indicated by arrows on (**a**) arthrogram and (**b**) coronal fat-suppressed T1-weighted MR arthrogram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b

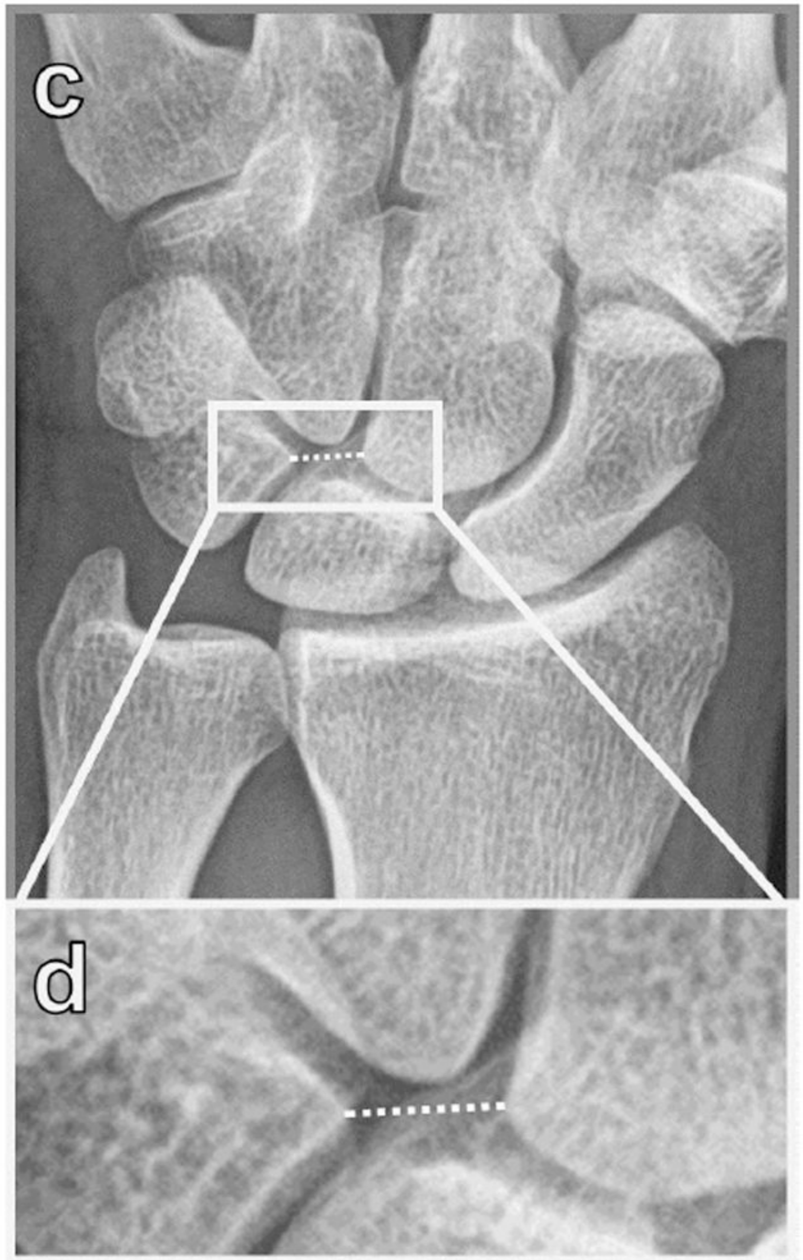


Fig 6.

Thirty-one-year-old man with full-thickness LTIL tear indicated by arrows on (**a**) arthrogram and (**b**) coronal fat-suppressed T1-weighted MR arthrogram

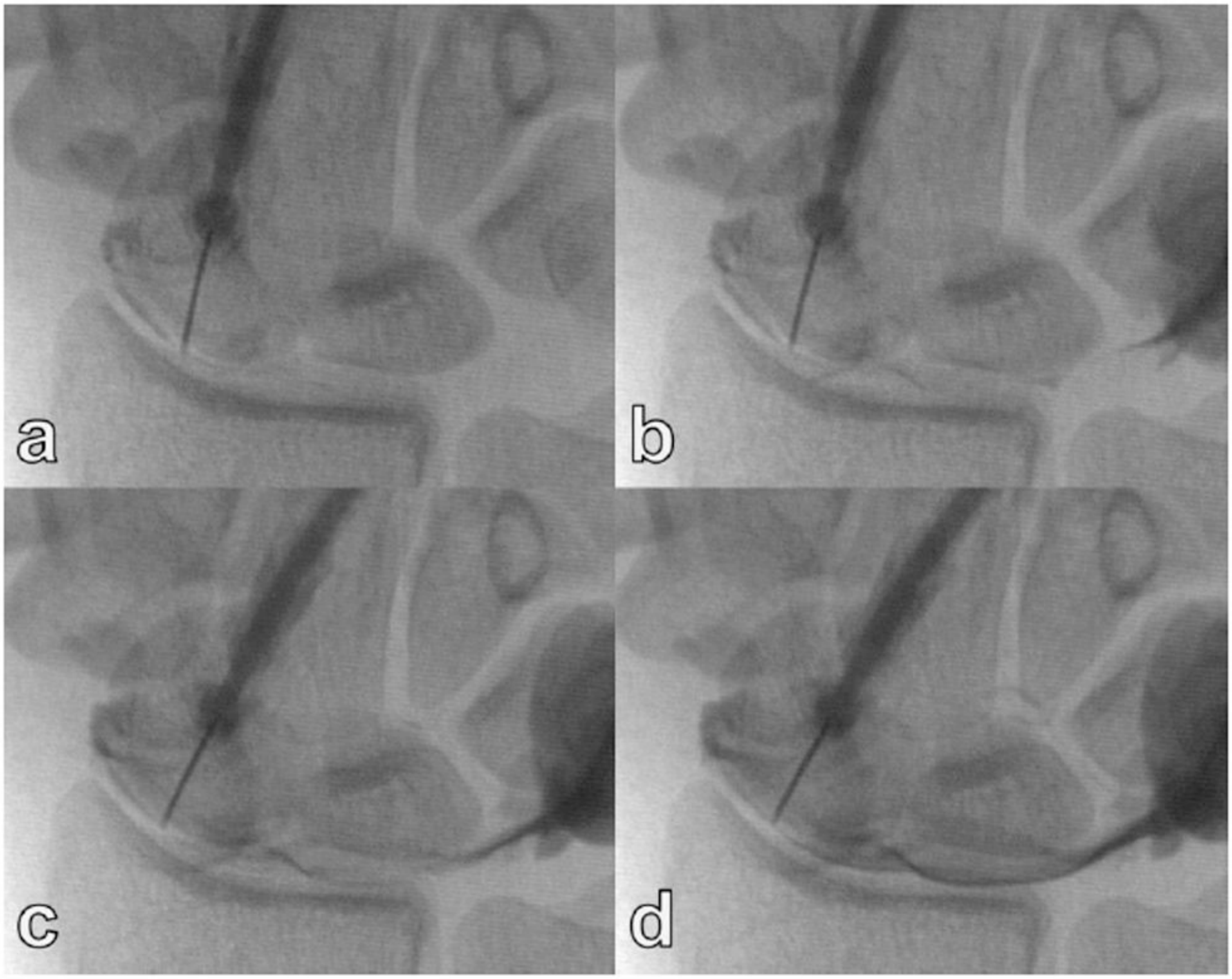


Fig 7.
Forty-one-year-old man with full-thickness LTIL tear indicated by extravasation of contrast from the radiocarpal to the midcarpal compartment through the lunotriquetral joint as seen at four time points (**a-d**) on cine fluoroscopy

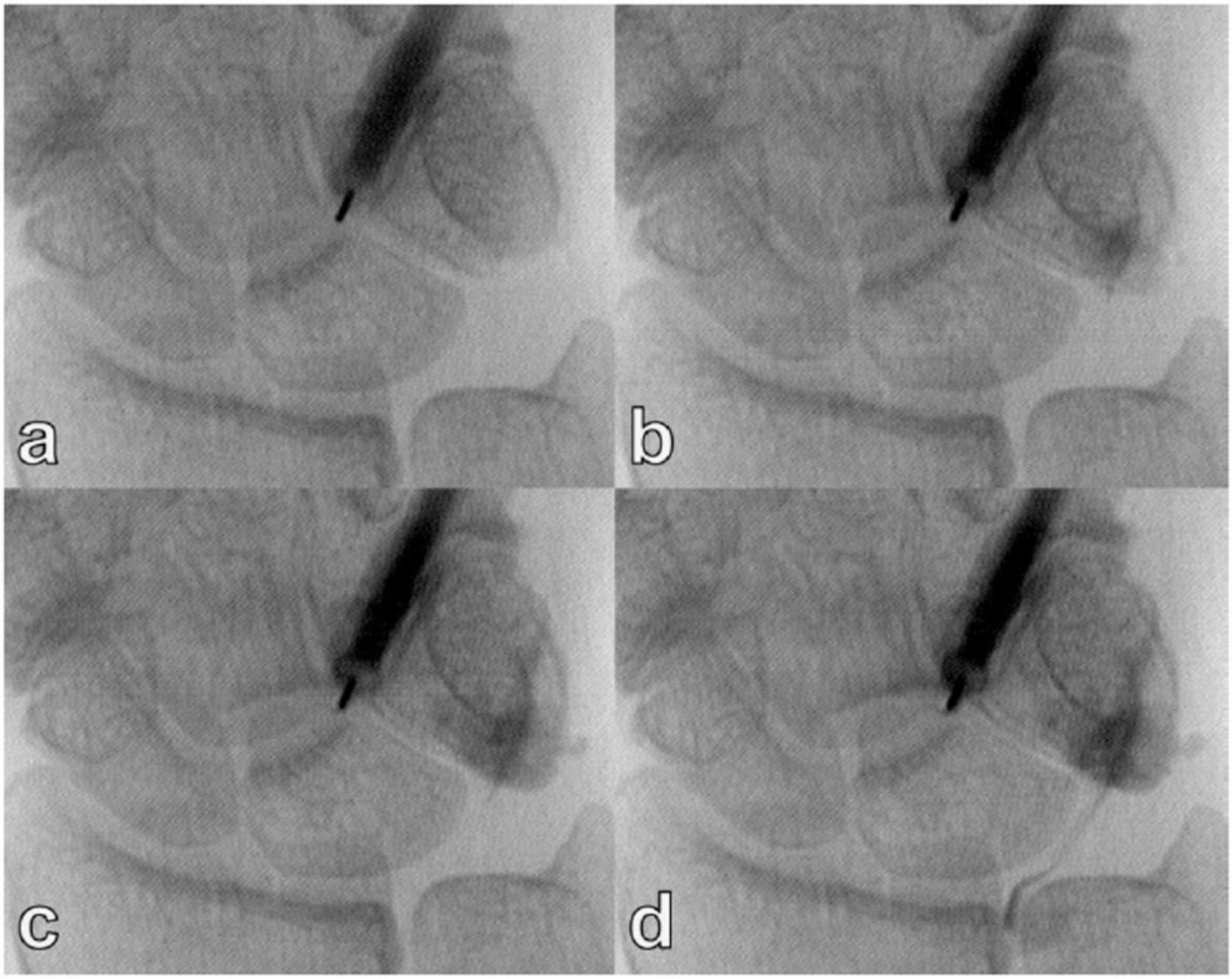
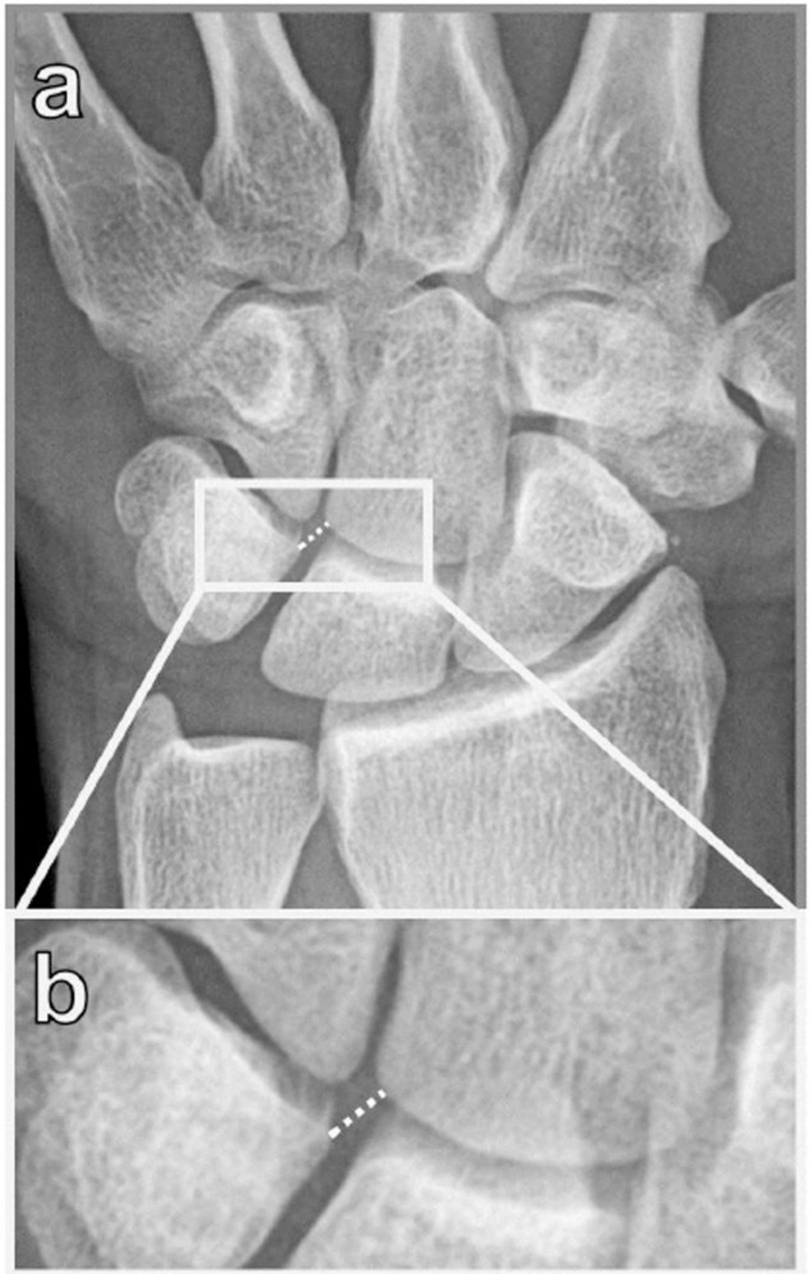


Fig 8.
Forty-two-year-old woman with full-thickness LTIL tear indicated by extravasation of contrast from the midcarpal to the radiocarpal compartment through the lunotriquetral joint as seen at four time points (**a-d**) on cine fluoroscopy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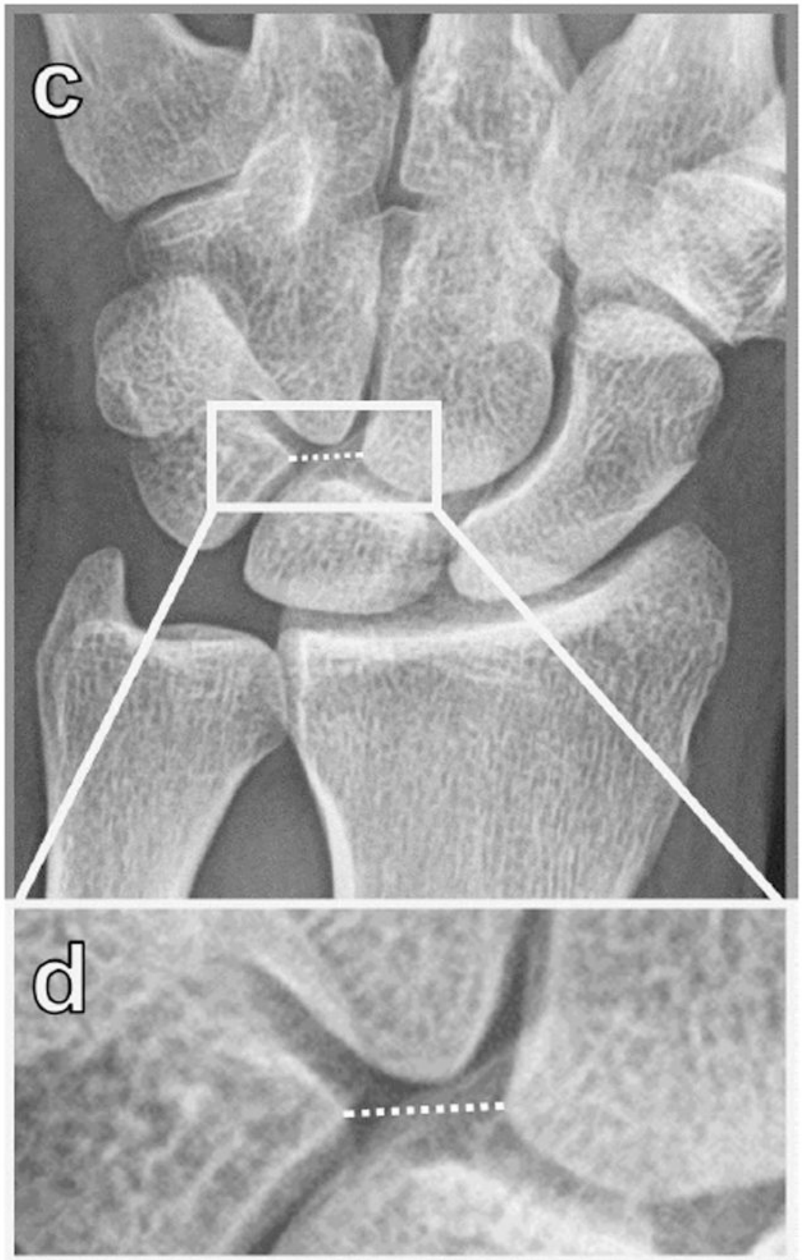

Fig 9.

Examples of the C-T distance measurement on posteroanterior radiographs for wrists with a type I (**a, b**: 3.2mm) and type II (**c, d**: 7.0mm) lunate

Table 1

LTIL status	Women (N=98)	Men (N=125)
Not torn	31 (18-44)	31 (18-44)
Torn	33 (19-42)	35 (20-44)

Numbers are mean (range) years of age

Table 2

LTIL status	Sex	Type I lunate C-T distance (mm)	Type II lunate C-T distance (mm)
Not torn	Women	2.5 (2.1-2.7)	4.3 (4.0-4.6)
	Men	2.7 (2.3-3.1)	4.5 (4.4-5.0)
	Grouped	2.6 (2.3-2.8)	4.4 (4.3-4.8)
Torn	Women	2.8 (1.6-4.5)	4.9 (3.5-6.0)
	Men	3.7 (2.4-5.2)	6.4 (5.6-7.1)
	Grouped	3.7 (2.6-4.5)	6.1 (5.3-6.6)

Numbers are median (95% CI)

Table 3

Lunate morphology	Sex	Sample size	Cutoff (mm)	Sensitivity (%)	Specificity (%)
Type I	Women	32	≥3.2	50	93
	Men	28	≥3.6	67	90
Type II	Women	66	≥4.7	63	67
	Men	97	≥5.9	67	82

Cutoff is the optimal C-T distance threshold for assessing full-thickness LTIL tears, found by maximizing sensitivity + specificity