



Changes in the morphology of the triangular fibrocartilage complex (TFCC) on magnetic resonance arthrography related to disruption of ulnar foveal attachment

Ji Hun Park¹ · Kyung-Sik Ahn² · Anseong Chang¹ · Young Woo Kwon³ · In Cheul Choi³ · Jong Woong Park³

Received: 22 April 2019 / Revised: 24 June 2019 / Accepted: 4 July 2019 / Published online: 18 July 2019
© ISS 2019

Abstract

Objective To assess whether a proximal ligamentous component (PLC) of the triangular fibrocartilage complex (TFCC) with a distally prolapsing morphology is associated with the presence of a TFCC foveal tear on arthroscopy.

Methods One-hundred thirty-two patients (134 wrists) who underwent MR arthrography and subsequent wrist arthroscopy between September 2014 and March 2018 were retrospectively evaluated. The degree of distal PLC prolapse was measured on coronal MR arthrography using the height-to-length ratio (HLR). Subjects' demographics, ulnar variance, presence of a degenerative TFCC tear, and ulnar styloid nonunion were assessed. The association between specific variables and the presence of a foveal tear was investigated.

Results A TFCC foveal tear was identified in a total of 101 of 134 wrists examined by arthroscopy. Univariable analysis showed that the HLR of the PLC was significantly greater in the foveal tear group compared with the intact fovea group (44.6 vs. 38.9%, respectively, $p < 0.001$). Multivariable analysis showed that HLR was positively associated with a foveal tear (odds ratio [OR], 1.211; $p < 0.001$). The estimated cut-off value of the HLR was 41% (area under the curve [AUC] 0.77).

Conclusions PLCs with a distal prolapse pattern and large HLR are associated with TFCC foveal tears. The HLR of the PLC measured on coronal MR images can therefore be used as an additional predictor of tears of the foveal attachment of the TFCC.

Keywords Triangular fibrocartilage complex · Ulnar fovea · Morphology · Wrist arthroscopy · Magnetic resonance arthrography

Introduction

The triangular fibrocartilage complex (TFCC) is a multifunctional three-dimensional link comprising several anatomic structures and spanning the radius, ulna, and carpus [1]. The articular disk and the dorsal and volar radioulnar ligaments make up the horizontal portion of the complex, referred to as the proximal ligamentous component (PLC) [2]. The two radioulnar ligaments of the PLC span the ulnar corners of the distal radius and form an apical attachment at the ulnar

fovea that acts as a primary stabilizer of the distal radioulnar joint (DRUJ) [3]. Disruption of the foveal attachment may cause instability of the DRUJ that requires surgical repair [4, 5].

Despite clinical recognition of the importance of TFCC foveal tears, the diagnosis remains challenging owing to the involvement of ulnocarpal joint, which contains numerous fine-scale structures and has a complex geometry. Recent studies have suggested that high-resolution magnetic resonance imaging (MRI) at 3 T is a promising technique for evaluating the integrity of the TFCC [6, 7]. Furthermore, magnetic resonance (MR) arthrography techniques and increased spatial resolution can provide better assessment of the intraarticular pathology of the wrist [8–10]. Despite these advances, evaluating TFCC mobility and dynamic stability using these techniques has several limitations [11]. In addition, the reported sensitivity, specificity, and accuracy of MRI vary widely among studies [6, 12–14].

Arthroscopic examination is generally considered a reference standard in the diagnosis of TFCC tears [12, 13]. The

✉ Jong Woong Park
ospark@korea.ac.kr

¹ Department of Orthopedic Surgery, Korea University Guro Hospital, 148 Gurodong-ro, Guro-gu, Seoul 08308, South Korea

² Department of Radiology, Korea University Anam Hospital, 73, Incheon-ro, Sungbuk-gu, Seoul 06334, South Korea

³ Department of Orthopedic Surgery, Korea University Anam Hospital, 73, Incheon-ro, Sungbuk-gu, Seoul 06334, South Korea

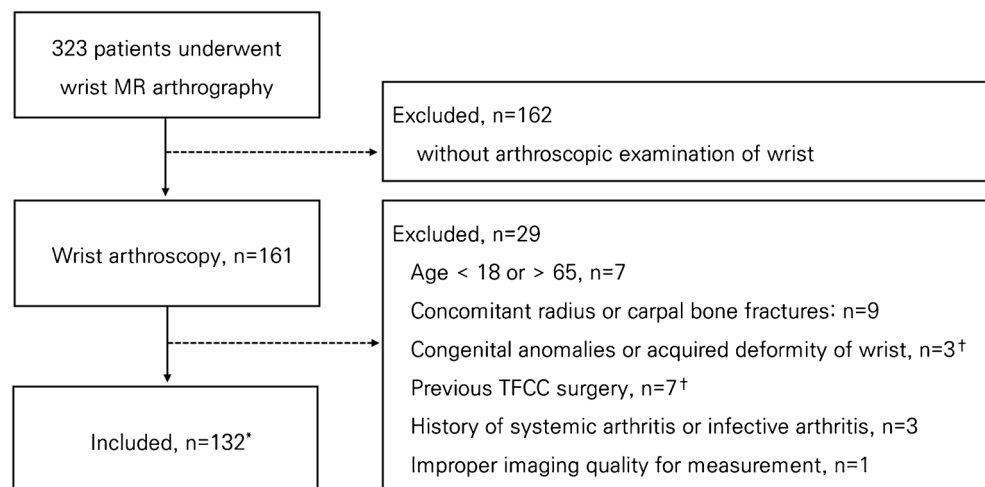
arthroscopic hook test can be used to assess foveal insertion of the TFCC [15]. A positive hook test occurs when the TFCC can be displaced off the ulna head by the probe, reliably identifying foveal disruption [16]. Loss of tension in the PLC after foveal tear can result in a positive test, suggesting that there may be a morphologic change reflecting tensioning loss of the PLC. To assess TFCC integrity as well as dynamic stability in imaging studies, secondary changes that occur after a foveal tear may provide important diagnostic information. However, differences in the morphology of the ligamentous component itself after a foveal tear have not been investigated in detail.

We hypothesized that TFCC foveal disruption would cause curvature of the PLC, resulting in a more distally prolapsed pattern with a direction opposite to that of the proximal foveal attachment. Thus, the purpose of this study was to determine if the extent of PLC distal prolapse on coronal MR arthrography is associated with TFCC foveal integrity as assessed by arthroscopy.

Materials and methods

A retrospective analysis was performed based on the medical records and imaging studies of 323 consecutive patients who underwent wrist MR arthrography at a single tertiary hospital between September 2014 and March 2018. Institutional Review Board approval was obtained for the study. MR arthrography is used more widely at our institute than conventional MRI for patients with suspected intraarticular pathology of the wrist joint based on previous reports on the accuracy of MR arthrography [8–10]. We excluded patients younger than 18 years, older than 65 years, and those with a congenital anomaly such as Madelung deformity, a concomitant acute radius or carpal bone fracture, previous surgical history on the same wrist, systemic arthritis, or soft tissue infection in the region of the wrist (Fig. 1).

Fig. 1 Flowchart showing patient selection from 2014 to 2018 (two patients had both wrist examination, *asterisk*; one individual had both conditions, *dagger*)



A total of 134 wrists from 132 patients met the study criteria and were enrolled. Radiographic series included the following positions: neutral wrist posteroanterior (PA) film with 90° shoulder abduction, maximal radial-ulnar deviation, pronated grip position, and lateral wrist view. Ulnar variance was measured in neutral PA view using the method of perpendiculars [17]. The mean time interval between performing MR arthrography and arthroscopy was 51 days (range, 1–172 days). No additional traumatic events were reported during this period. The preoperative clinical diagnosis was traumatic TFCC tear in 111 cases, ulnar impaction syndrome in 18 cases, ganglion cysts in four cases, and ulnar styloid impaction syndrome in one case. On arthroscopic examination, degenerative changes of the TFCC were assessed according to the Palmer classification by inspecting the ulnocarpal cartilage, TFCC perforation, and carpal ligament status [18]. Peripheral tears of the TFCC were subdivided according to the Atzei-EWAS (European Wrist Arthroscopy Society) classification as follows: Atzei class 2, a complete (both distal and proximal component) TFCC tear; and Atzei class 3, an isolated proximal (foveal) TFCC tear [15]. TFCC foveal tears were confirmed with a positive hook test. The hook test was performed by placing a probe into the prestyloid recess and applying a distally and radially directed traction force to the TFCC periphery as described previously [15, 19]. The test was recorded as positive when the TFCC could be displaced off the ulna head by the probe. Patients were divided into the TFCC foveal tear group or intact fovea group according to the results of the hook test.

Magnetic resonance arthrography

MR arthrography was performed using 3.0-T scanners with dedicated coil: Prisma (Siemens, Erlangen, Germany), Skyra (Siemens, Erlangen, Germany), and Achieva TX (Philips Medical Systems, Eindhoven, Netherlands). Intraarticular injections were performed using fluoroscopic guidance in the

sequence of the DRUJ followed by midcarpal joint for wrist MR arthrography as previously described [20]. DRUJ injection volume was approximately 2 ml, consisting of a 1:1 mixture of iodinated contrast (Omnipaque 300, GE Healthcare, Shanghai, China) and diluted (2.5 mmol/l) gadoteric acid (Dotarem, Guerbet, Roissy, France) solution. Larger volumes up to 4 ml were used when contrast material entered the radiocarpal joint from the DRUJ. When contrast material did not enter the radiocarpal joint from the DRUJ, a second contrast injection volume of 2–3 ml was performed immediately into the midcarpal joint. The wrist was placed in the prone position parallel to the long axis of the gantry with the center of the bore was determined by a laser mark. The following sequences were collected: fat-saturated T1-weighted turbo spin-echo sequences in the coronal, axial, and sagittal planes (slice thickness, 2.00–2.50 mm; no intersection gap; matrix size, 448 × 389; FoV, 72 × 90 mm); T2-weighted turbo spin-echo sequences in the coronal plane (slice thickness, 2.00 mm; no intersection gap; matrix size, 448 × 357; FoV, 75 × 90 mm); and fat-saturated THRIVE turbo fluid echo sequence in the coronal plane (slice thickness, 0.45 mm; no intersection gap; matrix size, 232 × 224; FoV, 80 × 90 mm). Data from the MR arthrography review from musculoskeletal radiologists made prior to arthroscopy were collected for the specific intraarticular pathology, including TFCC status. A TFCC foveal tear was diagnosed when signal changes were found at the peripheral foveal attachment or continuity loss of TFCC fiber with dye filling was noted at the foveal attachment site.

The amount of distal prolapse of the TFCC was measured on coronal MR images by calculating the height-to-length ratio (HLR) of the PLC (Fig. 2). HLR was defined as “height” divided by “length”, where “height” was defined as the perpendicular distance between a line perpendicular to the ulnar longitudinal axis passing the foveal recess and the most distal margin of the PLC, while “length” was defined as the perpendicular distance between the radius attachment point of the PLC to the center of the ulnar styloid base. The final ratio was multiplied by 100%. This measurement property has not been proposed as a diagnostic approach to MRI of TFCC and was newly employed for this study specifically to provide objective measurement of the degree of TFCC prolapse, which would be subjectively difficult to confirm. The triangular fibrocartilage angle (TFCA) was measured to compare the radiologic status of the PLC disc proper between groups as described in a previous imaging study [21]. The TFCA was measured as a straight line drawn parallel to the horizontal line from the radius attachment point of the TFCC to the center of the thinnest part of the disc (Fig. 3). For each patient, T1-weighted fat-suppressed coronal MR images were used to measure the HLR and TFCA. Image sections were selected at the thinnest central portion of the TFC in order to standardize measurements to a specific coronal section. All images were measured using digital angle and distance-measuring

tools integrated into our picture archiving and communication system. All measurements were independently evaluated twice with a 2-week interval by two experienced orthopedic surgeons and the mean values of each measurement were used for the final analysis. The inter- and intraobserver reproducibility of all measurements were analyzed by calculating the intraclass correlation coefficient (ICC).

Statistical analysis

A post hoc power analysis showed that a sample size of 134 wrists would have sufficient power to detect a difference in the HLR in the foveal tear group versus the intact fovea group with a precision of 5% (effect size 0.38, power 0.99). We assessed variables with the potential to contribute to individual differences in TFCC morphology, including, age, sex, subject hand, ulnar variance, degenerative TFCC central tears, and presence of an ulnar styloid fragment. Radiologic parameters and assessed variables were compared between the foveal tear group and intact fovea group. The Kolmogorov–Smirnov test was used to test the normality of variable distributions. Univariable analyses including Student’s *t* test for continuous data and Chi-square test for categorical data were performed as appropriate. Factors on univariable analysis with $p < 0.10$ were included in multivariable analysis. Logistic regression analysis was performed to control for potential confounders and explore radiographic parameters associated with TFCC foveal tears. Odds ratios with 95% confidence intervals and *p* values are reported. The Pearson correlation coefficient was calculated for radiologic parameters. Receiver operating characteristic (ROC) curve analysis was used to evaluate the prognostic performance of significant variables. The optimal cut-off value was determined to be the point on the ROC curve that was closest to the point with the following coordinates: (0,1). Subgroup analysis of the TFCC foveal tear group was performed to compare radiographic parameters between TFCC foveal tears with a distal component tear (Atzei class 2) and TFCC foveal tears without a distal component tear (Atzei class 3). A *p* value < 0.05 was considered statistically significant.

Results

A total of 101 wrists with TFCC foveal tears on arthroscopy were identified among the 134 enrolled wrists. Based on review of preoperative MR arthrography, 68 of 101 wrists had a foveal TFCC tear, whereas the remaining 33 had no peripheral tear, discordant with the result of arthroscopy.

Univariate analysis demonstrated that the HLR of the PLC was significantly greater in patients with a TFCC foveal tear (foveal tear, 44.6% SD 6.8%; intact fovea, 38.9% SD 3.9%, $p < 0.001$) (Fig. 4). Other variables including age, sex,

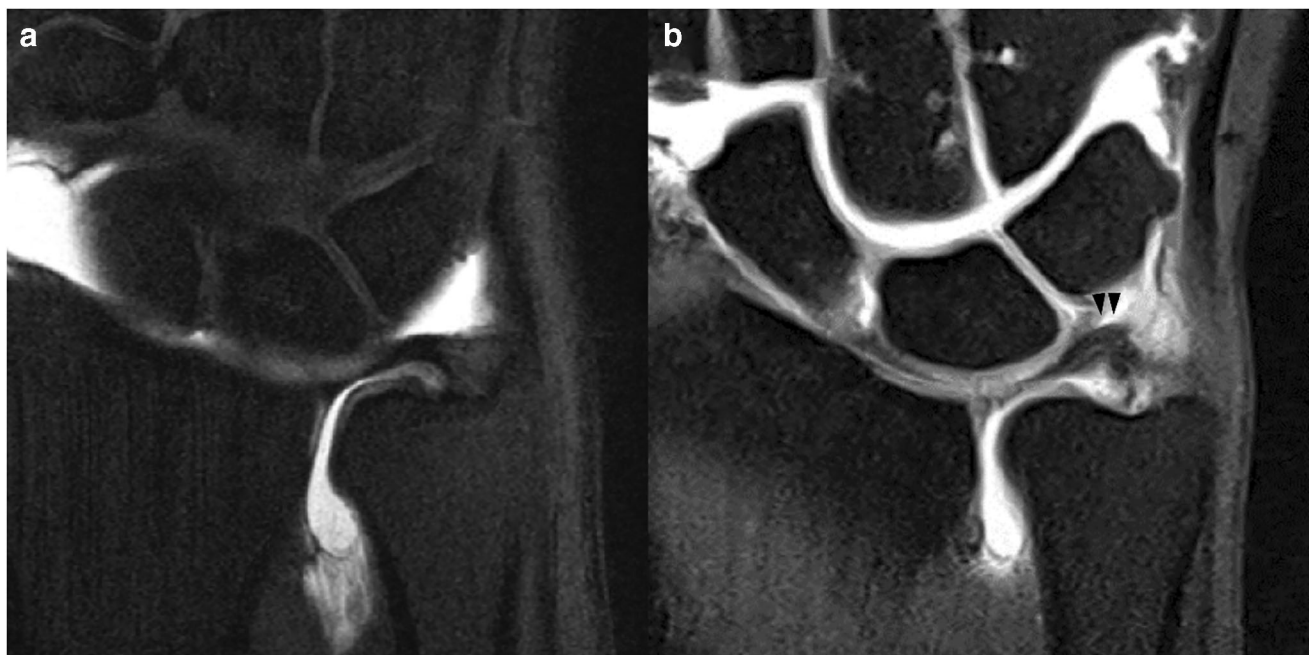


Fig. 2 Coronal morphologic differences of the TFCC. Coronal T1-weighted fat-suppressed MR arthrography images showing the proximal ligamentous component of the TFCC with a gentle curvature (**a**) and a more distally prolapsed curvature (**b**, *arrowheads*)

presence of degenerative TFCC central tears on arthroscopy, and presence of an ulnar styloid fragment were not significantly different between the two groups ($p < 0.05$ for all) (Table 1). Mean ulnar variance and TFCA were also not significantly different between the two groups ($p < 0.05$ for all). There

was a positive correlation between ulnar variance and TFCA ($r = 0.64$, $p < 0.001$), while ulnar variance and HLR were inversely correlated ($r = -0.28$, $p = 0.001$). No significant correlation was observed between TFCA and HLR ($p = 0.300$). The mean HLR of 33 wrists that showed discordant positive

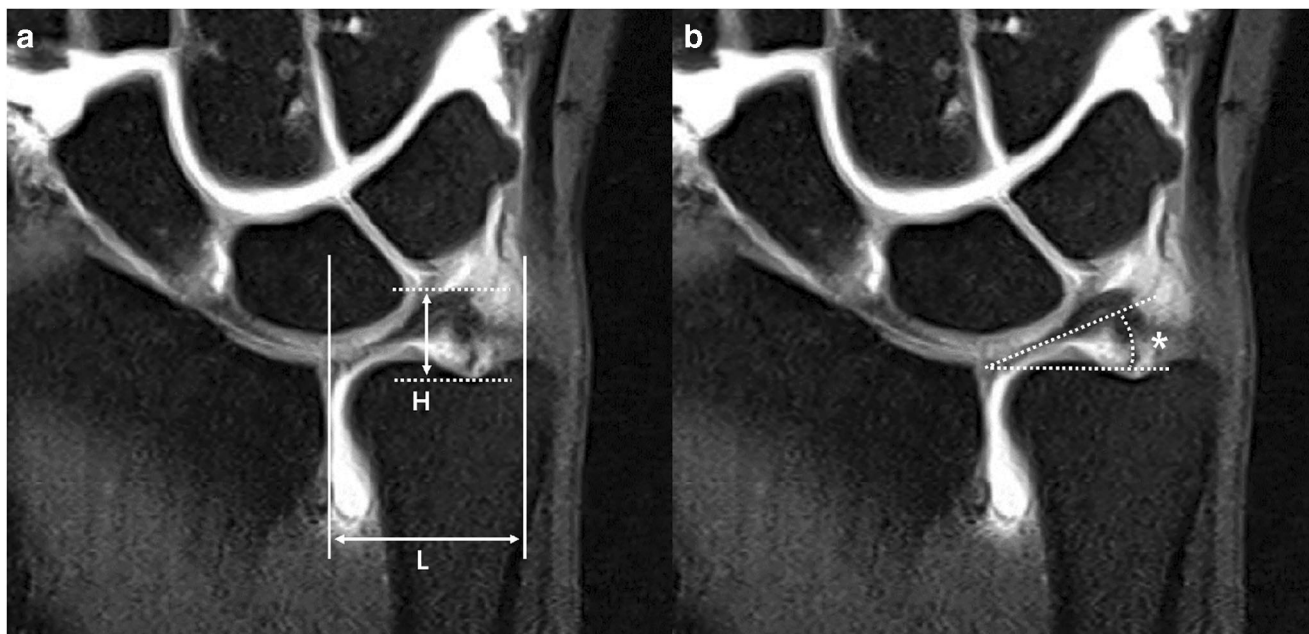


Fig. 3 Measurement of the height-to-length ratio (HLR) of the proximal ligamentous component (PLC) and triangular fibrocartilage angle (TFCA) on T1-weighted fat-suppressed MR arthrography images. **a** HLR is calculated as “height, H” divided by “length, L”, where “height” is defined as the distance between the line perpendicular to the ulnar longitudinal axis passing the foveal recess and the most distal margin of

PLC, and “length” is defined as the distance between the lines perpendicular to the radius attachment point of the PLC to the center of the ulnar styloid base. **b** The TFCA (*asterisk*) is measured by a straight line drawn parallel to the horizontal line from the radius attachment point of the TFCC to the center of the thinnest part of the disc

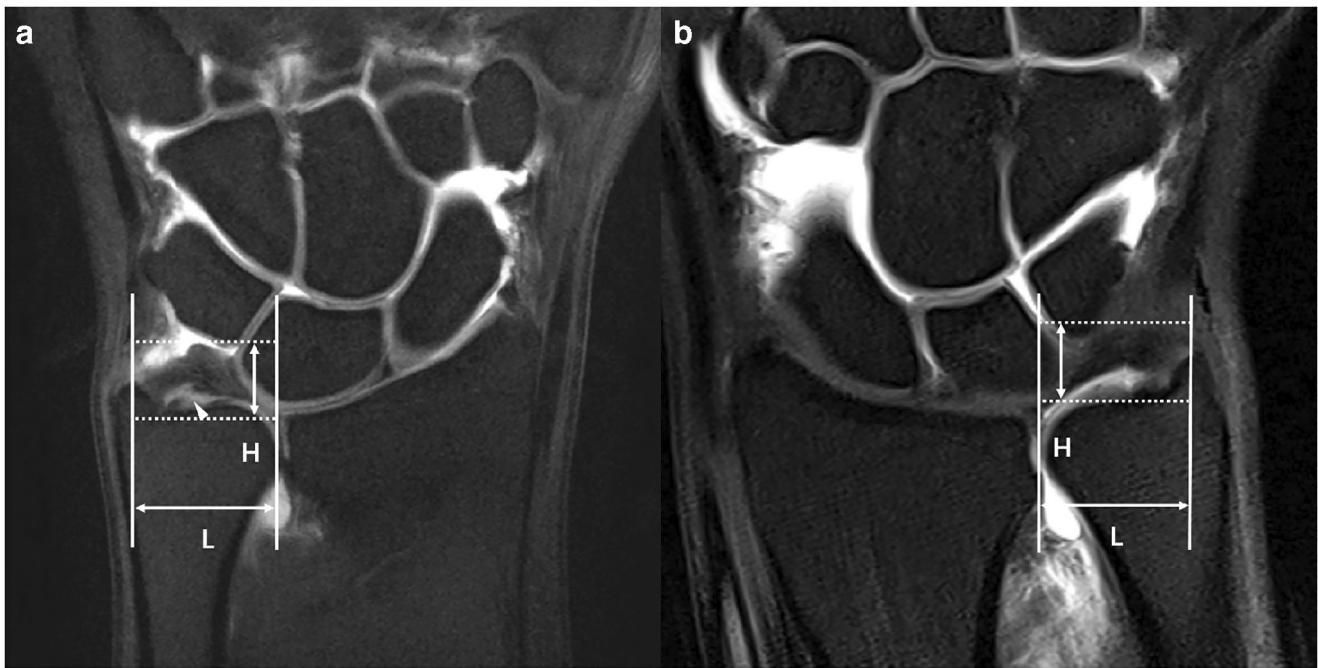


Fig. 4 Examples of HLR measurements in patients diagnosed with a TFCC foveal tear. **a** On coronal T1-weighted fat-suppressed MR arthrography, the calculated height-to-length ratio (HLR) was 46%. The initial MR arthrography report was interpreted as a TFCC peripheral foveal tear (*arrowhead*). Subsequent arthroscopy showed a positive hook

test. **b** On coronal T1-weighted fat-suppressed MR arthrography, the calculated HLR was 45%. The MR arthrography was reviewed as preserved TFCC. Subsequent arthroscopy showed a positive hook test indicating TFCC foveal disruption

arthroscopy and negative arthrography results for foveal tear was $44.0\% \pm \text{SD } 6.2\%$ and their mean TFCA was $25.3^\circ \pm \text{SD } 6.9^\circ$. Among the MR arthrography reports of 162 wrists excluded from this study due to no record of arthroscopy, 64 wrists were described as partial or complete tears of TFCC foveal attachment. The mean HLR of the excluded wrists was $40.3\% \pm \text{SD } 7.6\%$, and the mean TFCA was $24.6^\circ \pm \text{SD } 8.1^\circ$.

On multivariate logistic regression analysis, a greater HLR was associated with TFCC foveal tears (odds ratio [OR] 1.211, 95% CI 1.097–1.336, $p = 0.001$). Presence of an ulnar

styloid fragment showed no significant association with foveal tears ($p = 0.194$) (Table 2). The model satisfied the assumption of linearity between the covariates and the dependent variable. The estimated cut-off value of the ROC curve for HLR was 41% (Fig. 4). The area under the ROC (AUC) curve was 0.77 (95% CI 0.69–0.85, $p < 0.001$) (Fig. 5).

Within the TFCC foveal tear group, 76 wrists showed a complete tear on arthroscopy (Atzei class 2) and the remaining 25 showed a proximal tear (Atzei class 3). There was no significant difference in HLR and TFCA between patients with

Table 1 Demographic and clinical characteristics of the study patients

Variable	TFCC foveal tear ($n = 101$)	TFCC with intact fovea ($n = 33$)	p value
Mean age (years)	33.2 (SD 13.0, 18 to 65)	35.7 (SD 13.5, 18 to 63)	0.359*
Gender (male), n (%)	66 (65)	18 (55)	0.265†
Wrists (right), n (%)	68 (67)	19 (59)	0.451†
Mean ulnar variance (mm)	1.5 (SD 1.3)	1.6 (SD 1.4)	0.582*
Mean TFCA ($^\circ$)	25.8 (SD 7.1)	24.8 (SD 8.0)	0.503*
Mean HLR of PLC (%)	44.6 (SD 6.8)	38.9 (SD 3.9)	<0.001*
Degenerative TFCC central tear, n (%)	12 (12)	5 (15)	0.624†
Presence of ulnar styloid fragment, n (%)	20 (20)	2 (6)	0.064†

* p value, independent t test

† p value, Chi-square test

TFCC triangular fibrocartilage complex, HLR height-to-length ratio, PLC proximal ligamentous complex, SD standard deviation

Table 2 Multivariable logistic regression analysis of measured parameters for TFCC morphology on MR arthrography^a

Variable	Standard error	Odds ratio	95% CI	<i>p</i> value
HLR of PLC (%)	0.050	1.211	1.097 to 1.336	< 0.001
Presence of ulnar styloid fragment*	0.819	2.900	0.582 to 14.444	0.194

^a Variables with a *p* value in univariable analysis of < 0.1 were included as potential confounders in the multivariable model

HLR height-to-length ratio, PLC proximal ligamentous complex, CI confidence interval

an Atzei class 2 tear (HLR 44.6 SD 7.6, TFCA 26.5° SD 7.6°) and those with an Atzei class 3 tear (HLR 44.5 SD 6.6, TFCA 25.6° SD 7.0°) (*p* > 0.05) (Table 3).

The interobserver intraclass correlation coefficients (ICC) for ulnar variance, TFCA, and HLR were 0.87, 0.76, and 0.81, respectively. The intraobserver ICCs for ulnar variance, TFCA, and HLR were 0.90, 0.79, and 0.84, respectively.

Discussion

The TFCC comprises two radioulnar ligaments that extend from the ulnar corners of the distal radius and attach to the apical region of the ulnar fovea. In this study, we investigated the coronal shape of the PLC on MR arthrography performed for patients diagnosed with TFCC foveal insertion rupture on arthroscopy. We performed this study because the characteristic morphology of the TFCC after rupture of the ligamentous portion has not previously been evaluated in detail. We found that the degree of distal prolapse of the PLC as measured by the HLR was associated with foveal tears.

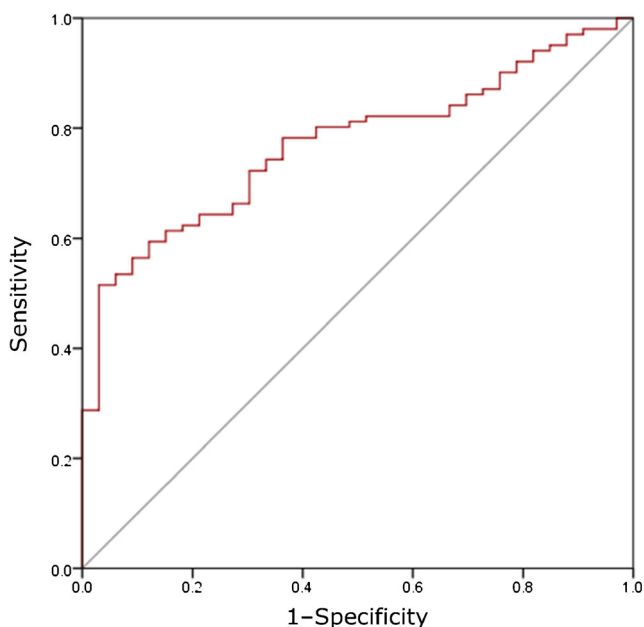


Fig. 5 Receiver operating characteristic curve of the height-to-length ratio of the proximal ligamentous component (red line) associated with foveal tears of the triangular fibrocartilage complex

Changes in the shape of the radioulnar ligament of the TFCC have recently become an area of interest [3, 22–24]. Schuind et al. [3] demonstrated radioulnar ligament changes in the axial plane, with both shortening and elongation of the radioulnar ligament observed during forearm rotation. In addition, a cadaveric study described twisting of the ulnar insertion of the radioulnar ligament according to forearm rotation [23]. These results suggest that the tension of the radioulnar ligament changes with rotation in the axial plane, resulting in changes to the length of the radioulnar ligament. Consistent with these findings, several imaging studies have demonstrated changes in both the coronal shape of the TFCC as well as length. Nakamura et al. [25] found that the disc proper of the TFCC becomes thinner with maximum pronation on coronal MR images. Yamanaka et al. [21] quantified coronal morphologic changes of the TFCC after ulnar shortening osteotomy by measuring TFCA. They observed that the ulnar insertion of the TFCC is pulled down as the ulna becomes shortened, suggesting that tightening or loosening of the TFCC due to environmental changes or movement may change the coronal morphology. In the present study, we investigated whether there were morphologic differences in the TFCC in the coronal plane in the presence of a foveal tear. However, rather than relying on the length of the radioulnar ligament, we used a ratio of height to length to better investigate overall changes in the shape of the ligamentous complex detached from the fovea. This approach was based on our hypothesis that use of the height-to-length ratio might reflect changes in the tautness of the radioulnar ligament.

Our results showed that both groups had a similar ulnar variance, and we found that the TFCC had a greater HLR in the presence of a distally prolapsed pattern, reflecting a more distal curvature of the radioulnar ligament. No proximal curvature of the TFCC was observed in our study. Several factors may contribute to this characteristic morphology. The geometry of the ulnar head and fovea, which abut the TFCC, may promote curvature of the radioulnar ligament. Thus, with detachment of the radioulnar ligament from the fovea, the curvature may become aggravated by tension on the distal connected structures, such as the ulnotriquetral and lunotriquetral ligaments, which originate from the volar radioulnar ligament and insert into the lunate and triquetrum. However, this prolapse pattern was not represented by the TFCA, which is measured in the central portion abutting the ulnar and lunate

Table 3 Subgroup analysis of TFCC foveal tear group comparing radiologic parameters between complete tear (Atzei class 2) and proximal tear (Atzei class 3) subgroups

Variable	TFCC complete tear (Atzei class 2) (n = 25)	TFCC proximal tear (Atzei class 3) (n = 76)	p value
Mean TFCA (°)	26.5 (SD 7.6)	25.6 (SD 7.0)	0.566
Mean HLR of PLC (%)	44.6 (SD 7.6)	44.5 (SD 6.6)	0.954

TFCC triangular fibrocartilage complex, TFCA triangular fibrocartilage angle, HLR height-to-length ratio, PLC proximal ligamentous complex, SD standard deviation

bones. We speculated that this finding was due to the fact that distal prolapses progress towards the more redundant space of the ulnar side to the tip of the triquetrum rather than the central portion. Interestingly, correlation analysis showed that while TFCA increased as the ulnar positive variance increased, HLR decreased. This may have been due to the decrease in ulnocarpal space with increasing ulnar variance. As most patients in this study had ulnar positive variance, TFCA may not have been significantly affected by peripheral attachment of TFCC due to possible contact with the ulnar head. On the other hand, attachment of the TFCC on the fovea is more proximal in the ulnar negative variance wrist. The pull back of the PLC after foveal disruption in the ulnar positive variance wrist may be less associated with shrinkage of the HLR than in the ulnar-negative wrist.

We found that 25% of the cohort with TFCC foveal tears had a complete peripheral tear on arthroscopy. When subgroup analysis was performed to compare TFCC proximal tears (Atzei class 3), and TFCC complete tears (Atzei class 2), presence of a distal component tear was not associated with a difference in HLR. Interestingly, there was no significant difference when wrists with or without an ulnar styloid fragment were compared, suggesting that the parameter we measured as height reflects the effect of a deep fiber tear rather than a superficial fiber tear.

Development of high-resolution MRI at 3.0 T has led to an increase in the diagnostic precision of TFCC pathology; however, high-resolution MRI is not available in every clinical situation. Furthermore, diagnostic results vary widely among studies and TFCC tear sites. As the proximal component of the peripheral TFCC mainly contributes to DRUJ instability, changes in signal that do not distinguish peripheral to proximal and peripheral to distal do not necessarily correspond to clinical instability. Therefore, several studies have analyzed secondary changes to obtain additional information about TFCC tears. Ulnar subluxation, which occurs mainly due to foveal tears, has been investigated extensively [26, 27]. Ehman et al. [28] proposed the use of an ulnar subluxation ratio and reported that it could predict TFCC foveal tears with high predictive power. Likewise, our results suggest that a large HLR can be another secondary measure of changes to TFCC associated with DRUJ instability. Clinicians should be aware that a TFCC with a large HLR may have a foveal tear.

This is one of the largest cohort studies of patients with TFCC foveal tears performed to date. A strength of our study lies in its large sample size and the fact that arthroscopic information was available for all subjects. A limitation of this study is that we performed two-dimensional analysis of the three-dimensionally structured TFCC. However, as shown in previous studies [21, 25], 2D analysis is often suitable for observing biomechanical and morphological changes and is easier to access in a clinical setting. Second, although patients in both the foveal tear group and intact fovea group showed similar demographics and ulnar variance, there may have been inclusion bias. Because most MR imaging studies are performed based on suspicion of wrist intraarticular pathology at our institution, our findings should be interpreted cautiously for populations with different patient and clinical demographics. Third, this study used the arthroscopic hook test as a reference standard, which may have introduced potential verification bias. Although the hook test is currently recognized as an acceptable reference standard, differences in interpretation may exist among examiners. Also, there may have been confirmation bias because the MRI report was accessible to the surgeon at the time of arthroscopy. Fourth, this study did not evaluate whether intraarticular injection of gadolinium into both the DRUJ and midcarpal compartments for MR arthrography affected TFCC shape. If MRI is used instead of MR arthrography, the results of this study will be limited. Finally, evaluation of HLR was not directly compared with MR criteria for detecting foveal tears. Therefore, it was not possible to conclude whether HLR measurement can be used as an alternative to MR criteria. For diagnostic use of morphologic changes of TFCC, other diagnostic image findings of foveal tears and their potential synergistic effects should be considered and verified in future studies.

Conclusions

PLC with a distally prolapsed morphology as represented by a large HLR was associated with TFCC foveal tears. HLR of the PLC can therefore be used as an additional predictor of tears of the foveal attachment of the TFCC.

Funding The authors did not receive any outside funding or grants in support of their research or for the preparation of this work.

Compliance with ethical standards

Conflict of interest The authors have no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

- Nakamura T, Yabe Y, Horiuchi Y. Functional anatomy of the triangular fibrocartilage complex. *J Hand Surg Br.* 1996;21:581–6.
- Nakamura T, Makita A. The proximal ligamentous component of the triangular fibrocartilage complex. *J Hand Surg Br.* 2000;25:479–86.
- Schuind F, An KN, Berglund L, et al. The distal radioulnar ligaments: a biomechanical study. *J Hand Surg Am.* 1991;16:1106–14.
- Park JH, Kim D, Park JW. Arthroscopic one-tunnel transosseous foveal repair for triangular fibrocartilage complex (TFCC) peripheral tear. *Arch Orthop Trauma Surg.* 2018;138:131–8.
- Nakamura T, Sato K, Okazaki M, Toyama Y, Ikegami H. Repair of foveal detachment of the triangular fibrocartilage complex: open and arthroscopic transosseous techniques. *Hand Clin.* 2011;27:281–90.
- Ochman S, Wieskotter B, Langer M, Vieth V, Raschke MJ, Stehling C. High-resolution MRI (3T-MRI) in diagnosis of wrist pain: is diagnostic arthroscopy still necessary? *Arch Orthop Trauma Surg.* 2017;137:1443–50.
- Zhan H, Zhang H, Bai R, Qian Z, Liu Y, Zhang H, et al. High-resolution 3-T MRI of the triangular fibrocartilage complex in the wrist: injury pattern and MR features. *Skelet Radiol.* 2017;46:1695–706.
- Lee RK, Ng AW, Tong CS, et al. Intrinsic ligament and triangular fibrocartilage complex tears of the wrist: comparison of MDCT arthrography, conventional 3-T MRI, and MR arthrography. *Skelet Radiol.* 2013;42:1277–85.
- Berna-Serna JD, Martinez F, Reus M, Alonso J, Domenech G, Campos M. Evaluation of the triangular fibrocartilage in cadaveric wrists by means of arthrography, magnetic resonance (MR) imaging, and MR arthrography. *Acta Radiol.* 2007;48:96–103.
- Schweitzer ME, Brahme SK, Hodler J, et al. Chronic wrist pain: spin-echo and short tau inversion recovery MR imaging and conventional and MR arthrography. *Radiology.* 1992;182:205–11.
- Andersson JK, Andernord D, Karlsson J, Friden J. Efficacy of magnetic resonance imaging and clinical tests in diagnostics of wrist ligament injuries: a systematic review. *Arthroscopy.* 2015;31:2014–20.
- Hobby JL, Tom BD, Bearcroft PW, Dixon AK. Magnetic resonance imaging of the wrist: diagnostic performance statistics. *Clin Radiol.* 2001;56:50–7.
- Magee T. Comparison of 3-T MRI and arthroscopy of intrinsic wrist ligament and TFCC tears. *AJR Am J Roentgenol.* 2009;192:80–5.
- Schmauss D, Pohlmann S, Lohmeyer JA, Germann G, Bickert B, Megerle K. Clinical tests and magnetic resonance imaging have limited diagnostic value for triangular fibrocartilaginous complex lesions. *Arch Orthop Trauma Surg.* 2016;136:873–80.
- Atzei A, Luchetti R. Foveal TFCC tear classification and treatment. *Hand Clin.* 2011;27:263–72.
- Trehan SK, Wall LB, Calfee RP, et al. Arthroscopic diagnosis of the triangular fibrocartilage complex foveal tear: a cadaver assessment. *J Hand Surg Am.* 2018;43:680.e1.
- Palmer AK, Glisson RR, Werner FW. Ulnar variance determination. *J Hand Surg Am.* 1982;7:376–9.
- Palmer AK. Triangular fibrocartilage complex lesions—a classification. *J Hand Surg-Am.* 1989;14:594–606.
- Ruch DS, Yang CC, Smith BP. Results of acute arthroscopically repaired triangular fibrocartilage complex injuries associated with intra-articular distal radius fractures. *Arthroscopy.* 2003;19:511–6.
- Ruegger C, Schmid MR, Pfirrmann CW, Nagy L, Gilula LA, Zanetti M. Peripheral tear of the triangular fibrocartilage: depiction with MR arthrography of the distal radioulnar joint. *AJR Am J Roentgenol.* 2007;188:187–92.
- Yamanaka Y, Nakamura T, Sato K, Toyama Y. How does ulnar shortening osteotomy influence morphologic changes in the triangular fibrocartilage complex? *Clin Orthop Relat R.* 2014;472:3489–94.
- Adams BD, Holley KA. Strains in the articular disk of the triangular fibrocartilage complex: a biomechanical study. *J Hand Surg Am.* 1993;18:919–25.
- Nakamura T. Triangular fibrocartilage complex: functional anatomy and histology. *Nihon Seikeigeka Gakkai Zasshi.* 1995;69:168–80.
- af Ekenstam F, Hagert CG. Anatomical studies on the geometry and stability of the distal radio ulnar joint. *Scand J Plast Reconstr Surg.* 1985;19:17–25.
- Nakamura T, Yabe Y, Horiuchi Y. Dynamic changes in the shape of the triangular fibrocartilage complex during rotation demonstrated with high-resolution magnetic resonance imaging. *J Hand Surg Br.* 1999;24:338–41.
- Mino DE, Palmer AK, Levinsohn EM. Radiography and computerized-tomography in the diagnosis of incongruity of the distal radio-ulnar joint—a prospective-study. *J Bone Joint Surg Am.* 1985;67:247–52.
- Wechsler RJ, Wehbe MA, Rifkin MD, Edeiken J, Branch HM. Computed tomography diagnosis of distal radioulnar subluxation. *Skelet Radiol.* 1987;16:1–5.
- Ehman EC, Hayes ML, Berger RA, Felmler JP, Amrami KK. Subluxation of the distal radioulnar joint as a predictor of foveal triangular fibrocartilage complex tears. *J Hand Surg-Am.* 2011;36:1780–4.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.