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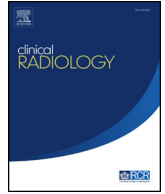2017-10-01

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High-resolution 3 T MRI of traumatic and degenerative triangular fibrocartilage complex (TFCC) abnormalities using Palmer and Outerbridge classifications

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ARTICLE INFORMATION

AIM: To investigate the usefulness of high-resolution 3 T magnetic resonance imaging (MRI) for the evaluation of traumatic and degenerative triangular fibrocartilage complex (TFCC) abnormalities among three groups: patients presenting with wrist pain who were (a) younger than age 50 years or (b) age 50 or older (PT<50 and PT≥50, respectively), and (c) asymptomatic controls who were younger than age 50 years (AC).

MATERIALS AND METHODS: High-resolution 3 T MRI was evaluated retrospectively in 96 patients, including 47 PT<50, 38 PT≥50, and 11 AC. Two board-certified radiologists reviewed the MRI images independently. MRI features of TFCC injury were analysed according to the Palmer classification, and cartilage degeneration around the TFCC was evaluated using the Outerbridge classification. Differences in MRI findings among these groups were detected using chi-square test. Cohen's kappa was calculated to assess interobserver and intra-observer reliability.

RESULTS: The incidence of Palmer class 1A, 1C and 1D traumatic TFCC injury was significantly ($p<0.05$) higher in PT≥50 than in PT<50 (class 1A: 47.4% versus 27.7%, class 1C: 31.6% versus 12.8%, and class 1D: 21.1% versus 2.1%). Likewise, MRI findings of TFCC degeneration were observed more frequently in PT≥50 than in PT<50 ($p<0.01$). Outerbridge grade 2 or higher cartilage degeneration was significantly ($p<0.01$) more frequently seen in PT≥50 than in PT<50 (55.3% versus 17% in the lunate, 28.9% versus 4.3% in the triquetrum, 73.7% versus 12.8% in the ulna).

CONCLUSION: High-resolution wrist MRI at 3 T enables detailed evaluation of TFCC traumatic injury and degenerative changes using the Palmer and Outerbridge classifications, with good or excellent interobserver and intra-observer reliability.

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Introduction

Ulnar-sided wrist pain is attributable to several disease entities, and accurate diagnosis is important.[1,2] The Palmer classification has been widely used for diagnosis of traumatic or degeneration abnormalities of the triangular fibrocartilage complex (TFCC), including evaluation of carpal bone cartilage[3]; however, it is often difficult and challenging to differentiate between traumatic injury and degenerative change at magnetic resonance imaging (MRI) because of complex ulnar-sided wrist anatomy and limited published knowledge or experience on MRI findings of degenerative changes.[4,5]

Degeneration of the wrist articular cartilage is described according to the subtypes of Palmer class 2 injury. Although the Outerbridge classification system has been widely used in cartilage evaluation of the knee,[6] application to the wrist joint has been limited by low spatial and contrast resolution on conventional MRI, resulting in poor diagnostic performance. In a prior study using 1.5 T MRI,[7] sensitivity for detection of cartilage abnormalities in the carpal bones and distal radius was 18–41%, and the weighted kappa values for interobserver reproducibility showed only fair agreement (0.279–0.360). Recent advances in 3 T high-resolution MRI have enabled precise evaluation of morphological changes in the ulnar-sided wrist, including in the articular cartilage.[8–10] Therefore, the primary objective of the present study was to evaluate imaging findings of traumatic injury and degenerative change using the Palmer classification at 3 T high-resolution MRI, with assessment of inter- and intra-rater reliability. A second objective was to evaluate cartilage degeneration around the TFCC using the Outerbridge classification, with assessment of inter- and intra-rater reliability. Based on prior cadaveric studies,[11,12] it was hypothesised that the incidence of abnormal imaging findings in the TFCC and the degree of wrist cartilage degeneration is different among three groups: patients presenting with wrist pain who were (a) younger than age 50 years or (b) age 50 or older (PT<50 and PT≥50, respectively), and (c) asymptomatic controls who were younger than age 50 years (AC).

Materials and methods

Participants

High-resolution 3 T MRI wrist examinations were evaluated retrospectively over a period from January 2012 through April 2015. The study encompassed a total of 96 subjects, including 47 patients with wrist pain who were younger than age 50 years (PT<50, mean age: 33.3 years.), 38 patients with wrist pain who were age 50 years or older (PT≥50, mean age: 61.5 years) and 11 asymptomatic control subjects who were younger than age 50 years (AC, mean age: 31.6 years). Regarding asymptomatic control subjects, four subjects were patients with painless subcutaneous nodules of the wrist, and seven subjects were healthy volunteers without wrist pain from the present previously published study approved by the Institutional Review Board (IRB).[8] The IRB approved this study, and written informed consent was waived because of its retrospective nature.

MRI parameters

All MRI images were obtained using an eight-channel wrist coil on a 3 T unit (Achieva TX, Philips Healthcare, Best, Netherlands). Each subject was placed in the supine position with the wrist at the side of the body and the forearm in neutral position. The following MRI sequences were reviewed for evaluation of this study: coronal three-dimensional (3D) isotropic fast spin echo (FSE) proton density-weighted images (PDWI)-fat suppression (FS), coronal two-dimensional (2D) FSE PDWI, coronal 2D FSE PDWI-FS, sagittal 2D FSE PDWI, sagittal 2D FSE PDWI-FS, axial 2D FSE PD and axial 2D FSE PDWI-FS. Imaging parameters are listed in Table 1. A parallel imaging technique named sensitivity encoding (SENSE) was used in both the 2D and 3D sequences. All 3D images were obtained in combination with the driven equilibrium (DRIVE) technique. Acquisition time was approximately 5 minutes for 3D isotropic MRI images and 2 minutes 30 seconds to 4 minutes for the 2D FSE sequences.

MRI interpretation

Two board-certified radiologists with 13 (R1) and 26 (R2) years of clinical experience in musculoskeletal radiology independently reviewed MRI images using a picture archiving and communication system (PACS) workstation (Impax 6.5.5, AGFA Healthcare, Greenville, SC, USA). One of the radiologists (R2) re-examined all studies after an 18-month interval for assessment of intra-observer variability. Patient clinical and demographic data were not provided. The Palmer classification was used to analyse the presence or absence of specific MRI features.[3] Palmer class 1 traumatic tears of the TFCC were characterised as follows: central perforation of the disc proper (class 1A), avulsion of the ulnar attachment (class 1B), distal avulsion (class 1C), or avulsion of the radial attachment (class 1D; Figs 1 and 2). Palmer class 2 degenerative changes were characterised as follows: fraying and mucoid degeneration of the disc proper, lunotriquetral ligament perforation, or ulnocarpal arthritis (Figs 3 and 4). Next, cartilage degeneration of the lunate, triquetrum, and ulna were evaluated based on the Outerbridge grading system as follows: grade 0, normal cartilage; grade 1, signal heterogeneity with normal cartilage thickness; grade 2, partial-thickness defect <50%; grade 3, partial thickness defect >50%; and grade 4, full-thickness cartilage loss.[6] Additional findings of cartilage degeneration that were assessed included the presence or absence of bone marrow oedema and degenerative cyst formation in the subchondral bone (Fig 5). Ulnar variance was measured in each patient by one radiologist. Discrepancies were resolved by means of consensus to evaluate the correlation of severity of Palmer and Outerbridge classifications with age.

Table 1
Magnetic resonance imaging parameters for the wrist.

|	2D	2D	2D	2D	2D	2D	3D
Sequence	Cor PD	Cor PD FS	Sag PD	Sag PD FS	Ax PD	Ax PD FS	Cor PD FS
Pixel size (mm × mm)	0.27 × 0.35	0.30 × 0.32	0.40 × 0.51	0.23 × 0.32	0.40 × 0.40	0.32 × 0.44	0.35 × 0.35
Section thickness (mm)	2.0	2.0	3.0	3.0	2.0	2.0	0.35
Section gap (mm)	0.2	0.2	0.3	0.3	0.2	0.2	0
Field of view (mm)	90	90	70—80	70—80	80	80	70
Echo time (ms)	30	27	30	27	30	30	29—37
Repetition time (ms)	3500	2500—3500	3000	2500—3500	2500	3000	1250—1400
Bandwidth (Hz/pixel)	194	222	354	175	250	153	362
Echo train length	13	13	12	13	9	11	70—88
No. of excitations	1	3	1	1	2	2	2
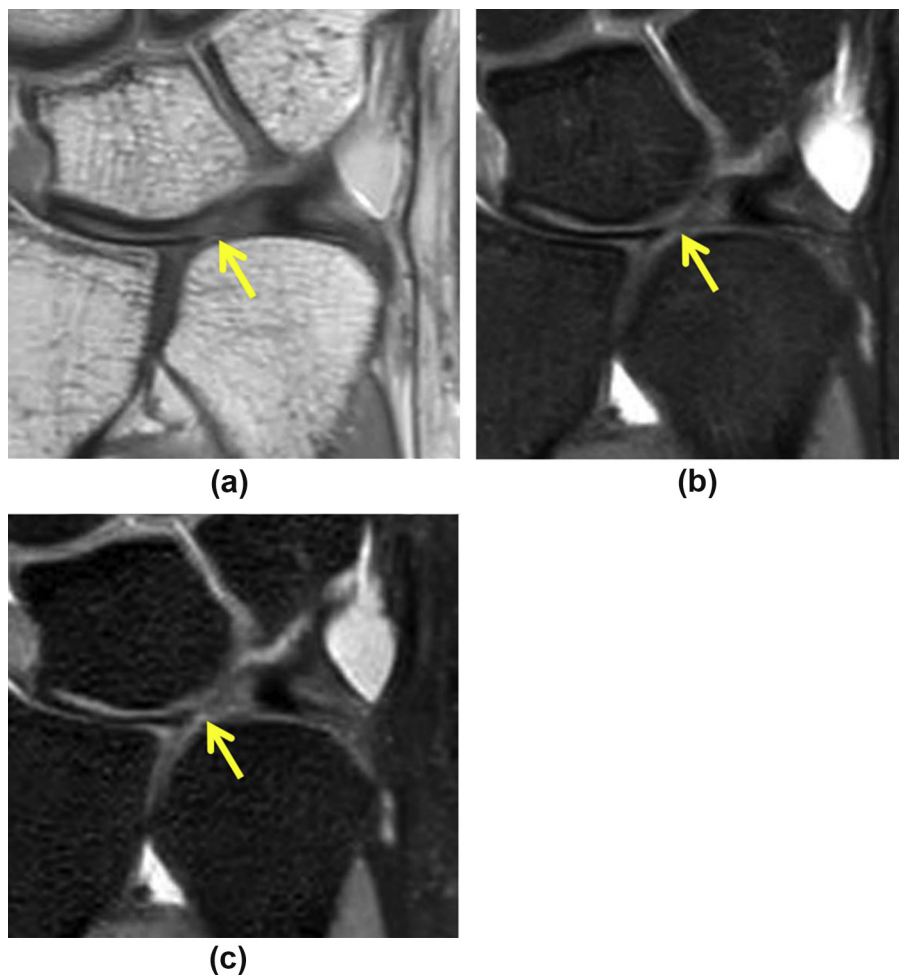
Figure 1 Coronal (a) PDWI, (b) PDWI-FS, and (c) 3D isotropic PDWI-FS in a 41-year-old man with history of wrist pain. MRI showed central perforation of the disc proper (arrows) with high intensity in the surrounding component, suggestive of Palmer class 1A injury.

Statistical analysis

The chi-square test was performed to assess differences in MRI findings among these three groups. In addition, the frequency of MRI findings and the average Outerbridge grading were analysed for different age groups in 10-year increments. Cohen's kappa was calculated to assess inter- and intra-observer reliability for diagnostic performance of MRI findings associated with Palmer and Outerbridge grading. The following ratings for the interpretation of kappa were used: poor (<0.40), moderate ($0.40-0.59$), good ($0.60-0.80$), and excellent (>0.80). One-way ANOVA was used to compare the length of ulnar variance among the three groups. In each analysis, a *p*-value of <0.05 was considered significant. All statistical analyses were performed using R version 3.0.2 for Windows software (R Development Core Team, Vienna, Austria).
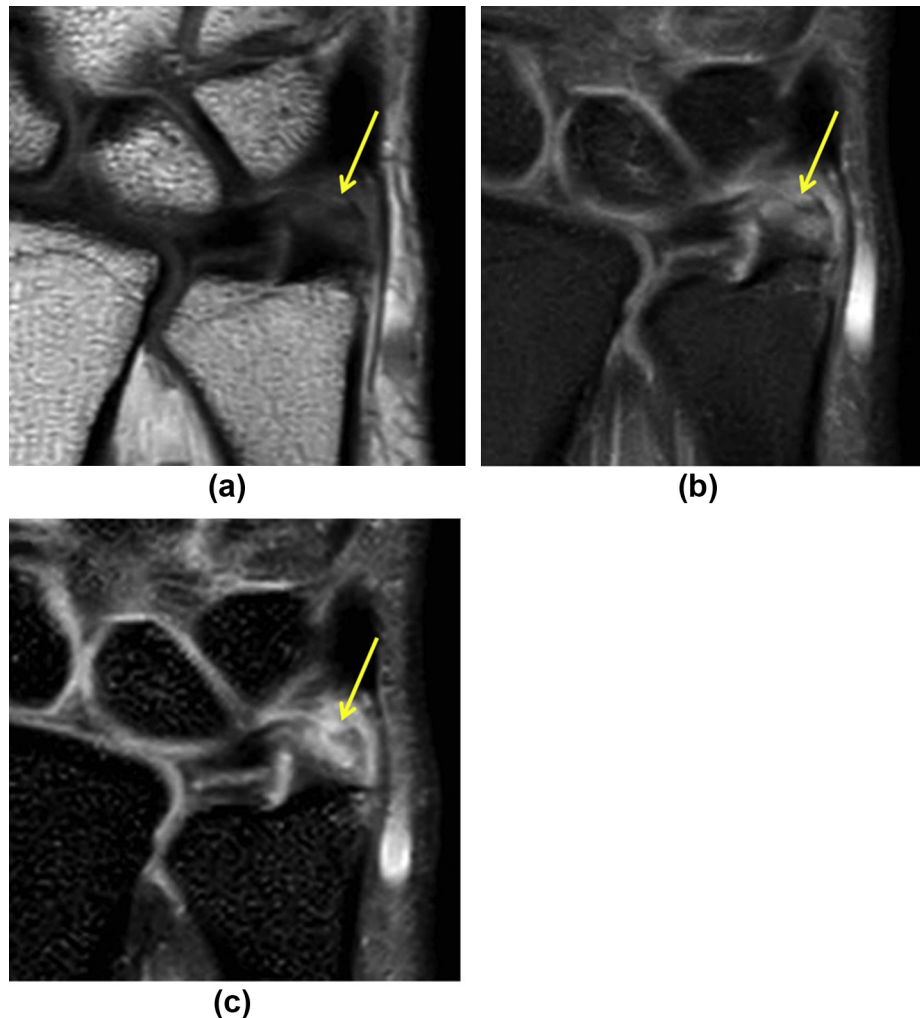
Figure 2 Coronal (a) PDWI, (b) PDWI-FS, and (c) 3D isotropic PDWI-FS in a 24-year-old woman with history of injury while rock climbing. MRI showed swelling, increased signal, and partial discontinuity of the triangular ligament at the ulnar styloid attachment (arrows), suggestive of Palmer class 1B injury.

Results

The results of each MRI finding among the three groups are shown in Table 2. The incidence of Palmer class 1A, 1C, and 1D traumatic TFCC injury was significantly higher in the older symptomatic patient group (PT$\geq$50) than in the younger patient group (PT$<$50; 47.4% versus 27.7% for class 1A, 31.6% versus 12.8% for class 1C, 21.1% versus 2.1% for class 1D, $p<0.05$), while there was no statistical difference in incidence of class 1B tears. Likewise, fraying of the disc proper, mucoid degeneration, lunotriquetral ligament perforation, and ulnocarpal arthritis were observed significantly more frequently in PT$\geq$50 than in PT$<$50 ($p<0.01$). There was a low incidence of abnormal findings in the asymptomatic younger control group (AC). The frequency of each MRI finding tended to increase as age increased. With regards to degenerative changes of the TFCC, this trend manifested as increased fraying/thinning and mucoid

degeneration with age (Fig 6). There was no statistical difference in ulnar variance among the three groups.

The results of Outerbridge grading of the lunate, triquetrum, and ulnar cartilage are shown in Fig 7. In all of the asymptomatic control subjects, articular cartilage degeneration was found to be Outerbridge grade 0 in each bone. Articular cartilage degeneration of Outerbridge grade 1 or lower was more frequently seen in PT$<$50 than in PT$\geq$50: 83% versus 44.7% for the lunate, 95.7% versus 71.1% for the triquetrum, 87.2% versus 26.3% for the ulna, $p<0.01$. Conversely, cartilage degeneration of Outerbridge grade 2 or higher was more frequently seen in PT$\geq$50 than PT$<$50: 55.3% versus 17% for the lunate, 28.9% versus 4.3% for the triquetrum, and 73.7% versus 12.8% for the ulna ($p<0.01$). Bone marrow oedema within the lunate and triquetrum was observed significantly more frequently in PT$\geq$50 than in PT$<$50 ($p<0.05$; Table 3). Likewise, subchondral cyst formation in the lunate was observed significantly more
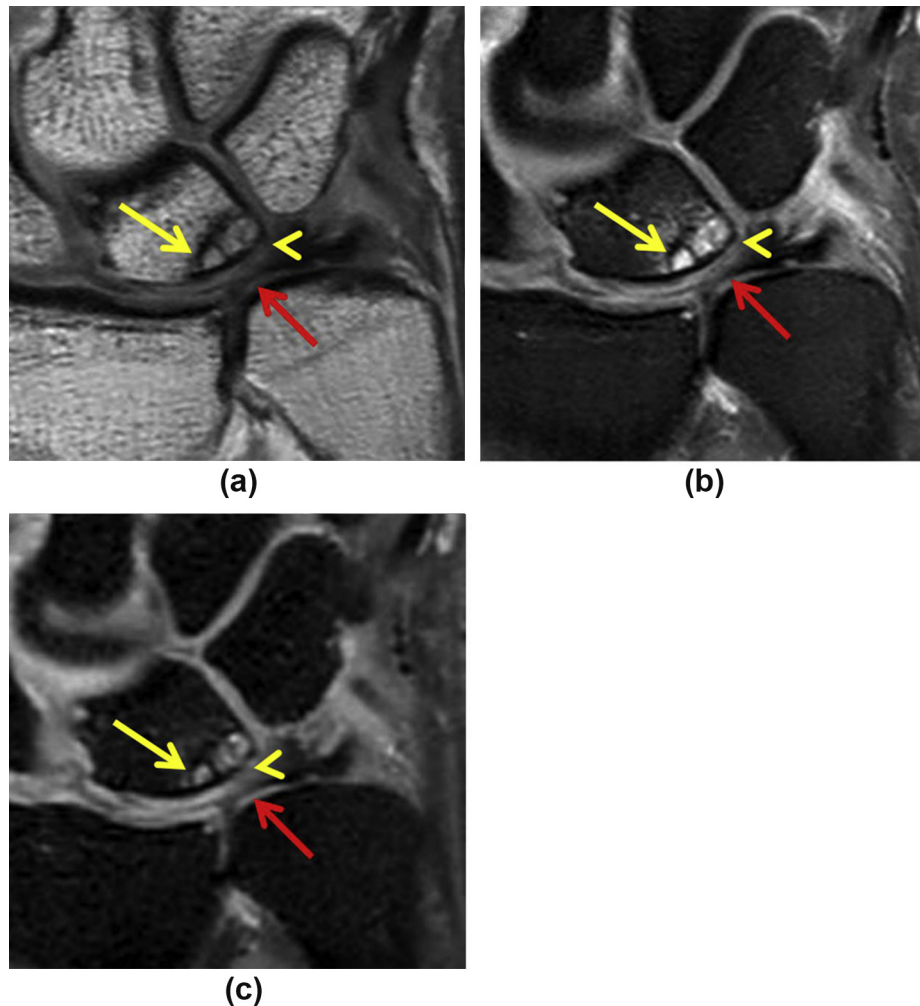
Figure 3 Coronal (a) PDWI, (b) PDWI-FS, and (c) 3D isotropic PDWI-FS in a 68-year-old woman with wrist pain and swelling. MRI showed thinning of the disc proper without perforation (red arrows), lunate chondromalacia (yellow arrowheads), and subchondral cyst formation in the lunate (yellow arrows), compatible with Palmer class 2B injury.

frequently in PT≥50 than in PT<50 ($p<0.001$). The average Outerbridge grading tended to increase with age (Fig 8). Increased grading severity was more apparent for patients over 50 years of age in all bones.

Inter- and intra-observer reliability of each MRI finding associated with traumatic and degenerative TFCC abnormalities were considered excellent or good. Inter- and intra-observer reliability of the Outerbridge grading were considered good and good to excellent, respectively (Table 4).

Discussion

In the present study, two major findings were demonstrated. First, TFCC abnormalities related to traumatic injury or degenerative change were evaluated with good or excellent inter- and intra-observer reliability using 3 T high-resolution MRI of the wrist. All types of traumatic and degenerative TFCC abnormalities except Palmer class 1B

traumatic injuries were seen more frequently in the study subjects aged 50 or older than in subjects younger than 50 years. The frequency of abnormal MRI findings including degeneration increased with age. Second, articular cartilage degeneration around the TFCC using the Outerbridge classification was evaluated at 3 T high-resolution MRI of the wrist with good inter-observer and good to excellent intra-observer reliability.

To the authors' knowledge, there have been no prior studies demonstrating reliable assessment of traumatic and degenerative TFCC injury based on the Palmer classification using 3 T high-resolution MRI of the wrist. A prior cadaveric study found that the incidence of disc perforation increases with age, and degenerative changes began to appear in the third decade of life.[11,12] Another recent report used biochemical MRI to assess degeneration of the disc proper in healthy volunteers.[13] The study found a significant difference in T2 values of the disc proper between subjects aged 30–50 years and subjects
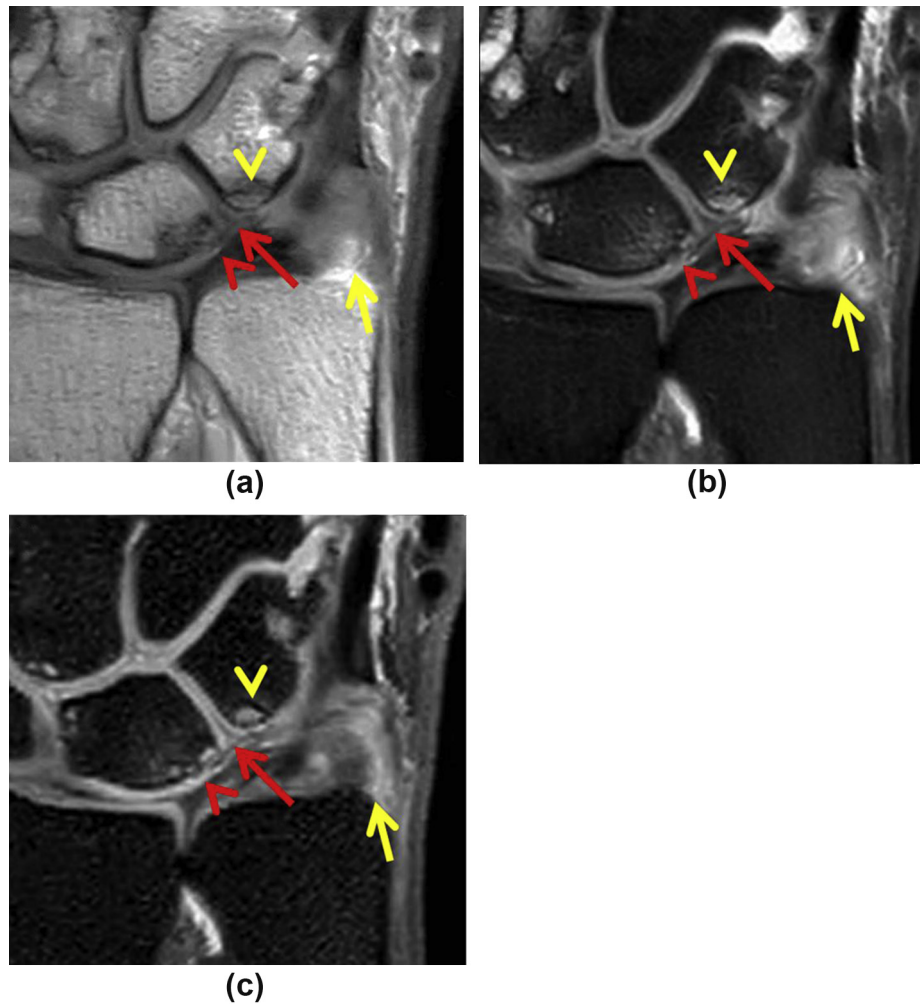
Figure 4 Coronal (a) PDWI, (b) PDWI-FS, and (c) 3D isotropic PDWI-FS in a 70-year-old man with acute soft-tissue fullness. MRI showed partial discontinuity of the triangular ligament at the ulnar styloid attachment (yellow arrows), lunate chondromalacia (red arrowheads), subchondral cyst formation in the triquetrum (yellow arrowheads), and lunotriquetral ligament perforation (red arrows) compatible with Palmer class 2D injury.

older than 50 years of age. These results suggested that increased T2 values of the disc proper reflect degeneration with aging. The present result demonstrating a higher incidence of Palmer class 2 TFCC degenerative abnormalities in PT≥50 than in PT<50 patients supports the findings of prior studies. Interestingly, the incidence of Palmer class 1 traumatic TFCC injuries also increases with age, with the exception of Palmer class 1B. It is unclear why the frequency of Palmer class 1B injury was similar between patients over 50 years and under 50 years of age. One explanation for this could be selection bias in the current study. Symptomatic young patients with TFCC injury who underwent MRI might suffer from class 1B injury more frequently. The incidence of class 1B injury was only 9.1% in the asymptomatic control group, supporting this explanation; however, this explanation requires validation with further study. The other explanation is that Palmer class 1B injuries may be overestimated and more difficult to diagnose, given the

physiological increased signal and striation in the normal TFCC near the ulnar attachment.

Articular cartilage of the ulna, triquetrum, and lunate were also evaluated using the Outerbridge classification on 3 T high-resolution MRI, because the presence or absence of chondromalacia is a criterion for Palmer class 2 degenerative TFCC changes. A previous study that evaluated cartilage damage associated with TFCC injury using standard 1.5 T MRI demonstrated poor diagnostic performance and poor interobserver reproducibility[7,14]; however, in the present study, cartilage degeneration could be evaluated in detail with good interobserver reliability using high-resolution 3 T MRI and optimised wrist MRI sequences. None of the bones evaluated in the asymptomatic control subjects showed cartilage degeneration or injury, while cartilage damage was demonstrated in the patient groups. Furthermore, the incidence of severe cartilage degeneration increases with age. Subchondral bone marrow oedema and subchondral cyst formation suggestive of arthropathic change were not
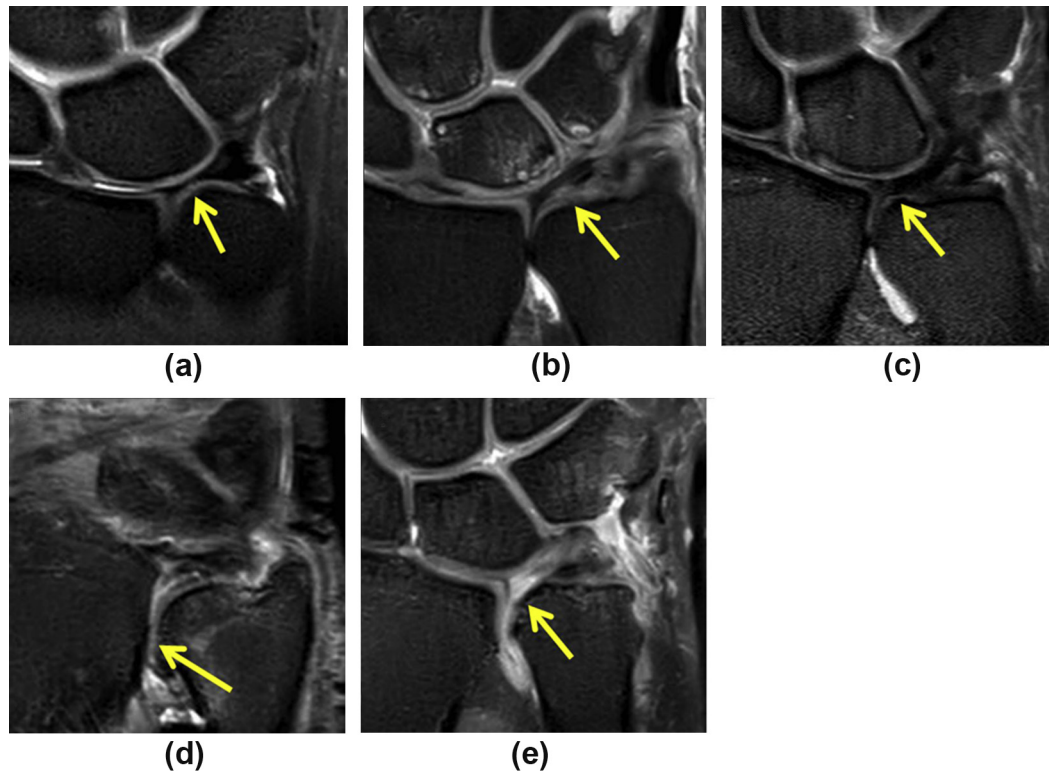
Figure 5 Outerbridge grading of the ulnar head. Fat-saturated coronal MRI images demonstrate different degrees of cartilage injury in the ulnar head as described by the Outerbridge classification: (a) normal = grade 0; (b) signal heterogeneity with normal cartilage thickness = grade 1; (c) partial thickness defect < 50% = grade 2; (d) partial thickness defect > 50% = grade 3; and (e) full-thickness cartilage loss = grade 4.

Table 2
Frequency of MRI findings associated with traumatic or degenerative TFCC injury.

Group	Patient group <50	Patient group ≥50	Control group	*p*-Value
Number	47	38	11	
Average age ± SD (years)	33.3 ± 9.8	61.5 ± 9.2	31.6 ± 9.1	
TFCC tear				
Class 1A	13 (27.7%)	18 (47.4%)	1 (9.1%)	0.03[a]
Class 1B	19 (40.4%)	15 (39.5%)	1 (9.1%)	0.13
Class 1C	6 (12.8%)	12 (31.6%)	0 (0%)	0.02[a]
Class 1D	1 (2.1%)	8 (21.1%)	0 (0%)	<0.01[a]
TFCC degeneration				
Fraying	22 (46.8%)	30 (78.9%)	3 (27.3%)	<0.01[a]
Mucoid degeneration	9 (19.1%)	29 (76.3%)	3 (27.3%)	<0.001[a]
LTL perforation	5 (10.6%)	13 (34.2%)	0 (0%)	<0.01[a]
Ulnocarpal arthritis	1 (2.1%)	8 (21.1%)	0 (0%)	<0.01[a]
Ulnar plus variant ± SD (mm)	−0.90 ± 1.41	−0.58 ± 1.94	−0.34 ± 0.53	0.47

TFCC, triangular fibrocartilage complex; LTL, lunotriquetral ligament.
[a] Statistically significant at $p<0.05$.

seen in most of the asymptomatic control subjects who were younger than 50 years of age. Conversely, MRI findings suggestive of degenerative arthropathic change were seen with higher frequency in symptomatic patients older than 50 years of age. Again, the present results support the concept that degenerative change of the TFCC and related structures increases with age.[11,12] As both traumatic and degenerative abnormalities can coexist as age increases, it is difficult to distinguish between those abnormalities in older patients.

Inter- and intra-rater reliability of TFCC evaluation and Outerbridge grading demonstrated good or excellent reliability. This is likely because high-resolution MRI sequences were used, including a 3D isotropic sequence with a dedicated wrist coil and both raters in the present study were experienced radiologists sub-specialised in musculoskeletal radiology. As Morley *et al.*[15] stated, a negative MRI examination does not exclude TFCC injuries when a dedicated wrist coil is not used. Specialised wrist MRI techniques including a dedicated wrist coil, high magnetic field
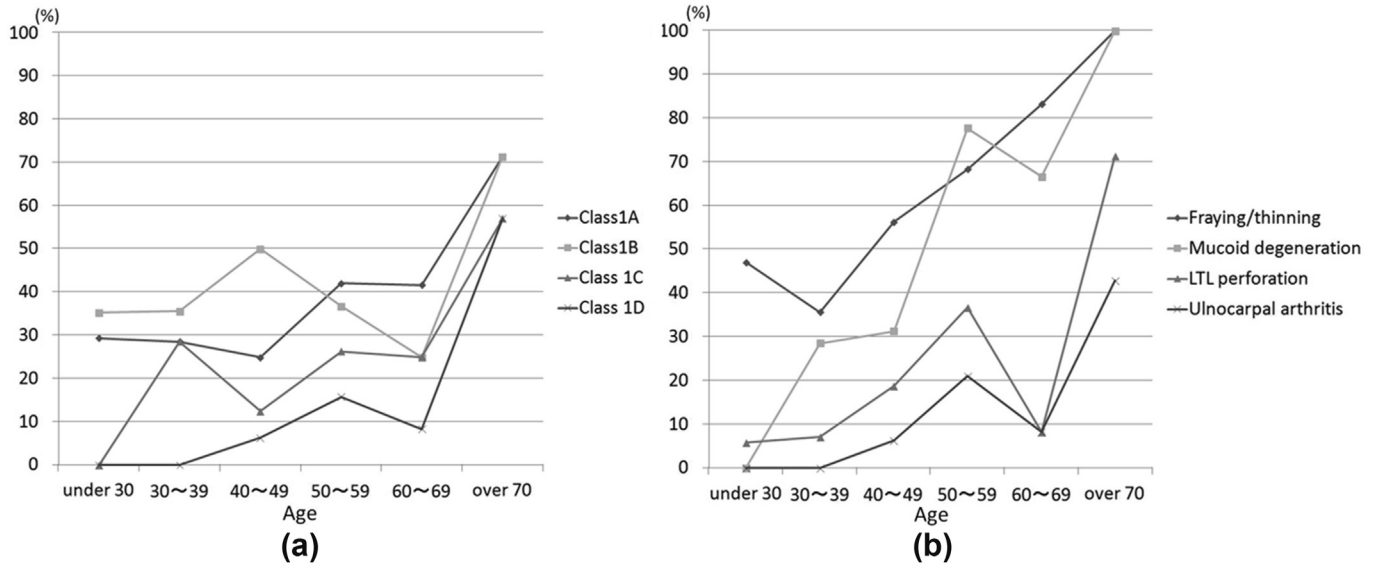
Figure 6 The frequency of (a) traumatic and (b) degenerative MRI findings among patients at each decade of age. The frequency of each MRI finding tended to increase with age. This trend is more apparent in fraying/thinning and mucoid degeneration. LTL, lunotriquetral ligament.
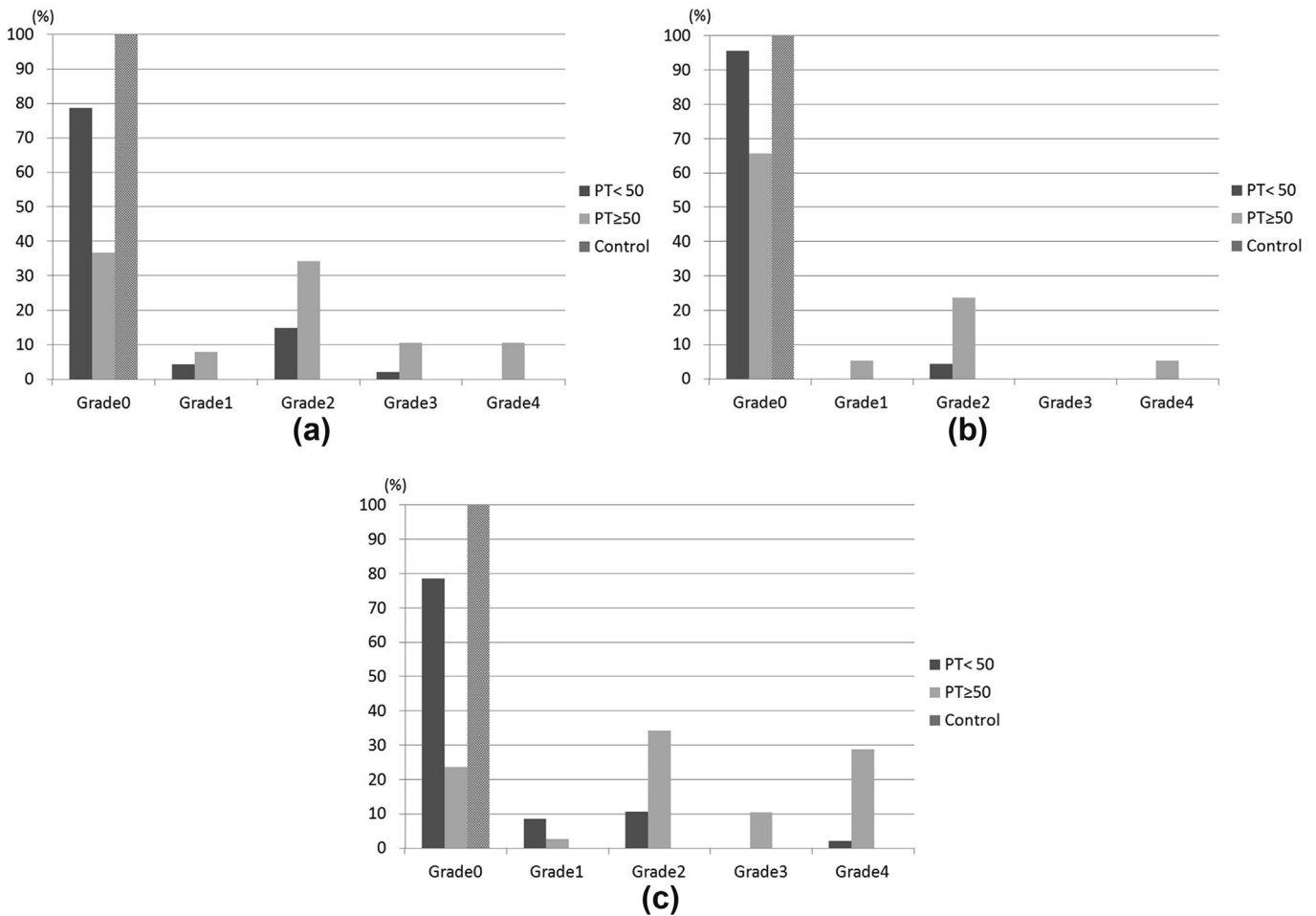

Figure 7 Outerbridge grading of the (a) lunate, (b) triquetrum, and (c) ulna among three study groups. In all of the asymptomatic control subjects, articular cartilage degeneration was found to be Outerbridge grade 0 in each bone. Articular cartilage degeneration of Outerbridge grade 1 or lower was more frequently seen in PT<50 than in PT≥50: 83% versus 44.7% for the lunate, 95.7% versus 71.1% for the triquetrum, and 87.2% versus 26.3% for the ulna. Conversely, cartilage degeneration of Outerbridge grade 2 or higher was more frequently seen in PT≥50 than PT<50: 55.3% versus 17% for the lunate, 28.9% versus 4.3% for the triquetrum, and 73.7% versus 12.8% for the ulna.

Table 3
Frequency of bone marrow oedema and subchondral cyst formation in the lunate, triquetrum, and ulna.

Group	Patient group <50	Patient group ≥50	Control group	*p*-Value
Number	47	38	11	
Average age ± SD (years)	33.3 ± 9.8	61.5 ± 9.2	31.6 ± 9.1	
Lunate				
Bone marrow oedema	2 (4.3%)	13 (34.2%)	1 (9.1%)	<0.001[a]
Subchondral cyst	0 (0%)	9 (23.7%)	0 (0%)	<0.001[a]
Triquetrum				
Bone marrow oedema	1 (2.1%)	7 (18.4%)	0 (0%)	0.03[a]
Subchondral cyst	0 (0%)	2 (5.3%)	0 (0%)	0.37
Ulna				
Bone marrow oedema	6 (12.8%)	10 (26.3%)	0 (0%)	0.09
Subchondral cyst	1 (2.1%)	2 (5.3%)	0 (0%)	0.71

[a] Statistically significant at $p<0.05$.
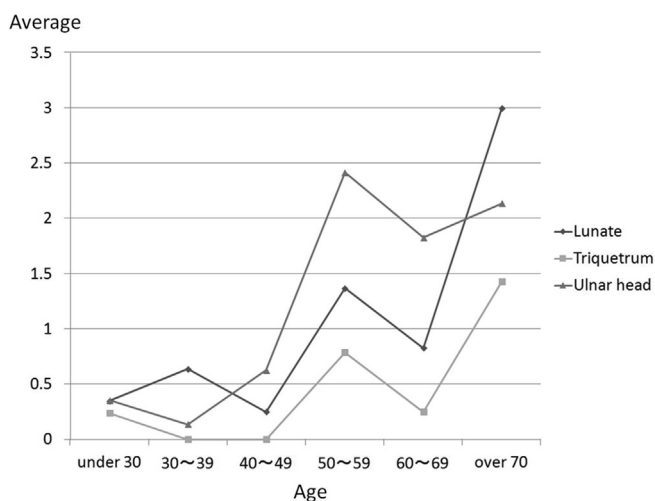
Figure 8 The average Outerbridge grading among patients at each decade of age. The average Outerbridge grading tended to increase with age.

strength, such as 3 T, and appropriate pulse sequences are imperative for accurate diagnosis of TFCC injuries.

The present study has several limitations. First, a limited numbers of subjects were included, especially asymptomatic normal controls. Asymptomatic normal control subjects older than 50 years of age were not included. Second, only limited patient clinical symptoms and history were available, because of the retrospective nature of the study. Third, the present cases were not correlated with arthroscopic or intraoperative findings, although the inter- and intra-observer reliability was good or excellent in all MRI findings. The correlation between the imaging findings and age could have been biased, due to the resolution of interobserver discrepancies by means of consensus. Further study will be necessary to correlate high-resolution MRI imaging findings with surgical findings. Fourth, as mentioned above, there may be a selection bias in this study. More class 1B patients with clinical symptoms may have been included in this study. Fifth, the present study did not evaluate whether 3 T MRI provides more accurate assessment of the TFCC than 1.5 T MRI. Good quality 1.5 T MRI may demonstrate similar results to the present study. Direct comparison will be necessary to demonstrate that 3 T MRI is better than 1.5 T MRI.

In conclusion, 3 T high-resolution MRI of the wrist enabled evaluation of TFCC traumatic injury or degeneration accurately based on the Palmer classification. Additionally, 3 T high-resolution MRI enabled evaluation of osteoarthritic grading of articular cartilage around the TFCC according to the Outerbridge classification with good or

Table 4
Inter- and intra-observer reliability of cartilage damage grading and qualitative evaluation of TFCC injuries at magnetic resonance imaging.

	Cohen's kappa		Percentage of agreement (%) exact/within 1 point	
	Inter-rater agreement	Intra-rater agreement	Inter-rater agreement	Intra-rater agreement
Outerbridge classification				
Lunate	0.69	0.91	69.8/84.4	91.7/96.9
Triquetrum	0.70	0.93	70.8/78.1	92.7/93.8
Ulna	0.61	0.78	61.5/85.4	79.2/90.6
TFCC injury				
Class 1A	0.86	0.94		
Class 1B	0.86	0.84		
Class 1C	0.92	0.90		
Class 1D	0.94	0.96		
Fraying of disc proper	0.72	0.87		
Mucoid degeneration	0.70	0.86		
LTL perforation	0.89	0.96		
Ulnocarpal arthritis	0.96	1.00		

TFCC, triangular fibrocartilage complex; LTL, lunotriquetral ligament.

excellent inter- and intra-observer reliability. The present study finds that with increasing age, there is an increasing incidence of MRI findings of degenerative TFCC injuries in patients with wrist pain.

Acknowledgment

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