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MUSCULOSKELETAL

Ultrashort time-to-echo quantitative magnetic resonance imaging of the triangular fibrocartilage: differences in position

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Abstract

Purpose To compare T2* values of the triangular fibrocartilage (TFC) obtained by ultrashort time-to-echo (UTE) techniques at the neutral position, ulnar flexion of the wrist, and pronation of the forearm.

Materials and methods MR imaging was performed in ten healthy volunteers with a 3-T MR system by using an eight-channel knee coil. Coronal wrist T2* maps from three-dimensional cone UTE pulse sequences were obtained at the neutral, ulnar flexion, and pronation positions (TR: 19 ms, TE: 0.032 ms/4 ms/8 ms/12 ms, FOV: 18 cm, matrix: 430 × 430, section thickness: 1.5 mm, scan time: 8 min 31 s). UTE-T2* maps were calculated on a pixel-by-pixel basis for all structures of the wrist visualized in the coronal planes. The entire region of interest (ROI) for TFC was manually delineated, and the average T2* value was calculated for each ROI by three radiologists. The Kruskal-Wallis test, Wilcoxon signed-rank test, or intraclass correlation coefficients (ICC) were used for statistics.

Results The difference in the average T2* value among the three groups according to the forearm/wrist position was significant ($p < 0.001$). The T2* value of the TFC at pronation (mean ± 2 SD: 7.92 ± 1.37 ms) was significantly lower than those at the neutral (10.08 ± 1.90 ms) and ulnar flexion positions (9.15 ± 1.03 ms) ($p < 0.017$). The ICC showed a substantial interobserver agreement in the T2* value measurements of the TFC (ICC = 0.986).

Conclusion T2* relaxation time measurement of the TFC using UTE may be useful for assessing the loading effect by the forearm/wrist position.

Key Points

• *The T2* value of the TFC may reflect the biomechanics of the wrist joint.*
• *Acute loading at pronation results in a decrease in the T2* value of the TFC.*
• *Quantitative wrist UTE MRI was successfully performed in vivo.*

Keywords Magnetic resonance imaging · Triangular fibrocartilage · Joints · Wrist · Pronation

Abbreviations

DSV	Diameter spherical volume
FOV	Field of view
ICC	Intraclass correlation coefficients
MRI	Magnetic resonance imaging
ROIs	Entire region of interest
TE	Time to echo
TFC	Triangular fibrocartilage
TFCC	Triangular fibrocartilage complex
TR	Repetition time
UTE	Ultrashort time-to-echo

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Introduction

The triangular fibrocartilage complex (TFCC) is the main biomechanical stabilizer of the distal radioulnar joint. The TFCC is a compound structure comprised of the triangular fibrocartilage (TFC) disc proper, proximal and distal laminae, volar and dorsal radioulnar ligaments, ulnocarpal ligaments (ulnolunate and ulnotriquetral ligaments), ulnar collateral ligament, and subsheath of the extensor carpi ulnaris tendon and the meniscus homolog. The TFCC works as a shock absorption cushion for axial loading [1].

MRI is the most important noninvasive diagnostic technique for the assessment of TFCC. High-field MRI imaging techniques at 3 T that improve the visualization of subtle TFC morphologic changes have been introduced. With sophisticated coils and high resolution, it has also become an esteemed modality for diagnosing the wrist. However, due to the smallness and complexity of the structures, the TFCC is still a challenging structure for MRI [2].

Previous ex vivo studies on human cartilage have shown that ultrashort time-to-echo T2* (UTE-T2*) mapping reflects the collagen structural integrity and degeneration in cartilage as determined by polarized microscopy. UTE-T2* mapping of articular cartilage is sensitive to matrix degeneration and detects the short T2 signal, particularly in deep tissue, that is not well captured by standard T2 mapping [3]. The spatial distribution of T2* relaxation times from protons within fibrocartilage, such as the meniscus, is also illustrated by UTE-T2* mapping, and the T2* value estimation can be provided without contrast media. In vivo human studies have recently shown UTE-T2* mapping to be reproducible in the clinical setting [4]. However, to our knowledge, there is no report that assesses the relationship between T2* values of the TFC and the forearm/wrist position. The purpose of our study was to compare T2* values of the TFC obtained by UTE techniques at the neutral position, ulnar flexion of the wrist, and pronation of the forearm.

Materials and methods

Study population

The study was approved by our institutional review board, and informed consent was obtained from all volunteers. Inclusion criteria were good health according to medical history, physical examination as well as the absence of contraindications to MR imaging. One board-certified hand surgeon (K.M. with 20 years of experience) screened the subjects. Subjects were included if they had no clinical evidence of wrist osteoarthritis; they had to have intact joint function with full strength and no history of chronic or frequent wrist pain. Further exclusion criteria were inflammatory arthritis, wrist affections secondary to other causes (acute or chronic infection, metabolic abnormalities, previous surgery, or previous fracture) and chronic or traumatic lesions of the TFC complex. Finally, a total of 10 volunteers (7 males, 3 females; age range, 27 to 35 years) took part in the examinations.

MR imaging

All experiments were performed using a 3-T clinical MR scanner (Discovery MR750W 3-T scanner, Signa HDxt GE Healthcare) with an eight-channel knee coil. All patients underwent MRI covering the right wrist, including coronal T2-weighted imaging and coronal UTE. Coronal wrist T2* maps from three-dimensional cone UTE pulse sequences were obtained at the neutral position, ulnar flexion of the wrist, and pronation of the forearm. For coronal T2* maps, the following pulse sequences were used: TR: 19 ms, TE: 0.032 ms/4 ms/8 ms/12 ms, FOV: 18 cm, matrix: 430 × 430, section thickness: 1.5 mm, and scan time: 8 min 31 s. We defined TE times in consideration of previous reports dealing with the T2* value of fibrocartilage (TFC and meniscus) and a clinically feasible scan time [2, 5]. The order of measurement at the neutral position, ulnar flexion of the wrist, and pronation of the forearm is random for each volunteer. The patients underwent imaging in prone position with the arm semi-flexed, clutching the fixed device in the center of the coil within the central homogeneous area of the MR system (40 cm DSV).

MR imaging data analysis

UTE-T2* maps were calculated on a pixel-by-pixel basis for all structures of the wrist visualized in the coronal planes. On T2-weighted images, normal MR appearance of the TFC was defined as a homogeneous hypointense bowtie-like structure. The entire region of interest (ROI) for the TFC was manually delineated on the images obtained at a TE time of 8 ms because of the clarity of the TFC outline (Fig. 1), and the average T2* value was calculated by three radiologists (two musculoskeletal radiologists and one general radiologist). T2-weighted imaging was used as a reference. The average ROI size for the

Fig. 1 Selection of the ROI was performed manually on the image obtained at TE time of 8 ms

TFC was 13.64 mm^2. The three readers did not know the results of the other radiologists.

Statistical analysis

The non-parametric Kruskal-Wallis test with Bonferroni correction was used to compare the average T2* values among the three groups according to the forearm/wrist position. Bonferroni correction for post-hoc pairwise analysis was performed by using two-tailed Wilcoxon signed-rank test. Using the Bonferroni correction, we set the significance level at $p < 0.017$ to adjust for multiple comparisons. Interobserver repeatability was assessed by intraclass correlation coefficients (ICC); ICC 0–0.2 indicates poor agreement: 0.3–0.4 indicates fair agreement; 0.5–0.6 indicates moderate agreement; 0.7–0.8 indicates strong agreement; > 0.8 indicates excellent agreement [6]. All calculations were performed by using IBM SPSS Statistics, version 22.0 (IBM, Armonk, NY).

Results

Quantitative wrist UTE MRI was successfully performed in vivo (Fig. 2). The ICC showed a substantial interobserver agreement in the T2* value measurements of the TFC (ICC = 0.986).

T2* values of TFC of the wrist according to the forearm/wrist position are summarized in Table 1. The difference in the average T2* value among the three groups according to the forearm/wrist position was significant ($p < 0.001$). The T2* value of the TFC at pronation (7.92 ± 1.37 ms) was significantly lower than those at the neutral (10.08 ± 1.90 ms) and ulnar flexion positions (9.15 ± 1.03 ms) ($p < 0.001$). The average T2* value of the TFC was not significantly different between the neutral and ulnar flexion positions ($p = 0.164$).

Figure 3 shows an example of coronal UTE T2* maps obtained at three different positions.

Discussion

Tissue (menisci, tendons, ligaments, and cartilage) with short intrinsic relaxation times cannot be adequately assessed with the conventional techniques because they do not generate enough signal with MRI [7]. Ultrashort TE pulse sequences enable T2- and T2*-weighted imaging of these tissues by using an extremely short TE [8]. Due to the moderately short T2 nature of TFC, MR sequences utilizing UTE techniques would capture signals normally unseen by conventional MR techniques [2, 9]. A quantitative MR technique using UTE is a sensitive mean for evaluating the TFC, which may complement conventional techniques and allow more minor change of early TFC injury.

Forearm rotation is not a simple hinge-like motion, but a complex motion with rotational and translational components. Forearm kinematics has been analyzed in various settings from cadaveric to in vivo studies. The rotation axis of the forearm passed through the radial head and the ulnar head; therefore, maximum forearm pronation results in an increase in positive ulnar variance. Distal translation of the

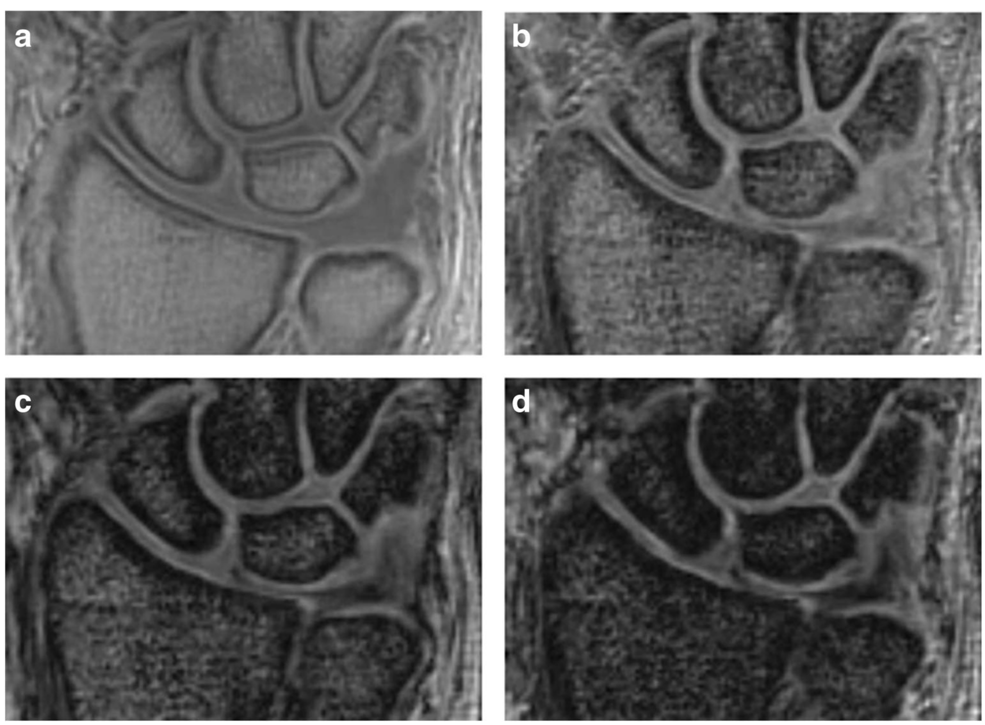

Fig. 2 UTE MR images of TFC in the coronal plane at the neutral position (**a**: TE = 0.032 ms; **b**: TE = 4 ms; **c**: TE = 8 ms; **d**: TE = 12 ms)

Table 1 Average T2* values of TFC of the wrist according to the forearm/wrist position

Position	Neutral	Pronation	Ulnar flexion
mean ± 2SD (ms)	10.08 ± 1.90	7.92 ± 1.37	9.15 ± 1.03
	* (Neutral vs Pronation)	* (Pronation vs Ulnar flexion)	

* $p < 0.017$ (two-tailed Wilcoxon signed-rank test)

ulna relative to the radius at pronation will increase the load of the TFC [10, 11]. In addition, changes in TFC configuration consistently occur during forearm rotation and resulted in a tensile strain primarily in the rotation axis [12].

According to the previous study, mean tendon and cartilage T2* values decreased in the knee joint under loading condition [13]. On the other hand, a recent MR experimental study by Jerban et al indicated that UTE T2 values decrease in tendons with the application of tensile strain [14]. Thus, we hypothesize that acute loading and tensile strain at pronation will also result in a decrease in the T2* value of the TFC. In this study, as expected, the average T2* value of the TFC at pronation was significantly lower than that at the neutral position. Our data may reflect the biomechanics of the wrist joint.

T2* values of musculoskeletal structures are widely considered to reflect the collagen microstructure rather than content. The collagen crimp reduction and flattening result in an angle decrease between the collagen fiber axes and static magnetic field (B0), which in turn leads to lower T2* values [14, 15]. The T2* decreases of the TFC at pronation may be corresponded to the changes in collagen orientation and organization upon acute loading and tensile strain.

The average T2* value of the TFC at the ulnar flexion position was slightly lower than that at the neutral position, but the difference was not statistically different. There is one prior study dealing with the TFC configuration at the ulnar flexion position, and the authors reported that the TFC configuration was not significantly different between the neutral and ulnar flexion position [16]. Although the ulnar flexion may slightly increase the load of the TFC in the long axis direction, the tensile strain of the TFC is considered reduced at the ulnar flexion position. The light load and tensile reduction of the TFC at ulnar flexion position may explain our result.

Our study had several limitations. First, the number of subjects evaluated was small, and the volunteers were predominantly young (< 35 years of age) since the aim of the present study was to examine the feasibility of biomechanical T2* assessment of the TFC. Second, we manually defined the TFC boundary and ROIs in our calculation of the T2* value of the TFC. Although the interobserver agreement in the T2* value measurements was excellent in this study, use of automatic or semiautomatic computational procedures might have improved the reproducibility. Third, we did not measure the actual compressive load applied to the wrist. Fourth, our current UTE sequence only permits a four-echo acquisition and requires a clinically reasonable scan time to achieve the desired voxel size and sample coverage, but additional echo images to calculate T2* values may be beneficial. Finally, clinical cases were not included in this study. Our results might have implications for the treatment of ulna impaction and future biomechanical study. Additional prospective study with a large number of cases is necessary to evaluate the clinical implications of the TFC T2* measurement in wrist kinematics.

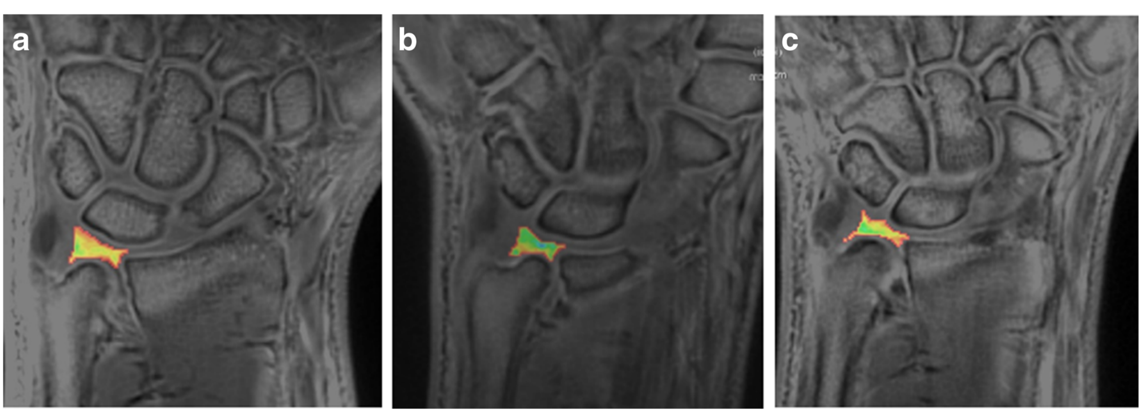

Fig. 3 UTE-T2* maps obtained at three different positions in a 29-year-old male (**a**: neutral position; **b**: pronation position; **c**: ulnar flexion position). T2* values of the TFC at pronation (**b**, 7.1 ± 0.6 ms) are lower than those at the neutral (**a**, 10.9 ± 1.2 ms) and ulnar flexion position (**c**, 9.9 ± 0.9 ms)

In conclusion, the T2* relaxation time measurement of the TFC using UTE may be useful for assessing the loading effect by the forearm/wrist position.

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Compliance with ethical standards

Guarantor The scientific guarantor of this publication is Takatoshi Aoki.

Conflict of interest The coauthor Atsushi Nozaki is an employee of GE Healthcare, the supplier of the MR unit and pulse sequence used in this study.

Statistics and biometry No complex statistical methods were necessary for this paper.

Informed consent Written informed consent was obtained from all subjects (patients) in this study.

Ethical approval Institutional Review Board approval was obtained.

Methodology
- prospective
- experimental
- performed at one institution

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