Received:
15 November 2016

Revised:
28 December 2016

Accepted:
11 January 2017

<https://doi.org/10.1259/bjr.20160867>

Cite this article as:

Oh E, Yoon YC, Park MJ. Diagnostic performance of wrist magnetic resonance (MR) arthrography: comparison of three-dimensional isotropic T_1 weighted fast spin-echo MR arthrography and two-dimensional MR arthrography. *Br J Radiol* 2017; **90**: 20160867.

FULL PAPER

Diagnostic performance of wrist magnetic resonance (MR) arthrography: comparison of three-dimensional isotropic T_1 weighted fast spin-echo MR arthrography and two-dimensional MR arthrography

¹EUNSUN OH, MD, ¹YOUNG C YOON, MD, PhD and ²MIN J PARK, MD, PhD

¹Department of Radiology, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Republic of Korea

²Department of Orthopedic Surgery, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Republic of Korea

Address correspondence to: Prof Young Cheol Yoon

E-mail: youngcheol.yoon@gmail.com

Objective: To compare the diagnostic performance of direct wrist MR arthrography (D-MRA) with two-dimensional (2D) T_1 weighted fast spin-echo (FSE) and three-dimensional (3D) isotropic T_1 weighted FSE sequences for detecting triangular fibrocartilage (TFC) central perforations and scapholunate ligament (SLL) and lunotriquetral ligament (LTL) tears.

Methods: 26 patients who had undergone pre-operative wrist D-MRA with 2D and 3D isotropic T_1 weighted FSE sequences and subsequent arthroscopic surgeries were included. Each MRI sequence was independently evaluated and scored by two readers retrospectively for the presence of TFC central perforations and SLL and LTL tears. Arthroscopic findings were used as the reference standard. Diagnostic performance was evaluated by using the area under the receiver operating characteristic curve. The sensitivity, specificity and accuracy of both sequences for diagnosing the injuries were calculated.

Results: Arthroscopic surgery revealed 21 TFC central perforations, 7 SLL tears and 3 LTL tears. The area under the receiver operating characteristic curve value

of 2D and 3D for central perforations in TFC and tears in SLL and LTL was identical or similar (0.667–0.947). The sensitivity, specificity and accuracy of both sequences for diagnosing the injury of each structure were not significantly different (TFC, 90.5/80/88.5% for both readers/sequences; SLL, 100/89.5/92.3% for both readers' 2D and Reader A's 3D, and 85.7/89.5/88.5% for Reader B's 3D; LTL, 66.7/100/96.2% for both readers' 2D and 33.3/100/92.3% for both readers' 3D). Interobserver agreements were substantial to excellent.

Conclusion: In wrist D-MRA, the diagnostic performances of 3D isotropic and 2D T_1 weighted FSE sequences are comparable for TFC central perforations and SLL and LTL tears.

Advances in knowledge: The diagnostic performance of 3D isotropic T_1 weighted FSE D-MRA and that of 2D T_1 weighted FSE D-MRA were not significantly different in the diagnosis of central perforations in the TFC and tears in the SLL and LTL. 3D isotropic T_1 weighted FSE D-MRA has potential for substituting 2D imaging.

INTRODUCTION

MRI of the wrist has been used as a diagnostic modality for detecting abnormality of the triangular fibrocartilage (TFC) complex, ligaments, cartilage, tendon and peripheral nerves.^{1–5} In particular, direct MR arthrography (D-MRA) of the wrist joint provides high tissue contrast and can be more sensitive and accurate than conventional MRI in delineating and evaluating the ligaments of the wrist.^{1,6,7}

Three-dimensional (3D) isotropic MRI at 3.0 T can provide multiplanar reformation along arbitrary planes that can be helpful in evaluating complex musculoskeletal structures.^{8,9} It has been commonly used for evaluating the knee,

shoulder and ankle joints.^{8–16} Multiple studies have compared the diagnostic performances of 3D isotropic fast spin-echo (FSE) MRI and two-dimensional (2D) conventional MRI in the knee^{9,12–14,17} and shoulder joints.^{10,18–20} However, the number of studies that have used 3D isotropic FSE techniques in the wrist joint is limited.^{8,21,22}

Additionally, although the D-MRA 3D isotropic FSE sequence provides high contrast and spatial resolution, only one study to date has reported the diagnostic performance of 3D isotropic FSE D-MRA for the wrist joint.²¹ However, they used 3D isotropic proton-density FSE MRI instead of T_1 weighted FSE MRI and did not use the arthroscopic findings

Table 1. Parameters of MRI sequences

Parameter	Axial fat-suppressed T_1 weighted MRI	Axial T_2 weighted MRI	Coronal fat-suppressed T_1 weighted MRI	Coronal T_1 weighted MRI	Coronal T_2 weighted MRI	Sagittal fat-suppressed T_1 weighted MRI	Coronal 3D isotropic fat-suppressed T_1 weighted FSE MRI
Repetition time (ms)	522.4	3379	575.3	566.9	3212.3	493.1	350
Echo time (ms)	21.1	100	20.7	15	100	20.5	22
matrix number	500×312	500×312	332×256	352×345	400×325	332×256	250×250
Field of view (cm)	10	10	10	10	10	10	10
Section thickness (mm)	4	4	2	2	2	3	0.4
Intersection gap (mm)	0	0	0	0	0	0	0
Echo train length	3	14	3	5	14	3	23
Number of signals acquired	1	1	2	2	2	2	2
Pixel bandwidth	263	179	269	254	223	269	347
SENSE factor	1	1	1.5	1.5	1.5	1.5	2
Imaging time	2 min 47 s	2 min 55 s	3 min 21 s	3 min 42 s	3 min 25 s	3 min 52 s	5 min 43 s

3D, three-dimensional; FSE, fast spin-echo; SENSE, sensitivity encoding.

Table 2. Findings with MR arthrography with two-dimensional (2D) fast spin-echo (FSE) and three-dimensional (3D) T₁ weighted FSE sequences, and arthroscopic surgery

Patient number	Sex	Age (years)	Central portion of the triangular fibrocartilage						Scapholunate ligament						Lunotriquetral ligament					
			Reader 1		Reader 2		Surgery		Reader 1		Reader 2		Surgery		Reader 1		Reader 2		Surgery	
			2D	3D	2D	3D	2D	3D	2D	3D	2D	3D	2D	3D	2D	3D	2D	3D	2D	3D
1	F	60	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	-	-	-	-	-	-
2	F	46	Tear	Tear	Tear	Tear	Tear	Tear	-	-	-	-	-	-	-	-	-	-	-	-
3	M	25	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	-	-	-	-	-	-	-
4	M	37	-	-	-	-	-	-	Tear	Tear	Tear	Tear	Tear	Tear	-	-	-	-	-	Tear
5	M	29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	M	23	Tear	Tear	Tear	Tear	Tear	Tear	-	-	-	-	-	-	Tear	-	Tear	-	-	Tear
7	F	23	Tear	Tear	Tear	Tear	Tear	Tear	-	-	-	-	-	-	-	-	-	-	-	-
8	M	22	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	-	-	-	-	-	-
9	F	28	Tear	Tear	Tear	Tear	Tear	Tear	-	-	-	-	-	-	-	-	-	-	-	-
10	M	22	Tear	Tear	Tear	Tear	Tear	Tear	-	-	-	-	-	-	-	-	-	-	-	-
11	M	40	Tear	-	Tear	Tear	Tear	Tear	-	-	-	-	-	-	-	-	-	-	-	-
12	M	54	Tear	Tear	-	-	Tear	Tear	-	-	-	-	-	-	-	-	-	-	-	-
13	M	28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	F	27	Tear	-	Tear	-	Tear	-	-	-	-	-	-	-	-	-	-	-	-	-
15	F	16	Tear	Tear	Tear	Tear	Tear	Tear	-	-	-	-	-	-	-	-	-	-	-	-
16	F	32	Tear	Tear	Tear	Tear	Tear	Tear	-	-	-	-	-	-	-	-	-	-	-	-
17	F	45	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	-	Tear	Tear	Tear	Tear	-	Tear
18	F	23	-	-	-	-	-	-	Tear	Tear	Tear	Tear	Tear	Tear	-	-	-	-	-	-
19	F	52	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	-	-	-	-	-	-
20	M	25	Tear	Tear	Tear	Tear	Tear	Tear	-	-	-	-	-	-	-	-	-	-	-	-
21	M	20	Tear	Tear	Tear	Tear	Tear	Tear	-	-	-	-	-	-	-	-	-	-	-	-
22	F	16	-	-	-	-	Tear	-	-	-	-	-	-	-	-	-	-	-	-	-
23	M	47	Tear	Tear	Tear	Tear	Tear	Tear	-	-	-	-	-	-	-	-	-	-	-	-
24	M	44	Tear	Tear	Tear	Tear	Tear	Tear	-	-	-	-	-	-	-	-	-	-	-	-
25	F	27	-	-	-	-	-	-	Tear	Tear	Tear	Tear	-	Tear	-	-	-	-	-	-
26	F	59	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	Tear	-	-	-	-	-	-

F, female; M, male.

Figure 1. Direct MR arthrography images show an arthroscopically proven central perforation in the triangular fibrocartilage (TFC) in a 25-year-old male. Fat-suppressed T_1 weighted coronal (a) image, as well as three-dimensional isotropic fat-suppressed T_1 weighted oblique coronal (b) and oblique axial (c) reformatted images along the axis of the TFC show a full-thickness defect in the central portion of the TFC (arrows), which was correctly interpreted as a tear by both readers when using both sequences. The central perforation in the TFC was clearly observed on arthroscopy (d).

as the gold standard. Therefore, we tried to address the limitations of this previous study. To the best of our knowledge, our study is the first trial to apply D-MRA with 3D isotropic T_1 weighted FSE sequence for the wrist joint by using arthroscopic findings as the gold standard. Thus, the purpose of our study was to compare the diagnostic performances of wrist D-MRA with 2D T_1 weighted FSE and 3D isotropic T_1 weighted FSE sequences for the detection of central perforations in the TFC, and tears in the scapholunate ligament (SLL) and lunotriquetral ligament (LTL).

METHODS AND MATERIALS

Patients

The institutional review board of Samsung Medical Center, Seoul, Korea approved this retrospective Health Insurance Portability and Accountability Act-compliant study and waived informed patient consent (2016-02-135-001). From January 2011 through March 2016, 26 patients who underwent pre-operative wrist D-MRA with 3D isotropic T_1 weighted FSE and conventional 2D sequences and arthroscopic surgery were enrolled in this study. The patient group included 13 males (mean age, 32 years; range, 20–54 years) and 13 females (mean age, 34.9 years; range, 16–60 years).

MRI protocol

For wrist D-MRA, joint injection was performed by musculoskeletal fellowship trainees under fluoroscopic guidance. The patients were placed on the fluoroscopy table in the supine position with the palm down. A triangular sponge placed under the wrist was used to flex the wrist joint passively. The target site for radiocarpal joint injection was dorsal aspect of the radioscaphoid joint, and the skin at this entry site was marked. After the skin was draped, the injection site and the soft tissues were infiltrated with 1% lidocaine hydrochloride. A 22-gauge needle was placed in the radioscaphoid joint, and a small test injection of iomeprol (Iomeron® 300; Bracco, Milano, Italy) was performed to verify proper joint space by fluoroscopy. A 3–5 ml of diluted gadoterate meglumine [0.4 ml of Dotarem® (Guerbet, Roissy CDG, France) per 100 ml of normal saline] was injected into the radiocarpal joint.

MRI was initiated within 60 min after the intra-articular injection. All MR images were acquired using a 3.0-T scanner (Intera Achieva® 3.0 T; Philips, Best, Netherlands) with a dedicated sensitivity encoding wrist 4- or 8-channel coil

Figure 2. Direct MR arthrography images show an arthroscopically proven central perforation in the triangular fibrocartilage (TFC) in a 27-year-old female. Fat-suppressed T_1 weighted coronal (a) image shows a defect in the central portion (arrow) of the TFC. Three-dimensional isotropic fat-suppressed T_1 weighted coronal (b) image does not show any defect in the central portion of the TFC. Both readers correctly interpreted the tear when using two-dimensional images.

Figure 3. Direct MR arthrography images show an arthroscopically proven central perforation in the triangular fibrocartilage (TFC) in a 16-year-old female. T_1 weighted coronal (a) image does not show any defect in the central portion of the TFC. Three-dimensional isotropic fat-suppressed T_1 weighted oblique coronal (b) and oblique axial (c) reformatted images along the axis of the TFC show a full-thickness defect in the central portion of the TFC (arrows). Both readers correctly interpreted the tear when using three-dimensional images. The central perforation in the TFC was clearly observed on arthroscopy by probing (d).

(Philips wrist coil; Philips). Conventional 2D MRI was performed first and was followed by 3D isotropic T_1 weighted FSE imaging. Conventional 2D MRI consisted of axial, coronal and sagittal fat-suppressed (FS) T_1 weighted FSE sequences and axial and coronal T_2 weighted FSE sequences. In seven patients, coronal T_1 weighted FSE sequences were obtained instead of coronal FS T_1 weighted FSE sequences. We obtained the 3D isotropic FS T_1 weighted FSE (volumetric isotropic turbo spin-echo acquisition; Philips Medical Systems) sequence with 0.4-mm thickness in the coronal plane. The imaging parameters of these sequences are summarized in Table 1.

Image analysis

MR images were retrospectively and independently reviewed by two musculoskeletal radiologists (Y.C.Y and E.O with 13 and 5 years of experience in musculoskeletal radiology, respectively) to evaluate the presence of central perforations in the TFC and tears in the SLL and LTL. The radiologists were blinded to the arthroscopic results. To prevent recall bias, the radiologists reviewed the MR images in random order and in two separate sessions (2D vs 3D images) at least 2 weeks apart. Images were

evaluated using a picture archiving and communication system (Centricity Radiology RA 1000; GE Healthcare, Chicago, IL). For 2D sequences, only T_1 weighted images were used for the analysis because 3D images were not obtained with the T_2 weighted sequence. For 3D images with reformation, Aquarius iNtuition, v. 4.4.11 (TeraRecon, Inc., San Mateo, CA) was used during image analysis. Reformatted images with a slice thickness of 0.4 mm in the axial and sagittal planes were semi-automatically generated in a standard fashion after digital imaging and communications in medicine files of 150 coronal images with 3D isotropic FS T_1 weighted FSE sequences were imported to the program network from the picture archiving and communication system. When injury was suspected, arbitrary planes according to the axis of the involved structures were also used.

Radiological assessment of the TFC, SLL and LTL was performed to determine the presence or absence of tears. A tear was defined as a full-thickness tear in the TFC, SLL and LTL based on the visualization of discontinuity of fibre. We considered increased signal intensity or partial-thickness discontinuity in the TFC, SLL and LTL as an absence of a tear.

Table 3. Area under the receiver operating characteristic curve values with two-dimensional (2D) fast spin-echo (FSE) and three-dimensional (3D) T_1 weighted FSE sequences in the detection of central perforations in the triangular fibrocartilage (TFC) and tears in the scapholunate ligament (SLL) and lunotriquetral ligament (LTL)

Abnormality and reader	2D FSE sequence	3D T_1 weighted FSE sequence	Difference	<i>p</i> -value
Central perforations in the TFC				
Reader A	0.852 (0.659, 0.960)	0.852 (0.659, 0.960)	0 (−0.0956, 0.0956)	1
Reader B	0.852 (0.659, 0.960)	0.852 (0.659, 0.960)	0 (−0.0676, 0.0676)	1
SLL tear				
Reader A	0.947 (0.783, 0.997)	0.947 (0.783, 0.997)	0 (0.000, 0.000)	1
Reader B	0.947 (0.783, 0.997)	0.876 (0.688, 0.972)	0.0714 (−0.0686, 0.211)	0.3173
LTL tear				
Reader A	0.833 (0.636, 0.949)	0.667 (0.456, 0.838)	0.167 (−0.160, 0.493)	0.3173
Reader B	0.833 (0.636, 0.949)	0.667 (0.456, 0.838)	0.167 (−0.160, 0.493)	0.3173

Figure 4. Direct MR arthrography images show an arthroscopically proven tear in the scapholunate ligament (SLL) in a 22-year-old male. Fat-suppressed T_1 weighted coronal (a) and three-dimensional isotropic fat-suppressed T_1 weighted coronal (b) reformatted images show a full-thickness interval gap in the SLL (arrows), which was correctly interpreted as a tear by both readers when using both sequences.

Arthroscopic surgery

Arthroscopic findings were used as the reference standard. Surgery was performed by one orthopaedic surgeon (M.J.P) with 23 years of experience in wrist surgery. The surgeon was not blinded to the diagnostic reports derived from the pre-operative

MR arthrographic images. The interval between MRI and arthroscopic surgery was less than 150 days except in one case, in which it was 405 days (range, 13–405 days; mean duration, 64.7 days). The surgeon recorded the abnormalities of the TFC, SLL and LTL in detail. When the abnormality was described as an

Figure 5. Direct MR arthrography images show an arthroscopically proven tear in the lunotriquetral ligament (LTL) in a 45-year-old female. Fat-suppressed T_1 weighted coronal (a) image and three-dimensional isotropic fat-suppressed T_1 weighted oblique coronal (b) and oblique axial (c) reformatted images show a tear in the LTL (arrows), which was correctly interpreted as a tear by both readers when using both sequences. The LTL tear was clearly observed on arthroscopy by probing (d).

incongruity, step-off, interval gap, full-thickness tear or complete tear in the SLL and LTL, we considered it as a tear. However, when the abnormality was described as fraying or thinning in the SLL and LTL, we considered it as an absence of a tear.

Statistical analysis

Data were analyzed using the receiver operating characteristic method. Each reader's performance in evaluating the TFC, SLL and LTL was evaluated by using the area under the receiver operating characteristic curve (AUC).

The sensitivity, specificity and accuracy for detecting central perforations in the TFC and tears in the SLL and LTL were calculated using the McNemar test. A weighted κ test was used to assess interobserver agreement. The degree of agreement was categorized as follows: a κ -value of <0 indicated poor agreement; 0–0.20 indicated slight agreement; 0.21–0.40 indicated fair agreement; 0.41–0.60 indicated moderate agreement; 0.61–0.80 indicated substantial agreement; and 0.81–1.0 indicated near-perfect agreement.

Statistical analysis was performed using MedCalc v. 12.5.0 (MedCalc Software, Mariakerke, Belgium). A $p < 0.05$ was considered statistically significant.

RESULTS

Patient data and results are summarized in Table 2. Arthroscopic surgery revealed 21 central perforations in the TFC (Figures 1–3). The AUCs reflecting the diagnostic performances of Readers A and B while using the 3D T_1 weighted FSE and 2D T_1 weighted FSE sequences were identical (0.852) for the detection of central perforations in the TFC (Table 3).

Arthroscopic surgery revealed seven tears in the SLL (Figure 4). The AUCs reflecting the diagnostic performances of Readers A and B while using 3D T_1 weighted FSE sequences were 0.947 and 0.876, respectively, and the corresponding values for 2D T_1 weighted FSE sequences were 0.947 and 0.947, respectively, for the detection of SLL tears (Table 3).

Arthroscopic surgery also revealed three tears in the LTL (Figure 5). The AUCs reflecting the diagnostic performance of Readers A and B while using 3D T_1 weighted FSE sequences were 0.667 and 0.667, respectively, and the corresponding values for 2D T_1 weighted FSE sequences were 0.833 and 0.833, respectively, for the detection of LTL tears (Table 3).

The sensitivity, specificity and accuracy of central perforations in the TFC were 90.5%, 80% and 88.5% for both readers and both sequences, respectively. Those of tears in SLL were 100%, 89.5% and 92.3% for both Readers' 2D and Reader A's 3D and were 85.7%, 89.5% and 88.5% for Reader B's 3D, respectively. Those of tears in LTL were 66.7%, 100% and 96.2% for both Readers' 2D and were 33.3%, 100% and 92.3% for both Readers' 3D, respectively (Table 4).

Interobserver agreement was substantial for both the 2D and 3D sequences for the diagnosis of central perforations in the TFC. Interobserver agreement was nearly perfect for the 2D and 3D sequences for the diagnosis of SLL and LTL tears.

Table 4. Sensitivity, specificity and accuracy of two-dimensional (2D) fast spin-echo (FSE) and three-dimensional (3D) T_1 weighted FSE sequences in the detection of central perforations in the triangular fibrocartilage (TFC) and tears in the scapholunate ligament (SLL) and lunotriquetral ligament (LTL)

Abnormality and reader	Sensitivity (%)		Specificity (%)		Accuracy (%)	
	2D FSE sequence	3D T_1 weighted FSE sequence	p -value	2D FSE sequence	3D T_1 weighted FSE sequence	p -value
Central perforations in the TFC						
Reader A	90.5% (19/21)	90.5% (19/21)	1.0	80% (4/5)	88.5% (23/26)	1.0
Reader B	90.5% (19/21)	90.5% (19/21)	1.0	80% (4/5)	88.5% (23/26)	1.0
SLL tear						
Reader A	100% (7/7)	100% (7/7)	N/A	89.5% (17/19)	92.3% (24/26)	N/A
Reader B	100% (7/7)	85.7% (6/7)	1.0	89.5% (17/19)	88.5% (23/26)	1.0
LTL tear						
Reader A	66.7% (2/3)	33.3% (1/3)	1.0	100% (23/23)	92.3% (24/26)	1.0
Reader B	66.7% (2/3)	33.3% (1/3)	1.0	100% (23/23)	92.3% (24/26)	1.0

N/A, not applicable.

DISCUSSION

3D isotropic MRI allows the acquisition of thin slices without gaps between slices and multiplanar reconstruction with a single acquisition resulting in the reduction of the partial volume averaging effect and imaging time. Although several studies have compared the diagnostic performances of 3D isotropic sequences and 2D sequences in the wrist joints, most of these used a gradient-recalled echo sequence^{8,23} or FSE images with intermediate-weighted sequences.^{8,21,22} We used 3D isotropic T_1 weighted FSE sequences in this study, and to our knowledge, it was the first such study on the wrist joint. This sequence uses flip angle sweep, short and non-volume selective refocusing pulse, and parallel imaging, which makes it possible to get shorter echo spacing and a better signal-to-noise ratio.¹⁰

In this study, the diagnostic performance of 3D isotropic T_1 weighted FSE D-MRA as measured with the AUC value was identical or similar to that of 2D D-MRA in the diagnosis of central perforations in the TFC and tears in the SLL and LTL. We found no significant difference between the diagnostic performance of 2D and 3D sequences in detecting central perforations in the TFC and tears in the SLL and LTL with the AUC analysis either. Therefore, 3D isotropic T_1 weighted FSE D-MRA has potential for substituting 2D imaging while offering several advantages, such as the convenience for image reformation into arbitrary planes, shorter scan time than that of 2D imaging including all three planes (5 min 43 s vs 10 min) and the reduction of partial volume averaging effects.

In our study, there was one false-positive detection of central perforation in the TFC by both readers and with both sequences. In that case, the interval between surgery and the date of D-MRA scans was 405 days. Therefore, the central perforations in the TFC which were detected on D-MRA with 2D and 3D T_1 weighted FSE images could have healed spontaneously with granulation or fibrotic tissues.²⁴

Moreover, there were two false-positive detections of SLL tears by both readers and with both sequences. At second review, the abnormal defects at the SLL were still definitely identified in two cases. In one case, arthroscopic finding revealed that the superficial portion of the SLL looked like tear, whereas the deep portion of the SLL was intact. In the other case, arthroscopic finding revealed that the SLL was intact.

There was also one false-negative detection of LTL tear by both readers and with both sequences. At second review, we still could not identify the LTL tear. Arthroscopy revealed a mild step off

and mild widening <2 mm at the lunotriquetral joint when probing was performed.

In our study, the sensitivity and specificity of detection of central perforations in the TFC and tears in the SLL and LTL with 3D isotropic T_1 weighted FSE MRI were similar to one another and were comparable with the sensitivity and specificity reported in previous studies using the 3D fast gradient technique, except for the sensitivity of detecting LTL tears.²³ The sensitivity of detecting LTL tears was 33.3% and 84.6% in our study and previous study, respectively. We hypothesized that the marked difference in the sensitivity of detecting LTL tears could be due to our small sample size and small number of cases of LTL tears.

Our study has several limitations. This study had a retrospective design and a small sample size. In addition, there may have been a patient selection bias because we included only patients who had undergone arthroscopic surgery. We also cannot exclude the possibility of a recall bias. To avoid recall bias, both the radiologists reviewed the 2D images first and the 3D images 2 weeks later. However, the detection rate with the 3D sequence might have been affected by bias. Another limitation was that we obtained a coronal T_1 weighted FSE sequence instead of a coronal FS T_1 weighted FSE sequence in seven patients; the former sequence might have resulted in low-level contrast. However, in these seven cases, none highlighted the lower diagnostic performance of 2D images over 3D images. Moreover, we obtained axial and sagittal FS T_1 -weighted FSE images, and they could supplement the above limitation. The other limitation was that we performed contrast material injection at the radiocarpal joint and the presence of contrast materials in either the mid-carpal joint or the radioulnar joint indicated a perforation among the structures that we tried to evaluate. It could bias the readers against evaluating structures. However, it did not exactly indicate the damaged structure. Finally, we did not evaluate the peripheral portion of the TFC, articular cartilage or other ligaments.

In conclusion, the diagnostic performance of 3D isotropic T_1 weighted FSE D-MRA and that of 2D T_1 weighted FSE D-MRA were not significantly different in the diagnosis of central perforations in the TFC and tears in the SLL and LTL. A larger prospective study is needed to corroborate 3D isotropic T_1 weighted FSE imaging as a substitute for conventional 2D imaging for diagnosing central perforations in the TFC and tears in the SLL and LTL. We also recommend that subsequent study is needed for evaluating the diagnostic performance of 3D isotropic T_1 weighted FSE imaging for detecting tears in the peripheral portion of the TFC and partial tears in the intrinsic ligaments.

REFERENCES

1. Magee T. Comparison of 3-T MRI and arthroscopy of intrinsic wrist ligament and TFCC tears. *AJR Am J Roentgenol* 2009; **192**: 80–5. doi: <https://doi.org/10.2214/AJR.08.1089>
2. Bencardino JT. MR imaging of tendon lesions of the hand and wrist. *Magn Reson Imaging Clin N Am* 2004; **12**: 333–47. doi: <https://doi.org/10.1016/j.mric.2004.02.010>
3. Haims AH, Moore AE, Schweitzer ME, Morrison WB, Deely D, Culp RW, et al. MRI in the diagnosis of cartilage injury in the wrist. *AJR Am J Roentgenol* 2004; **182**: 1267–70. doi: <https://doi.org/10.2214/ajr.182.5.1821267>

4. Bordalo-Rodrigues M, Amin P, Rosenberg ZS. MR imaging of common entrapment neuropathies at the wrist. *Magn Reson Imaging Clin N Am* 2004; **12**: 265–79.
5. Hobby JL, Tom BD, Bearcroft PW, Dixon AK. Magnetic resonance imaging of the wrist: diagnostic performance statistics. *Clin Radiol* 2001; **56**: 50–7. doi: <https://doi.org/10.1053/crad.2000.0571>
6. Zanetti M, Bram J, Hodler J. Triangular fibrocartilage and intercarpal ligaments of the wrist: does MR arthrography improve standard MRI? *J Magn Reson Imaging* 1997; **7**: 590–4. doi: <https://doi.org/10.1002/jmri.1880070322>
7. Scheck RJ, Romagnolo A, Hierner R, Pfluger T, Wilhelm K, Hahn K. The carpal ligaments in MR arthrography of the wrist: correlation with standard MRI and wrist arthroscopy. *J Magn Reson Imaging* 1999; **9**: 468–74. doi: [https://doi.org/10.1002/\(SICI\)1522-2586\(199903\)9:3<468::AID-JMRI16>3.0.CO;2-T](https://doi.org/10.1002/(SICI)1522-2586(199903)9:3<468::AID-JMRI16>3.0.CO;2-T)
8. Jung JY, Yoon YC, Jung JY, Choe BK. Qualitative and quantitative assessment of wrist MRI at 3.0 T: comparison between isotropic 3D turbo spin echo and isotropic 3D fast field echo and 2D turbo spin echo. *Acta Radiol* 2013; **54**: 284–91. doi: <https://doi.org/10.1258/ar.2012.120475>
9. Gold GE, Busse RF, Beehler C, Han E, Brau AC, Beatty PJ, et al. Isotropic MRI of the knee with 3D fast spin-echo extended echo-train acquisition (XETA): initial experience. *AJR Am J Roentgenol* 2007; **188**: 1287–93. doi: <https://doi.org/10.2214/AJR.06.1208>
10. Choo HJ, Lee SJ, Kim OH, Seo SS, Kim JH. Comparison of three-dimensional isotropic T1-weighted fast spin-echo MR arthrography with two-dimensional MR arthrography of the shoulder. *Radiology* 2012; **262**: 921–31. doi: <https://doi.org/10.1148/radiol.11111261>
11. Jung JY, Yoon YC, Choi SH, Kwon JW, Yoo J, Choe BK. Three-dimensional isotropic shoulder MR arthrography: comparison with two-dimensional MR arthrography for the diagnosis of labral lesions at 3.0 T. *Radiology* 2009; **250**: 498–505. doi: <https://doi.org/10.1148/radiol.2493071548>
12. Jung JY, Yoon YC, Kwon JW, Ahn JH, Choe BK. Diagnosis of internal derangement of the knee at 3.0-T MR imaging: 3D isotropic intermediate-weighted versus 2D sequences. *Radiology* 2009; **253**: 780–7. doi: <https://doi.org/10.1148/radiol.2533090457>
13. Kijowski R, Davis KW, Woods MA, Lindstrom MJ, De Smet AA, Gold GE, et al. Knee joint: comprehensive assessment with 3D isotropic resolution fast spin-echo MR imaging—diagnostic performance compared with that of conventional MR imaging at 3.0 T. *Radiology* 2009; **252**: 486–95. doi: <https://doi.org/10.1148/radiol.2523090028>
14. Notohamiprodjo M, Horng A, Pietschmann MF, Muller PE, Horger W, Park J, et al. MRI of the knee at 3T: first clinical results with an isotropic PDfs-weighted 3D-TSE-sequence. *Invest Radiol* 2009; **44**: 585–97. doi: <https://doi.org/10.1097/RLI.0b013e3181b4c1a1>
15. Stevens KJ, Busse RF, Han E, Brau AC, Beatty PJ, Beaulieu CF, et al. Ankle: isotropic MR imaging with 3D-FSE-cube—initial experience in healthy volunteers. *Radiology* 2008; **249**: 1026–33. doi: <https://doi.org/10.1148/radiol.2493080227>
16. Yao L, Pitts JT, Thomasson D. Isotropic 3D fast spin-echo with proton-density-like contrast: a comprehensive approach to musculoskeletal MRI. *AJR Am J Roentgenol* 2007; **188**: W199–201. doi: <https://doi.org/10.2214/AJR.06.0556>
17. Subhas N, Kao A, Freire M, Polster JM, Obuchowski NA, Winalski CS. MRI of the knee ligaments and menisci: comparison of isotropic-resolution 3D and conventional 2D fast spin-echo sequences at 3 T. *AJR Am J Roentgenol* 2011; **197**: 442–50. doi: <https://doi.org/10.2214/AJR.10.5709>
18. Magee T. Can isotropic fast gradient echo imaging be substituted for conventional T1 weighted sequences in shoulder MR arthrography at 3 Tesla? *J Magn Reson Imaging* 2007; **26**: 118–22. doi: <https://doi.org/10.1002/jmri.21000>
19. Lee JH, Yoon YC, Jee S, Kwon JW, Cha JG, Yoo JC. Comparison of three-dimensional isotropic and two-dimensional conventional indirect MR arthrography for the diagnosis of rotator cuff tears. *Korean J Radiol* 2014; **15**: 771–80. doi: <https://doi.org/10.3348/kjr.2014.15.6.771>
20. Jung JY, Jee WH, Park MY, Lee SY, Kim YS. Supraspinatus tendon tears at 3.0 T shoulder MR arthrography: diagnosis with 3D isotropic turbo spin-echo SPACE sequence versus 2D conventional sequences. *Skeletal Radiol* 2012; **41**: 1401–10. doi: <https://doi.org/10.1007/s00256-012-1361-1>
21. Sutherland JK, Nozaki T, Kaneko Y, Yu HJ, Rafiqah G, Hitt D, et al. Initial experience with 3D isotropic high-resolution 3 T MR arthrography of the wrist. *BMC Musculoskelet Disord* 2016; **17**: 30. doi: <https://doi.org/10.1186/s12891-016-0890-5>
22. Yamabe E, Anavim A, Sakai T, Miyagi R, Nakamura T, Hitt D, et al. Comparison between high-resolution isotropic three-dimensional and high-resolution conventional two-dimensional FSE MR images of the wrist at 3 Tesla: a pilot study. *J Magn Reson Imaging* 2014; **40**: 603–8. doi: <https://doi.org/10.1002/jmri.24428>
23. Lee YH, Choi YR, Kim S, Song HT, Suh JS. Intrinsic ligament and triangular fibrocartilage complex (TFCC) tears of the wrist: comparison of isovolumetric 3D-THRIVE sequence MR arthrography and conventional MR image at 3 T. *Magn Reson Imaging* 2013; **31**: 221–6. doi: <https://doi.org/10.1016/j.mri.2012.06.024>
24. Tatebe M, Hirata H, Horii E, Nakao E, Nakamura R. Regeneration of the triangular fibrocartilage complex: second-look arthroscopy. *Riv Chir Mano* 2006; **43**: 377–9.