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Is the quantitative Diffusion-Weighted MR Imaging and ADC mapping with b-values of 50, 400, and 800 sec/mm^2 a reliable method for evaluation of meniscal tears in the knee?

Hasan Aydin, Volkan Kizilgöz, Baki Hekimoğlu

Departmant of Radiology, Dışkapı Yıldırım Beyazıt Eğitim Ve Araştırma Hastanesi, Ankara, Turkey

Author's address: Hasan Aydın, Departmant of Radiology, Dışkapı Yıldırım Beyazıt Eğitim Ve Araştırma Hastanesi, Dışkapı Eğ. Araşt. Hast. İrfan Baştuğ Caddesi Altındağ/Ankara-Turkey Postal Code: 06110, e-mail: dr.hasanaydin@hotmail.com

Summary

Background: Our aim was to evaluate the efficacy of Diffusion-Weighted Imaging (DWI) and Apparent Diffusion Coefficient (ADC) mapping with different b-factors in visualisation of meniscal tears.

Material/Methods: Seventy-four patients; 30 males and 44 females, 37 left and 37 right knees with meniscal tears were involved in this study. Eleven of them were lateral meniscal tears and 63 - medial meniscal tears. DWI was obtained by 3D-SE Echo-planar Imaging (EPI) in coronal and sagittal planes. ADC mapping was carried out in coronal planes with b-factors of 50, 400, and 800 sec/mm^2. The statistical analysis of DWI and ADC mapping results was performed with the use of the Fisher's test and the chi-square test.

Results: 1. For both menisci and 74 tears: DWI revealed 86% sensitivity and 100% specificity (p=0.149) with a positive predictive value (PPV) of 1 and a negative predictive value (NPV) of 0.09. ADC mapping with b-value of 400 sec/mm^2 had 78% sensitivity, and 100% specificity, with PPV of 1 and NPV of 0.06 (p=0.230). 2. For the lateral meniscal tears: DWI and ADC mapping with b-value of 800, for the medial meniscal tears: DWI and ADC mapping with b-factor of 400 s/mm2 revealed higher sensitivity and specificity than other methods.

Conclusions: Quantitative DWI and ADC mapping, especially with b-factor of 400 sec/mm^2, may be an alternative to routine MR imaging sequences for the visualisation of meniscal tears in the knee.

Key words: **DWI • ADC mapping • b-factors • medial meniscus tears • lateral meniscus tears**

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Background

MR imaging shows high accuracy in the identification of internal pathologies of the knee, especially the meniscal tears and injuries [1,2]. MR imaging provides important information about bone and soft tissue disorders in and around the knee joint [3,4]. It can help avoiding unnecessary diagnostic arthroscopy and show the size, location and characteristics of meniscal tears that will guide treatment [2–5]. Coupled with a patient's history and physical exam findings, MR imaging has a high utility in directing the treatment of individuals with knee pain [2,4–6]. In most of the radiology departments, T1 and PD-T2W SE, FSE, Gradient Echo (GE) sequences of transverse, sagittal and coronal images with or without Fat-Saturation (FS) are still used as a routine knee MR protocol [4,5]. The accuracy for meniscal tears and other knee pathologies evaluated by 3D-MR imaging was shown to be more than 90% in several papers [1,2,4,5]. With the advancement of the technology, newer MRI sequences have been introduced to improve the quality of a routine MR imaging protocol and and have been applied to increase the sensitivity and specificity for the diagnosis of meniscal injuries [2,4,7]. Such a new sequence, that is the DWI and ADC mapping, will be analysed in this study. We will also try to provide information about the utility of 3D-DWI and ADC mapping with different b-factors in the diagnostics of meniscal tears of the knee in comparison to the routine MR imaging protocol.

Material and Methods

Our study included 74 consecutive patients referred to hospital due to pain and mechanical symptoms such as catching and locking, between May and November 2009. Thirty men and 44 women were analysed. Their age ranged from 24 to 63, and their mean age was 44. There were 37 left and 37 right knees with meniscal tears that were included in this study. Eleven of them were lateral meniscal tears, and 63 – medial meniscal tears. All of the tears originated from posterior horns. One tear, from medial meniscus, showed maceration as well. Twelve tears were also found in the anterior horns of the menisci: four of them in the lateral meniscus and 8 in the medial meniscus. Ten patients had both medial and lateral meniscal tears. All of them were included. Twenty patients underwent arthroscopic surgery followed by histopathological confirmation. The interval between MR imaging and arthroscopy of the meniscal tears in those 20 patients was about 15 days to 2 months. Other patients were were alive with meniscal tears. Each patient underwent a detailed history and physical examination at the time of initial evaluation. Informed consent was taken from all the patients prior to the section. Ethics committee approval from the hospital's review board was also added. MR examinations were performed with Siemens Symphony Power 1.5 T magnet (Siemens-Erlangen-Germany) with a maximum gradient strength of 30 mT/m, and a slew rate of 120 mlt per millisecond. A standard knee coil was used. A conventional knee MR protocol was as follows: T1W SE and T2W GE sagittal, T1W and PD-FS coronal, PD-FS axial planes; DWI was obtained by 3D-SE Echo-planar Imaging (EPI) in coronal and sagittal planes with TR 1900, TE 100, FOV 125*295 to 157*295 mm; ADC mapping was performed in coronal planes with b-factors of 50, 400, and 800 sec./mm^2. Scanning time was about 0.15 min. T1W coronal and sagittal image parameters were as follows: TR/TE of 530/20, slice thickness of 4 mm, matrix of 256*512 and FOV of 240×160 mm, NEX 2, scanning time of about 45 seconds. T2W FS axial image parameters: TR/TE of 2030/80, slice thickness of 4 mm, matrix of 152*480, and FOV of 250×150 mm, NEX 2, scanning time of about 57 seconds.T2W GE sagittal sequence parameters: TR/TE of 400/15, slice thickness of 4 mm, matrix of 256*256 and FOV of 250×150 mm, NEX 2, scanning time of about 2.15 minutes. PDW FS coronal sequence parameters: TR/TE of 2230/30, slice thickness of 4 mm, matrix of 244*400 and FOV of 240x160 mm, NEX 3, scanning time of about 1.17 min. Slice thickness of DWI sequence was 3 mm.

Analysis of the data set obtained with all sequences was interpreted by a single radiologist with an 8-year experience for musculoskeletal radiology who was blinded and unaware of the results of arthroscopy in 20 patients. In MR imaging: an increased meniscal signal was regarded as a meniscal tear when it could communicate with the inferior, superior or free edge of meniscal surface (or more than one of those) on two consecutive images and planes (sagittal and coronal) [5,7]. Tears were categorised as follows: **Horizontal,** a tear parallel to the tibial plateau separating the meniscus into the upper and the lower part; **oblique**, a tear extending obliquely to the main axis of the meniscus; **longitudinal**, a vertical tear perpendicular to the tibial plateau extending parallelly to the main axis of the meniscus; **radial**, a vertical tear that begins in the central free margin perpendicular both to the tibial plateau and the free edge of the meniscus; **complex**, multiple tears of more than one configuration and one cleavage orientation lacking continuity; **root**, defined as a tear in the posterior or anterior meniscal attachments [2,7,8]. There were 2 radial tears, 7 complex and oblique tears, 2 root tears, 38 horizontal tears, and 18 longitudinal tears analysed in 74 patients. Lateral meniscal tears were of root, oblique and horizontal type, whereas medial meniscal tears included all types of tears.

The criteria of meniscal tears in DWI and ADC mapping were the same as in routine MR imaging: an increased meniscal signal was regarded as a horizontal, oblique, longitudinal, vertical, or complex meniscal tear if communicating with the inferior, superior or free edge of meniscal surface (or more than one of those) on sagittal and coronal images. All types of tears, either in the medial meniscus or the lateral meniscus, were termed meniscal tears and classified as: medial meniscal tears and lateral meniscal tears.

Tear involving either the posterior or anterior horns of menisci or both horns was also visualised. The absence or great damage to meniscus tissue due to the tear was recorded as maceration and we had one such case in this paper. Tears remaining after arthroscopy and residual meniscal fragments after surgery were excluded from the study. The differentiation between the meniscal tears and meniscal degeneration was based on the following criteria in DWI and ADC mapping: A) increased meniscal signal, located in the meniscal bodies, without any relationship to the inferior, superior or free edges of meniscal surfaces, was regarded as degeneration. B) horizontal or triangular hyperintensity limited to meniscal bodies, was regarded as degenerated meniscal fragments C) oblique or vertical signals in articular surfaces and increased meniscal signals in meniscal attachment sites were never classified as degeneration.

Statistical analysis

Statistical analysis of DWI and ADC mapping with different b-factors was performed with the use of the **Fisher's test, Pearson chi square statistics** and SPSS 11.5 software (SPSS-Inc, Chicago-IL). Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated with regard to routine knee MR imaging. $P<0.05$ was considered to be statistically significant.

Results

Table 1 summarises all datas of 74 patients with meniscal tears, including age and gender, location of the meniscal tear (in the right or in the left knee – in the medial or lateral meniscus and originating from anterior or posterior horns), MRI-DWI and ADC mapping findings, operational status and match or mismatch of MRI to DWI and ADC mapping for b-factors 50, 400, and 800 sec./mm^2.

When we compared the DWI results with the results of the routine MRI for both menisci and 74 tears, we found that DWI has 86% sensitivity and 100% specificity (p=0.149) with

Table 1. The list of patients and the corresponding findings.

	Name-Age-Gender	Knee (Right-Left)	Medial Meniscus	Lateral Meniscus	Anterior Horn	Posterior Horn	Routine MRI Findings	DWI Findings	ADC b=50	ADC b=400	ADC b=800	Arthroscopy Findings	MRG-DWI+ADC Map Matching
1	E.T 60 M	Right	+			Tear	Positive	Positive	Negative	Positive	Positive	–	Match
2	E.G 50 M	Left	+			Tear	Positive	Positive	Negative	Positive	Negative	–	Match
3	E.B 35 M	Left	+			Tear	Positive	Positive	Negative	Positive	Positive	–	Match
4	F.C 57 F	Right	+			Tear	Positive	Positive	Negative	Negative	Positive	–	Match
5	F.E 50 F	Right	+			Tear	Positive	Positive	Negative	Negative	Positive	–	Match
6	F.K 40 F	Right	+			Tear	Positive	Negative	Negative	Negative	Negative	–	No match
7	F.Ş 25 F	Left	+			Tear	Positive	Positive	Negative	Positive	Positive	–	Match
8	V.P 35 F	Right	+			Tear	Positive	Positive	Negative	Positive	Positive	–	Match
9	G.U 55 F	Left	+			Tear	Positive	Positive	Negative	Positive	Negative	–	Match
10	G.A 42 F	Right	+			Tear	Positive	Negative	Negative	Negative	Negative	–	No match
11	G.P 45 F	Right	+			Tear	Negative	Positive	Positive	Positive	Positive	–	Match
12	A.B 32 M	Right	+			Tear	Positive	Positive	Negative	Positive	Positive	–	Match
13	A.D 30 M	Left	+			Tear	Positive	Positive	Negative	Positive	Positive	–	Match
14	H.H 50 F	Left	+			Macerated	Positive	Positive	Positive	Positive	Positive	–	Match
15	A.T 45 F	Left	+			Tear	Positive	Positive	Negative	Positive	Positive	+	Match
16	A.A 25 F	Right	+			Tear	Positive	Positive	Negative	Positive	Positive	–	Match
17	A.B 34 F	Left	+			Tear	Positive	Positive	Negative	Positive	Positive	–	Match
18	B.Ş 35 F	Right	+			Tear	Positive	Positive	Negative	Positive	Negative	–	Match
19	C.E 32 M	Right	+			Tear	Positive	Positive	Negative	Positive	Positive	–	Match
20	D.Ö 50 F	Left	+			Tear	Positive	Positive	Positive	Positive	Positive	+	Match
21	D.Ö 50 F	Left		+		Tear	Positive	Positive	Negative	Positive	Positive	–	Match
22	T.D 51 F	Left	+		Tear	Tear	Positive	Positive	Negative	Positive	Positive	+	Match
23	E.K 63 F	Right	+		Tear	Tear	Positive	Positive	Negative	Negative	Positive	+	Match
24	E.K 63 F	Right		+	Tear	Tear	Positive	Positive	Negative	Negative	Positive	–	Match
25	Ş.T 60 M	Left	+			Tear	Positive	Positive	Positive	Positive	Positive	–	Match
26	F.H 29 M	Right	+			Tear	Positive	Positive	Negative	Positive	Positive	–	Match
27	F.H 29 M	Right		+		Tear	Positive	Negative	Negative	Negative	Negative	–	No match
28	G.B 47 F	Left	+		Tear	Tear	Positive	Positive	Positive	Positive	Positive	+	Match
29	İ.E 52 M	Left	+			Tear	Positive	Positive	Negative	Positive	Positive	–	Match
30	İ.E 52 M	Left		+	Tear	Tear	Positive	Positive	Negative	Positive	Positive	–	Match
31	L.B 55 F	Left	+		Tear	Tear	Positive	Positive	Negative	Negative	Positive	+	Match
32	M.İ 45 M	Left	+		Tear	Tear	Positive	Positive	Negative	Positive	Positive	–	Match
33	M.İ 45 M	Left		+	Tear	Tear	Positive	Negative	Negative	Negative	Negative	–	No match
34	Ö.F 39 M	Left	+			Tear	Positive	Positive	Negative	Positive	Positive	–	Match
35	S.A 59 F	Right	+			Tear	Positive	Positive	Negative	Positive	Positive	+	Match
36	E.D 51 F	Left	+			Tear	Positive	Positive	Negative	Positive	Positive	–	Match
37	E.D 51 F	Left		+	Tear	Tear	Positive	Positive	Negative	Positive	Positive	–	Match

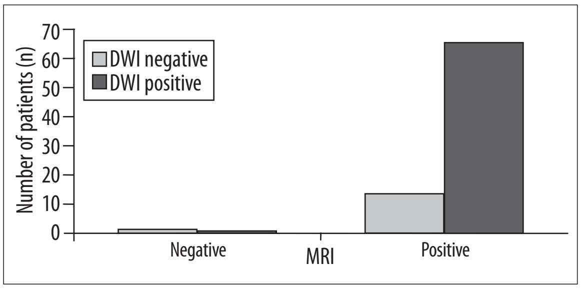
Table 1 continued. The list of patients and the corresponding findings.

	Name-Age-Gender	Knee (Right-Left)	Medial Meniscus	Lateral Meniscus	Anterior Horn	Posterior Horn	Routine MRI Findings	DWI Findings	ADC b=50	ADC b=400	ADC b=800	Arthroscopy Findings	MRG-DWI+ADC Map Matching
38	S.Ç 45 M	Right	+			Tear	Positive	Negative	Negative	Negative	Negative	+	No match
39	P.Ö 58 F	Right	+		Tear	Tear	Positive	Positive	Negative	Negative	Positive	–	Match
40	C.K 45 F	Right	+			Tear	Positive	Positive	Negative	Positive	Positive	–	Match
41	A.D 24 M	Left	+			Tear	Positive	Negative	Negative	Negative	Negative	–	No match
42	A.P 59 F	Right	+		Tear	Tear	Positive	Positive	Positive	Positive	Positive	–	Match
43	A.Ü 57 F	Right	+		Tear	Tear	Positive	Positive	Negative	Positive	Positive	+	Match
44	H.A 50 F	Left	+			Tear	Positive	Negative	Negative	Negative	Negative	–	No match
45	H.V 47 F	Left	+			Tear	Positive	Positive	Negative	Negative	Positive	–	Match
46	N.D 45 F	Right	+			Tear	Positive	Positive	Negative	Positive	Positive	+	Match
47	N.Y 49 F	Left	+			Tear	Positive	Positive	Positive	Positive	Positive	–	Match
48	N.Y 44 F	Left	+			Tear	Positive	Positive	Positive	Positive	Positive	–	Match
49	H.T 22 M	Left	+			Tear	Positive	Positive	Negative	Positive	Negative	–	Match
50	G.Ü 51 F	Right	+			Tear	Positive	Positive	Negative	Positive	Positive	+	Match
51	G.Ü 51 F	Right		+		Tear	Positive	Positive	Positive	Positive	Positive	–	Match
52	H.Ç 62 M	Right	+			Tear	Positive	Negative	Negative	Negative	Negative	+	No match
53	H.Ç 62 M	Right		+		Tear	Positive	Positive	Positive	Positive	Positive	–	Match
54	B.G 45 F	Left	+			Tear	Positive	Positive	Positive	Positive	Positive	–	Match
55	Ç.A 22 M	Right	+			Tear	Positive	Positive	Positive	Positive	Negative	–	Match
56	E.D 25 M	Right	+			Tear	Positive	Positive	Negative	Positive	Positive	–	Match
57	F.E 39 M	Right	+			Tear	Positive	Negative	Negative	Positive	Negative	+	No match
58	H.Ç 50 F	Left	+			Tear	Positive	Positive	Positive	Positive	Positive	–	Match
59	S.S 42 M	Left	+			Tear	Positive	Positive	Negative	Positive	Positive	–	Match
60	M.D 63 F	Right	+			Tear	Positive	Positive	Positive	Positive	Positive	–	Match
61	H.Ç 38 M	Right	+			Tear	Positive	Positive	Positive	Positive	Negative	+	Match
62	K.U 50 F	Right	+			Tear	Positive	Positive	Positive	Positive	Positive	–	Match
63	K.U 50 F	Right		+		Tear	Positive	Positive	Positive	Negative	Positive	–	Match
64	B.A 43 F	Left	+			Tear	Positive	Positive	Positive	Positive	Negative	+	Match
65	A.D 48 M	Left	+			Tear	Positive	Positive	Positive	Positive	Negative	–	Match
66	F.D 38 F	Left	+			Tear	Positive	Positive	Positive	Positive	Negative	–	Match
67	E.D 63 F	Left	+			Tear	Positive	Positive	Positive	Positive	Negative	+	Match
68	H.Ç 63 M	Left	+			Tear	Positive	Positive	Positive	Positive	Positive	+	Match
69	H.Ç 63 M	Left		+		Tear	Positive	Negative	Positive	Positive	Negative	–	No match
70	İ.Ç 36 M	Right	+			Tear	Positive	Positive	Positive	Positive	Negative	+	Match
71	İ.Ç 36 M	Right		+		Tear	Positive	Positive	Positive	Positive	Negative	–	Match
72	A.Y 37 M	Left	+			tear	positive	positive	positive	positive	negative	–	Match
73	D.K 38 F	Right	+			tear	positive	positive	positive	positive	positive	+	Match
74	D.K 38 F	Left	+			tear	positive	negative	positive	Negative	negative	+	No match

Table 2. DWI findings obtained during visualisation of all meniscal tears.

			MRI findings		Total
			Negative	Positive	
DWI findings	Negative	n	1	10	11
		%n	9.1%	90.9%	100.0%
	Positive	n	0	63	63
		%n	0.0%	100.0%	100.0%
Total		n	1	73	74
		%n	1.4%	98.6%	100.0%

Sensitivity=%86
Specificity=%100
PPV=1
NPV=0.09
Fisher's test P=0.149



PPV of 1 and NPV of 0.09 (Table 2, Figure 1). DWI results were not significantly statistically different from routine MRI findings for visualisation of meniscal tears (p>0.05). ADC mapping with b-value of 50 sec/mm^2 has 38% sensitivity, and 100% specificity, with PPV of 1 and NPV of 0.02 (p=1.00) (Table 3A). ADC mapping with b-value of 400 sec/mm^2 has 78% sensitivity and 100% specificity, with PPV of 1 and NPV of 0.06 (p=0.230) (Table 3B, Figure 2), and ADC mapping with b-value of 800 sec/mm^2 has 68% sensitivity and 100% specificity, with PPV of 1 and NPV of 0.04 (p=0.230) (Table 3C, Figure 2), correlated with MR imaging results. ADC mapping with all b-factors revealed no significant statistical differences when compared to routine MRI in visualisation of meniscal tears (p>0.05). DWI and ADC mapping with b-factor of 400 sec/mm^2 have higher sensitivity and specificity than other imaging modalities, with 100% PPV and less than 10% NPV.

For 63 medial meniscal tears: DWI revealed 87% sensitivity and 27% specificity (p=0.352) with PPV of 0.87 and NPV of 0.27 (Table 4A, Figure 3). **For 11 lateral meniscal tears:** DWI has 73% sensitivity and 13% specificity (p=0.352) with PPV of 0.13 and NPV of 0.73 (Table 4B, Figure 4). There were no significant statistical differences between DWI results for both menisci and routine MRI findings, for the diagnosis of meniscal tears (p>0.05). However, DWI had a very low specificity and a high NPV, especially for the lateral meniscal tears.

ADC mapping with b-value of 50 sec/mm^2 for 63 medial meniscal tears reveals 37% sensitivity and 45% specificity

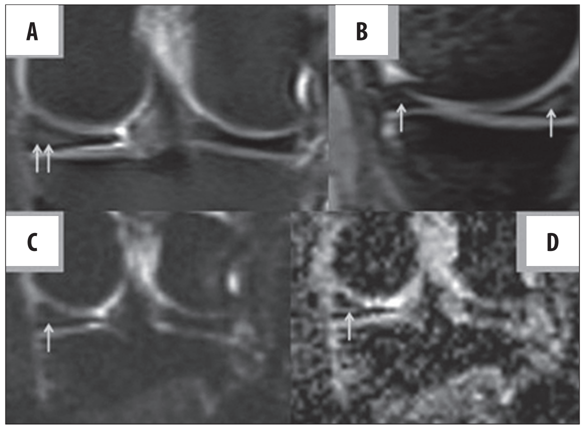


Figure 1. Medial meniscal tear. Coronal PDW (**A**) showing a medial meniscal tear. In the sagittal T2W image (**B**) the tear was found in posterior horn mostly. In this patient, coronal ADC mapping (with b-value of 800 sec/mm^2) (**C**) also showed the tear but DWI image (d) depicted the tear more clearly, when compared to ADC map (b=800).

(p=0.738), with PPV of 0.82 and NPV of 0.13 (Table 5A). For 11 lateral meniscal tears, its sensitivity is 45% and specificity 63% (p=0.738), with PPV of 0.18 and NPV of 0.87 (Table 5B). The results of ADC mapping with b-value of 50 sec/mm^2 for both menisci reveal no significant statistical differences as compared to the findings of the routine MRI in the evaluation of meniscal tears (p>0.05). Moreover, ADC mapping had a lower sensitivity and specificity for the evaluation of medial meniscal tears but (especially for the visualisation of lateral meniscal tears) it showed some difficulties due to its low PPV and high NPV when compared to the routine MRI.

In contrast to routine MRI findings, ADC mapping with b-factor of 400 sec/mm^2 used for 63 medial meniscal tears has 79% sensitivity and 64% specificity (p=0.263), with PPV of 0.88 and NPV of 0.24 (Table 6A, Figures 2, 3, 5). For 11 lateral meniscal tears, it has 64% sensitivity and 21% specificity (p=0.263), with PPV of 0.12 and NPV of 0.76 (Table 6B, Figure 6). ADC mapping with b-value of 400 sec/mm^2 for medial and lateral menisci tears revealed no significant statistical differences as compared to the routine MRI (p>0.05); it had higher sensitivity, specificity and PPV, especially for diagnosing medial meniscal tears but had lower specificity and high NPV for the identification of lateral meniscal tear.

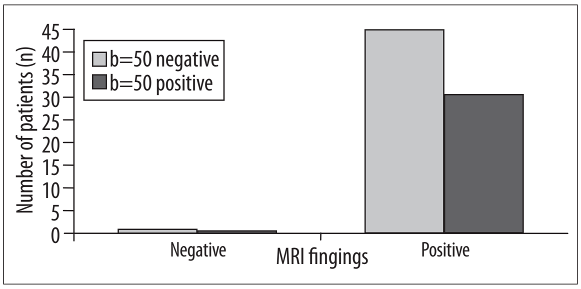
ADC mapping with b-factor of 800 sec/mm^2 for the medial meniscal tears has 68% sensitivity and 36% specificity (p=0.740), with PPV of 0.86 and NPV of 0.17 (Table 7A, Figures 1–3). In the evaluation of lateral meniscal tears, it has 64% sensitivity and 32% specificity (p=0.740) with PPV of 0.14 and NPV of 0.83 (Table 7B, Figure 4). ADC mapping with b-value of 800 sec/mm^2 for medial and lateral menisci tears has no significant statistical differences in comparison to the routine MRI (p>0.05); it has higher sensitivity in visualisation of both meniscal tears than ADC mapping with other b-factors. However, it reveals lower specificity and a high NPV, especially for lateral meniscal tears (like the other ADC map sequences).

When we study the concordance of DWI and ADC mapping (with three b-factors) and compare their results with

Table 3A–C. Results of ADC mapping for all meniscal tears, with b-values of 50, 400, and 800 sec/mm^2.

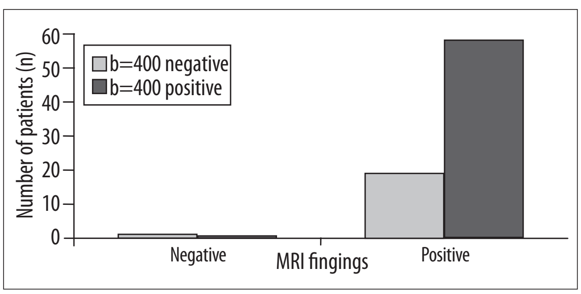
A			MRI findings		Total
			Negative	Positive	
b=50	Negative	n	1	45	46
		%n	2.2%	97.8%	100.0%
	Positive	n	0	28	28
		%n	0.0%	100.0%	100.0%
Total		n	1	73	74
		%n	1.4%	98.6%	100.0%

Sensitivity=%38
Specificity=%100
PPV=1
NPV=0.02
Fisher's test P=1.000



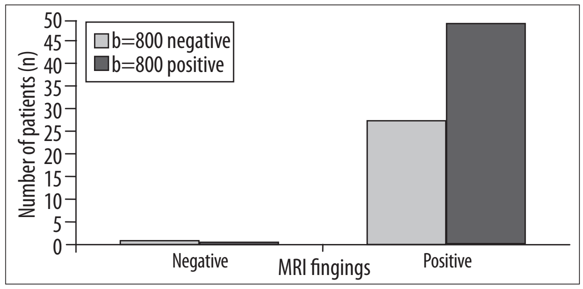
B			MRI findings		Total
			Negative	Positive	
b=400	Negative	n	1	16	17
		%n	5.9%	94.1%	100.0%
	Positive	n	0	57	57
		%n	0.0%	100.0%	100.0%
Total		n	1	73	74
		%n	1.4%	98.6%	100.0%

Sensitivity=%78
Specificity=%100
PPV=1
NPV=0.06
Fisher's test P=0.230



C			MRI findings		Total
			Negative	Positive	
b=800	Negative	n	1	23	24
		%n	4.2%	95.8%	100.0%
	Positive	n	0	50	50
		%n	0.0%	100.0%	100.0%
Total		n	1	73	74
		%n	1.4%	98.6%	100.0%

Sensitivity=%68
Specificity=%100
PPV=1
NPV=0.04
Fisher's test P=0.230



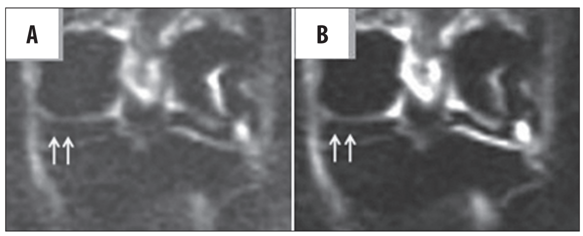


Figure 2. Medial horizontal meniscal tear visualised with coronal ADC mapping with b-value of 400 (**A**) and 800 (**B**).

MR imaging findings, we find no significant statistical differences in the evaluation of any of the meniscal tears ($p>0.05$): for medial meniscal tears, the sensitivity of 87%, with a lower specificity – of 27% (p value of 0.352). PPV and NPV for all matched sequences: 0.87/0.27. For lateral tears, 73% sensitivity with a very low specificity, of 13%, is observed (p: 0.352). PPV and NPV for all matched sequences for the lateral menisci: 0.13/0.73 (Table 8). As shown above, matching of DWI plus ADC mapping correlated with MRI shows a very low specificity and a higher NPV, especially in visualisation of lateral meniscal tears.

Discussion

The menisci serve several important biomechanical functions in the knee: absorb shock, distribute load during dynamic loading and assist in joint lubrication [2,3,9]. Both menisci are also mobile and allow movement in either antero-posterior or lateral-medial direction. They provide stability to the knee in weight-bearing or non-weight-bearing

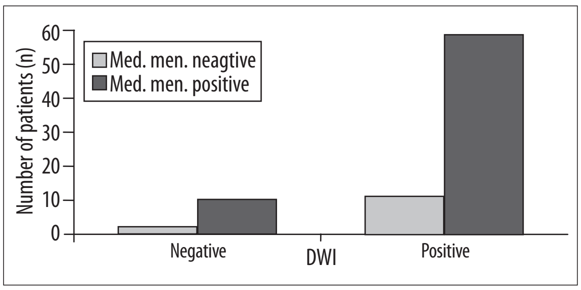
Table 4A,B. DWI results for both menisci. No significant statistical differences in comparison to routine MRI findings – the diagnosis of meniscal tears (p>0.05).

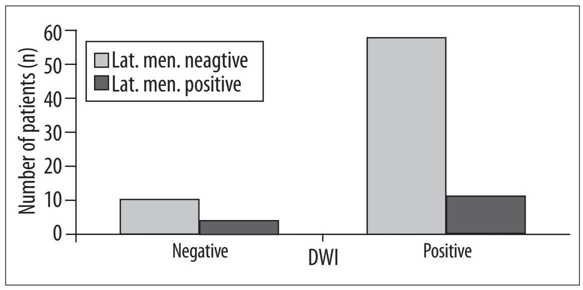
A			Medial meniscus		Total
			Negative	Positive	
DWI findings	Negative	n	3	8	11
		%n	27.3%	72.7%	100.0%
	Positive	n	8	55	63
		%n	12.7%	87.3%	100.0%
Total		n	11	63	74
		%n	14.9%	85.1%	100.0%

Sensitivity=%87
Specificity=%27
PPV=0.87
NPV=0.27
Fisher's test P=0.352

B			Lateral meniscus		Total
			Negative	Positive	
DWI findings	Negative	n	8	3	11
		%n	72.7%	27.3%	100.0%
	Positive	n	55	8	63
		%n	87.3%	12.7%	100.0%
Total		n	63	11	74
		%n	85.1%	14.9%	100.0%

Sensitivity=%73
Specificity=%13
PPV=0.13
NPV=0.73
Fisher's test P=0.352





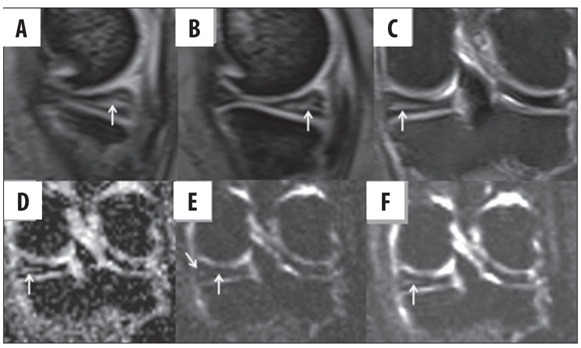


Figure 3. Sagittal T2W images (**A and B**) and coronal PDW image showing medial meniscal tear, especially in posterior horn. DWI (**D**), ADC map with b-factor of 400 (**E**) and 800 (**F**) showed the tear clearly.

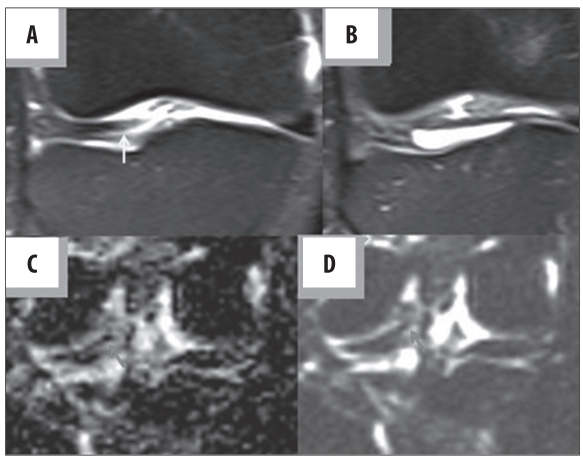


Figure 4. Lateral meniscal tear. Coronal PDW image (**A**) presenting the tear, especially in the medial parts of the lateral meniscus. There was also a fluid collection surrounding the lateral meniscus (**B**). Coronal DWI (**C**) and Coronal ADC mapping (b=800) scans also showed the tear in the lateral meniscus clearly.

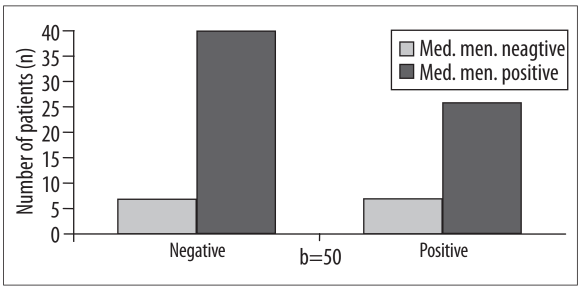
body positions and 50–90% of body weight is transmitted through the menisci in extension or flexion [2,3]. They distribute the stress forces over a large area of articular cartilage and over the underlying bone, enhance the ability of articular cartilage to provide a nearly frictionless articulation that can perform extensive biomechanical maneuvers which minimise the stress effect on the joint [3,9]. Meniscal tears can therefore disable the load-bearing function of meniscus, increase stress on tibial and femoral articular cartilages, ultimately leading to degeneration and spontaneous osteonecrosis [3,9,10].Treatment of meniscal tears depends on the configuration, size and location of the tear. It includes non-meniscal surgery, meniscal repair, partial meniscectomy and complete meniscectomy. Oblique-horizontal and longitudinal tears are usually amenable to repair, whereas radial and complex tears usually require partial or complete meniscectomy [6,9,10].

As mentioned above, MR imaging is the most sensitive, non-invasive technique for the diagnosis of meniscal tears

Table 5A,B. Results of ADC mapping with different b-values for medial and lateral meniscal tears.

A			Medial meniscus Negative	Medial meniscus Positive	Total
b=50	Negative	n	6	40	46
		%n	13.0%	87.0%	100.0%
	Positive	n	5	23	28
		%n	17.9%	82.1%	100.0%
Total		n	11	63	74
		%n	14.9%	85.1%	100.0%

Sensitivity=%37
Specificity=%45
PPV=0.82
NPV=0.13
Fisher's test P=0.738



B			Lateral meniscus Negative	Lateral meniscus Positive	Total
b=50	Negative	n	40	6	46
		%n	87.0%	13.0%	100.0%
	Positive	n	23	5	28
		%n	82.1%	17.9%	100.0%
Total		n	63	11	74
		%n	85.1%	14.9%	100.0%

Sensitivity=%45
Specificity=%63
PPV=0.18
NPV=0.87
Fisher's test P=0.738

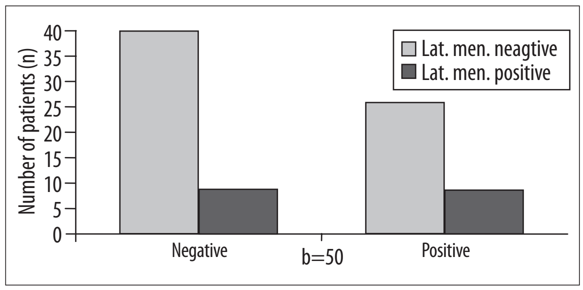
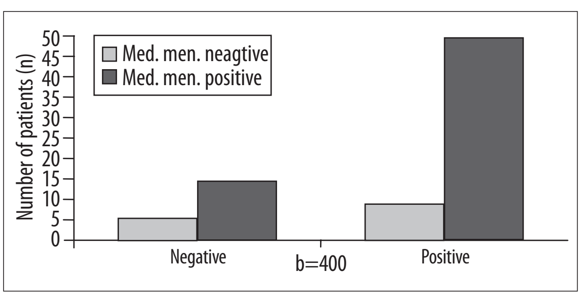


Table 6A,B. Results of ADC mapping with different b-values for medial and lateral meniscal tears.

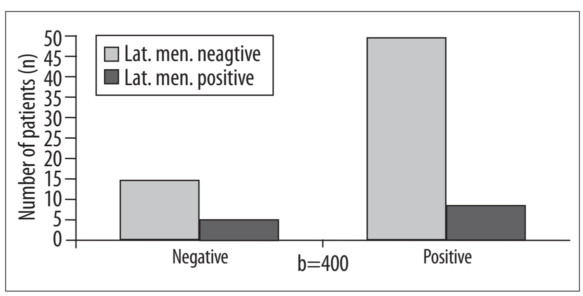
A			Medial meniscus Negative	Medial meniscus Positive	Total
b=400	Negative	n	4	13	17
		%n	23.5%	76.5%	100.0%
	Positive	n	7	50	57
		%n	12.3%	87.7%	100.0%
Total		n	11	63	74
		%n	14.9%	85.1%	100.0%

Sensitivity=%79
Specificity=%64
PPV=0.88
NPV=0.24
Fisher's test P=0.263



B			Lateral meniscus Negative	Lateral meniscus Positive	Total
b=400	Negative	n	13	4	17
		%n	76.5%	23.5%	100.0%
	Positive	n	50	7	57
		%n	87.7%	12.3%	100.0%
Total		n	63	11	74
		%n	85.1%	14.9%	100.0%

Sensitivity=%64
Specificity=%21
PPV=0.12
NPV=0.76
Fisher's test P=0.263



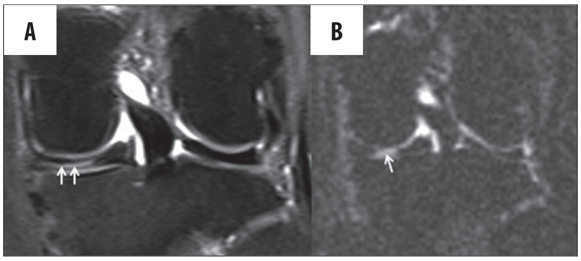


Figure 5. Medial meniscal tear. Coronal PDW image (**A**) and coronal ADC mapping with b-value of 400 sec/mm^2 (**B**).

in the knee. High-quality knee MRI can be performed on high- or low-field systems with a local knee coil [2–5]. Images are acquired in transverse, coronal and sagittal planes, with a field of view of about 16 cm, 3–4 mm slice thickness, imaging matrix of about 192*256, an adequate signal-to-noise ratio and an appropriate receiver bandwidth [3–5].

Several authors reported that 3D-MR imaging with a stan-

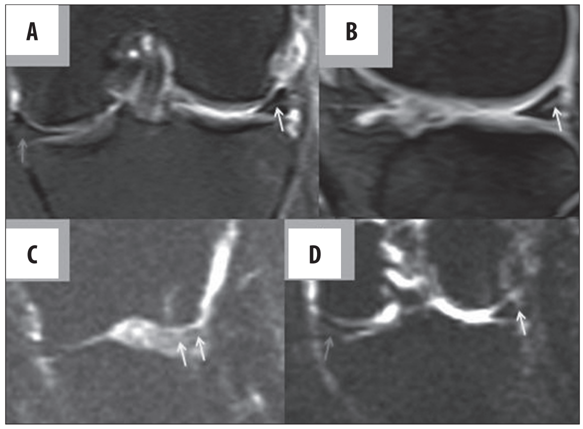


Figure 6. Coronal PDW image (**A**) and sagittal T2W image (**B**) of the lateral meniscal tear, especially in the posterior horn (yellow arrows). ADC mapping with b-value of 400 (**C**) and 800 (**D**) in the coronal plane, showing the lateral meniscal tear. ADC map with b=800 also visualised the tear in the medial menisci, as shown in PDW imaging (green arrows).

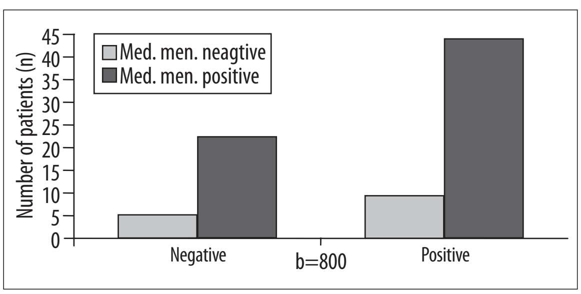
Table 7A,B. Results of ADC mapping with different b-values for medial and lateral meniscal tears.

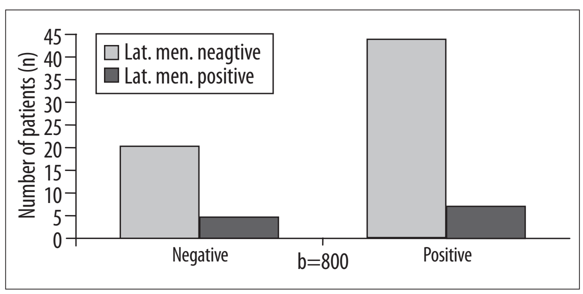
A			Medial meniscus		Total
			Negative	Positive	
b=800	Negative	n	4	20	24
		%n	16.7%	83.3%	100.0%
	Positive	n	7	43	50
		%n	14.0%	86.0%	100.0%
Total		n	11	63	74
		%n	14.9%	85.1%	100.0%

Sensitivity=%79
Specificity=%64
PPV=0.88
NPV=0.24
Fisher's test P=0.263

B			Lateral meniscus		Total
			Negative	Positive	
b=800	Negative	n	20	4	24
		%n	83.3%	16.7%	100.0%
	Positive	n	43	7	50
		%n	86.0%	14.0%	100.0%
Total		n	63	11	74
		%n	85.1%	14.9%	100.0%

Sensitivity=%64
Specificity=%32
PPV=0.14
NPV=0.83
Fisher's test P=0.740





dard protocol had 86–96% sensitivity and 84–94% specificity for diagnosing the medial meniscal tears, 68–86% sensitivity and 92–98% specificity for the lateral meniscal tears [4–6,11]. With great advances in MR systems, technology and RF coils, new sequences appear both in the studies and in a daily practice [3–5]. 3D-DWI and ADC mapping with b-factors are so new that they are used nowadays in examinations of the whole body [12]. DWI provides image contrast by measuring the diffusion properties of water within tissues, either unidirectional (isotropic) or multidirectional (anisotropic) [12,13]. The majority of DWI studies performed clinically to date has focused on the measurement of extra-cellular water diffusion – both the magnitude and direction of diffusion – in order to show free diffusion of water protons [13]. DWI-ADC mapping can be adversely affected by artifacts from motion rather than from the diffusion of molecules. Even vascular pulsations, voluntary movements and respiration can easily interfere with the

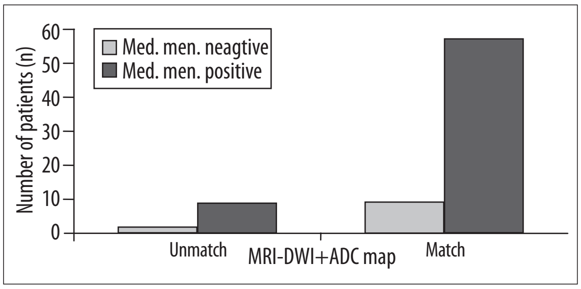
Table 8A,B. Concordance of DWI+ADC mapping (with three b-factors) with regard to MR imaging findings. No significant statistical differences between sequences for the evaluation of any meniscal tears (p>0.05).

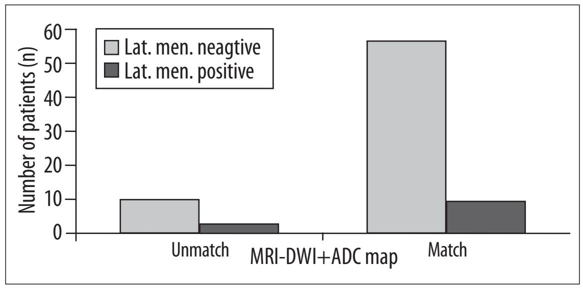
A			Medial meniscus		Total
			Negative	Positive	
MRG-DWI + ADC map	Negative	n	3	8	11
		%n	27.3%	72.7%	100.0%
	Positive	n	8	55	63
		%n	12.7%	87.3%	100.0%
Total		n	11	63	74
		%n	14.9%	85.1%	100.0%

Sensitivity=%87
Specificity=%27
PPV=0.87
NPV=0.27
Fisher's test P=0.352

B			Lateral meniscus		Total
			Negative	Positive	
MRG-DWI + ADC map	Negative	n	8	3	11
		%n	72.7%	27.3%	100.0%
	Positive	n	55	8	63
		%n	87.3%	12.7%	100.0%
Total		n	63	11	74
		%n	85.1%	14.9%	100.0%

Sensitivity=%73
Specificity=%13
PPV=0.13
NPV=0.73
Fisher's test P=0.352





quality of images and measurements [12,13]. Single-shot EPI, SE or GE is a standard technique that can provide us with a complete image within a second; it is robust to motion and has high resistance to magnetic field inhomogeneities leading to image distortion [12]. Spatial resolution in this technique tends to be used to obtain high-speed imaging and a high signal-to-noise ratio [12,13]. DWI sensitivity to diffusion (characterised by its b-value) can be adjusted by altering the combination of gradient pulse amplitude; the higher the b-factor, the more sensitive is the image to the effects of diffusion [12]. Besides motion, DWI can still be affected by MR properties other than that of diffusion, e.g. T2 weighting. To remove the effects different than diffusion, ADC map is used. It is created by combining two images – with and without DWI – or by using two b-values (in order to create an ADC map free of all contrast influences other than the displacement of water during the application of the diffusion gradients) [12,13]. ADC mapping with b-values from 0 to 1000 s/mm^2 can be performed and it has been shown to be more sensitive than DWI, as it is influenced only by the magnitude of the diffused water molecules [12]. In the early days, DWI and ADC mapping provided very useful information about the stroke and tumours of the brain and were used especially within the central nervous system. However, recently, they have also been applied in head and neck tumours, to diagnose breast cancer, illustrate the extension of prostate and rectal carcinomas, response of the tumours to radiotherapy or chemotherapy and even for the whole-body studies [12]. Here, in this report, for the first time in the literature, the efficacy of DWI and ADC mapping with different b-factors was analysed in the diagnosis of meniscal tears.

As mentioned above; DWI and ADC mapping with b-value of 400 s/mm^2 do have higher sensitivity and 100% specificity in visualising meniscal tears. ADC map with b-factor of 50 s/mm^2 has the least importance in the diagnosis of all meniscal tears, due to the lowest sensitivity connected with its less spatial resolution. DWI results, especially in the diagnosis of the lateral meniscal tears, reveal a very low specificity and a higher NPV. The detectability of meniscal tears with DWI is better for the medial meniscus than for the lateral site. ADC map with b-factor of 400 sec/mm^2 is more successful to reveal the medial meniscal tears, while the ADC map with b-value of 800 s/mm^2 is better suited for revealing the lateral meniscal tears than other imaging modalities. However, in the identification of lateral meniscal tears, ADC mapping with either of the b-factors shows lower specificity, with higher NPV and lower PPV. DWI combined with ADC mapping with three b-values shows a sensitivity of over 70% for lateral tears and of over 85% for medial meniscal tears. Both combined sequnces, seem to be less relevant, especially in visualisation of lateral meniscal tears, due to their low specificity and higher NPV.

Considering all above items, we should report that DWI and ADC mapping can easily be applied in daily practice, especially in diagnosing medial meniscus tears but the application of both imaging modalities with different b-factors does not seem to provide any additional information on the visualised lateral tears. This may be due to a less spatial resolution of techniques in lateral sites and lateral menisci, or maybe due to a lower number of relevant lateral meniscal tears, as compared to medial meniscal tears. We believe that with advancement of MRI technology, with more experienced musculoskeletal radiologists and with further studies involving more patients, DWI and ADC mapping with different b-factors may become more important for the diagnosis of meniscal tears.

Limitations of the research were as follows: the images obtained were of low quality due to a low spatial resolution in DWI and ADC mapping. DWI and ADC mapping of meniscal tears were evaluated by one musculoskeletal radiologist, inter- and intraobserver variability of the results couldn't be obtained, which might further affect the sensitivity and specificity of the research. With further technological advancement, advanced hardware (coils), and increasing experience of musculoskeletal radiologists, the clinical application of DWI and ADC mapping in meniscal tears diagnosis can be easily increased. About 30% of patients with meniscal tears underwent surgery and only 20 patients (20/74) had the histopathological verification. We could not confirm our data arthroscopically in most of the cases due to patients' refusal to arthroscopic procedures.

Conclusions

In our research, the sensitivity and specificity of DWI and ADC mapping was calculated with the use of the routine knee MRI as a golden standard of meniscal tear diagnostics in non-operated patients. We studied the diagnostic performance of DWI and ADC mapping in 20 meniscal tears by using arthroscopic diagnosis as a standard reference. Quantitative DWI and ADC mapping, especially with b-factor of 400 sec/mm^2, may be an alternative imaging modality to the routine MR imaging sequences for visualisation of meniscal tears of the knee, especially in the medial site. These scans are relatively fast and despite their low spatial resolution, they should be easily used by an experienced musculoskeletal radiologists for detailed knee MR imaging

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