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Contribution of thin-slice (1 mm) axial proton density MR images for identification and classification of meniscal tears: correlative study with arthroscopy

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Objective: To evaluate the diagnostic efficacy of thin-slice (1 mm) axial proton density-weighted (PDW) MRI of the knee for meniscal tear detection and classification.
Methods: We prospectively assessed pre-operative MR images of 58 patients (41 males, 17 females; age range 18–62 years) with arthroscopically confirmed meniscal tear. First, we evaluated the performance of the sagittal and thin-slice axial MR images for the diagnosis of meniscal tears. Second, we compared the correlation of tear types presumed from sagittal and axial MRI with arthroscopy and tear classification from axial MRI. Tears were classified on the sagittal plane and the axial plane separately. The diagnostic performance and tear classification were compared statistically with arthroscopy results, which is accepted as the standard of reference.
Results: 8 of 58 patients were removed from the study group because they had complex or degenerative tears. A total of 62 tears were detected with arthroscopy in 50 patients. On the sagittal images, sensitivity and specificity values were 90.62% and 70.37%, respectively, for medial meniscus tears and 72.73% and 77.14%, respectively, for lateral meniscus tears. The corresponding values for axial images were 97.30% and 84.00%, respectively, for medial meniscus tears and 95.65% and 80.50%, respectively, for lateral meniscus tears. There was no significant difference in tear classification between the arthroscopy results and the thin-slice axial PDW MRI results ($p>0.05$).
Conclusion: thin-slice axial PDW MRI increases the sensitivity and specificity of meniscal tear detection and especially classification, which is important for surgical procedure decisions.

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Meniscal tears often occur because of trauma in young athletes or because of degenerative changes in the elderly. Diagnosis of meniscal tears is established by history, clinical examination and radiological assessment. MRI findings significantly contribute to the clinical evaluation, and preclude unnecessary diagnostic arthroscopy [1]. Currently, the accuracy of knee MRI for meniscopathy is reported to be 78–83% by various studies [2, 3]. Although arthroscopy is recognised as the ''gold standard'', it should be performed by an experienced operator as arthroscopic examination of the posterior horns of both menisci is not an easy task [4].

According to the current classification system, meniscal tears are recognised by their grade 3 signal intensity relative to the meniscal articular surface; however, this classification does not include the anatomy of various meniscus tear patterns (*e.g.* horizontal, vertical) that are determined during arthroscopic surgery of the knee [5]. Moreover, routine sagittal and coronal images are not adequate for detection of tear configuration. Meniscal tears can be categorised into two primary tear planes based on the cross-sectional anatomy of the meniscus on sagittal MR images: vertical and horizontal [5]. Vertical tears extend towards the meniscal surface as longitudinal, radial or flap (oblique) tears [5]. Non-cleavage horizontal tears (vertical–horizontal) demonstrate either longitudinal or flap surface tear patterns [5]. Classification of vertical and non-cleavage horizontal tears in such a fashion can only be performed by using axial sections. Axial images depict tears in an additional third plane and can provide information on orientation, size and displacement of tears [6].

The four main approaches for management of meniscal tears are: partial meniscectomy, meniscal repair, conservative treatment and complete meniscectomy [7]. There are various factors that influence the treatment of meniscal lesions such as the patient's age, chronicity, lesion type, location of the lesion relative to the vascular zone and size of the tear [4]. Repairable meniscal tears often prove to be unstable longitudinal or flap tears. Radial, horizontal or complex tears are generally not suitable for repair [7, 8]. Meniscal tears over the peripheral and vascularised portion of the meniscus can heal owing to ingrowth of capillaries and may subsequently have an appearance similar to that of fibrocartilage [4, 9]. The majority of small, acute tears may heal spontaneously and render arthroscopy unnecessary [4]. Some surgeons may prefer not to perform surgery on partial thickness horizontal or oblique tears [10].

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An accurate description of a meniscal tear has become increasingly important, with the emphasis on meniscal preservation and repair, because of the long-term complications of meniscectomy that comprise degenerative changes, patient dissatisfaction, marked disability and chronic pain [4, 11].

In this study, we aimed to investigate the efficacy of axial 1-mm-thick proton density-weighted (PDW) MRI in the detection and classification of meniscal tears. Accurate identification of meniscal tears is important to avoid unnecessary surgery, provide better treatment and ensure meniscal preservation and success of repair.

Methods and materials

Patients

In this prospective study, 58 consecutive patients with a suspected meniscal tear underwent both MRI and arthroscopy of the knee. The decision to perform arthroscopy was based on clinical examination and previous conventional MRI studies. We performed MRI on our patients for investigative purposes. Our study included 32 right and 26 left knees of 58 patients (41 males and 17 females; mean age 30.22 years; range 18–62 years). The presenting complaint was pain in 29, painful swelling of the knee in 18, and locking and instability of the leg in the remaining 11 patients. The time interval between the onset of symptoms or injury and MRI examination varied between 1 day and 6 months (median 3 months). Patients with a history of previous knee joint surgery or a contraindication for MRI (*e.g.* presence of a pacemaker, metallic or cochlear implant, claustrophobia) were excluded from the study. Our study was conducted after obtaining the approval of the institutional review board and gaining informed consent from each participant.

MRI protocol

The average time between MRI examination and knee arthroscopy was 4 days (range 1–11 days). MRI was performed with a 1.5 T MRI system (Magnetom Vision Plus, Siemens, Erlangen, Germany) using a dedicated knee coil, with patients in a supine position and with the knee fully extended. MRI protocols were standard in all cases. Following the localisation sequence, routine conventional images were acquired as follows: coronal turbo spin echo (TSE) T_1 weighted [repetition time (TR), 600 ms; echo time (TE), 12 ms; flip angle (FA), 90°; slice thickness, 3 mm; interslice gap, 0.10 mm; matrix, 128×256; field of view (FOV), 160 mm; excitation number, 1; imaging time, 2 min]; sagittal TSE fat-saturated (FS) PDW and T_2 weighted (TR, 3000 ms; TE, 98/16 ms; FA, 180°; slice thickness, 3 mm; interslice gap, 0.15 mm; matrix, 240×256; FOV, 160 mm; excitation number, 1; imaging time, 2.30 min); and axial TSE FS T_2 weighted (TR, 4000 ms; TE, 120 ms; FA, 180°; slice thickness, 3 mm; matrix, 252×256; FOV, 160 mm; excitation number, 1; imaging time, 2 min). Additional axial TSE PDW and T_2 weighted sequences (TR, 3000 ms; TE, 102/17 ms; FA, 180°; slice thickness, 1 mm; interslice gap, 0.15 mm; matrix, 260×512; FOV, 160 mm; excitation number, 3; imaging time, 6 min) were also obtained. Axial images were obtained in the plane parallel to the meniscus using sagittal and coronal images for section positioning. Total imaging time was 15–20 min and no contrast agent was used.

Image analysis

MR images were analysed by using Merge e-film v. 2.0 (Merge Technologies Inc., Milwaukee, WI) software and workstation. Images were evaluated by two experienced radiologists (GG and OFN) blinded to the clinical and arthroscopic findings, with the aim of identifying meniscal tears. A single, experienced orthopaedic surgeon (BD) conducted all of the arthroscopic assessments in patients suspected of having a torn meniscus or any other internal derangement of the knee. The orthopaedic surgeon was blinded to the results of MRI studies.

The location and type of the meniscal tears were evaluated at different time points on sagittal and axial images. First, we compared the diagnostic performance of sagittal TSE FS PDW/axial TSE PDW MRI with that of arthroscopy with regard to meniscal tears by a five-point scale (0, definitely absent; 1, probably absent; 2, equivocal; 3, probably present; 4, definitely present). Second, sagittal TSE FS PDW/axial TSE PDW MRI and arthroscopy results were compared in terms of the type of meniscal tear. Tears were categorised separately on sagittal [vertical, vertical–horizontal (oblique), horizontal, bucket-handle] and axial (radial, flap, longitudinal, horizontal, bucket-handle) images. Axial PDW MRI findings were compared with those of arthroscopy, which were recognised as the reference data. The diagnostic criteria for meniscal tear were abnormal signal intensity within the meniscus extending towards the meniscal articular surface or abnormal meniscal morphology.

In our study, meniscal tears were defined as follows:

(1) Vertical tear: a tear perpendicular to the tibial plateau in the sagittal plane.
(2) Horizontal tear (cleavage tear): a tear parallel to the tibial plateau in the sagittal and axial plane that slices the meniscus into top and bottom portions.
(3) Vertical–horizontal tear: a tear oblique to the tibial plateau in the sagittal plane.
(4) Radial tear: a tear perpendicular to the free edge of the meniscus in the axial plane.
(5) Flap tear: a combination of longitudinal and radial tears, which begin over the free edge of the meniscus and extend obliquely into the meniscal fibrocartilage in the axial plane.
(6) Longitudinal tear: a tear perpendicular to the tibial plateau in the axial plane.
(7) Bucket-handle tear: displacement of the meniscal tissue in a fashion similar to a bucket-handle that involves at least two-thirds of the meniscal circumference. In cases in which there was less displaced meniscal tissue, this was called a displaced flap tear.

The presence of a meniscal tear was evaluated and noted on a tear-by-tear basis, not on a meniscus-by-meniscus basis. For instance, even in the presence of multiple tears in a single meniscus, the readers noted

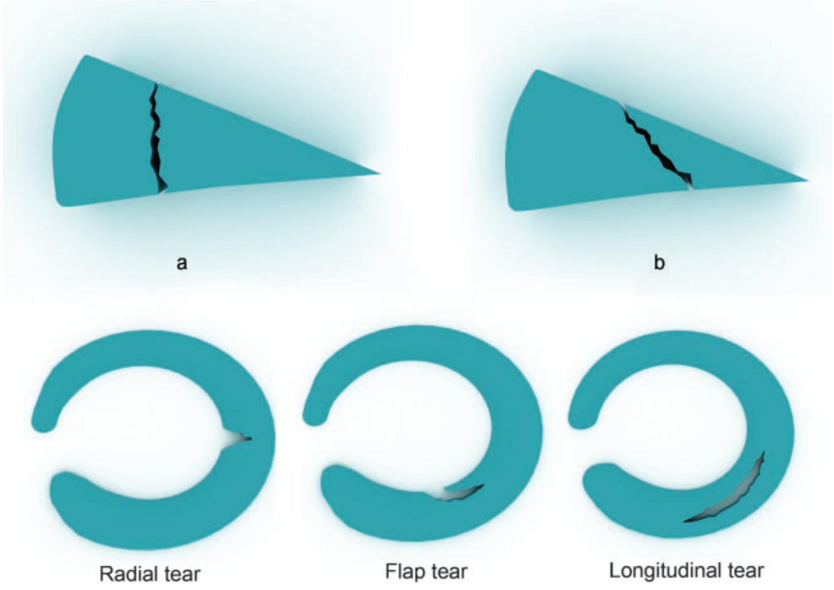


Figure 1. (a) Vertical tear. (b) Vertical–horizontal (oblique) tear on the sagittal plane. A vertical tear may be radial, flap or longitudinal; a vertical–horizontal tear may be flap or longitudinal on the axial plane.

each tear separately because the principal target of our study was to classify the types of meniscal tear. Identification of the types of meniscal tear was carried out according to the classification system of Stoller et al [5]. Accordingly, vertical tears were categorised as radial, flap or longitudinal; vertical–horizontal tears were categorised as flap or longitudinal (Figure 1).

Statistical analysis

All statistical analyses were performed using the Statistical Package for Social Sciences for Windows v. 13.0 (SPSS Inc., Chicago, IL). Continuous variables were presented as the mean $\pm$ standard deviation. Categorical data were expressed as frequency and percentage. Arthroscopy findings were used as the reference values. Sensitivity and specificity values were calculated for sagittal FS PDW MRI and axial PDW MRI, both of which were used in detection of the meniscal tears, and for axial PDW MRI, which was used in classification of the meniscal tears. We used a McNemar test to identify significant differences in sensitivity and specificity. A p-value <0.05 indicated a statistically significant difference. Receiver operating characteristic (ROC) curves that represented the overall performance were obtained.

Results

8 of 58 patients were excluded because they had complex or degenerative tears that were difficult to classify properly. In total, 62 (39 medial and 23 lateral menisci) tears were found with arthroscopy in 50 patients. There was no significant difference between the sagittal, axial and arthroscopic findings with regard to meniscal tear detection ($p>0.05$). Sensitivity and specificity values for sagittal PDW images were 90.62% and 70.37%, respectively, in the medial meniscus and 72.73% and 77.14%, respectively, in the lateral meniscus. Sensitivity and specificity values for axial PDW images were 97.30% and 84%, respectively, in the medial meniscus and 95.65% and 80.56%, respectively, in the lateral meniscus. Axial PDW images showed a higher diagnostic capability than conventional sagittal PDW images (Table 1; values for the area under the ROC curve).

The types of meniscal tears identified in the sagittal plane based on arthroscopy (Table 2) included:

- vertical tear: longitudinal ($n=3$), flap ($n=3$), radial ($n=5$)
- horizontal tear: flap ($n=2$), horizontal ($n=8$)
- vertical–horizontal tear: longitudinal ($n=11$), flap ($n=7$), radial ($n=2$)

Table 1. The diagnostic performance of sagittal and axial images for meniscus tears

Planes	Sensitivity (%)	Specificity (%)	*p*-value	AUC value
Sagittal FS PDW images (medial meniscus)	90.62	70.37	0.227	0.80
Sagittal FS PDW images (lateral meniscus)	72.73	77.14	0.791	0.74
Axial PDW images (medial meniscus)	97.30	84.00	0.375	0.90
Axial PDW images (lateral meniscus)	95.65	80.56	0.070	0.88

AUC, area under the receiver operating characteristic curve; FS, fat suppressed; PDW, proton density weighted.

Table 2. Sagittal classification of the tears in the medial and lateral menisci and the tear subgroups with corresponding arthroscopic findings

	Arthroscopy findings					
Sagittal FS PDW images	No tear	Longitudinal tear	Flap tear	Radial tear	Horizontal tear	Bucket-handle tear
No tear (%)	43 (84.4)	0	2 (3.9)	4 (7.8)	2 (3.9)	0
Vertical tear (%)	5 (31.25)	3 (18.75)	3 (18.75)	5 (31.25)	0	0
Horizontal tear (%)	6 (35.3)	0	2 (11.8)	0	8 (47)	1 (5.9)
Vertical–horizontal tear (%)	8 (28.6)	11 (39.3)	7 (25)	2 (7.1)	0	0
Bucket-handle tear (%)	0	0	0	0	1 (20)	4 (80)

FS, fat suppressed; PDW, proton density weighted.

- Bucket-handle tear: bucket-handle (n=4), horizontal (n=1).

Since classification of tear types was different on the sagittal images, it was not statistically compared with the arthroscopy results.

The types of meniscal tears identified in the axial plane based on arthroscopy are given in Table 3. Arthroscopy and axial PDW MRI results were not significantly different in terms of tear classification ($p>0.05$). The results for sensitivity, specificity, p-value and area under the ROC curve for medial and lateral menisci on axial PDW images are shown in Table 4.

Examples of cases are presented in Figures 2–5.

Discussion

MRI is routinely used for evaluating the broad range of internal derangements and articular disorders of the knee [5]. Moreover, in addition to its diagnostic utility, MRI has also been shown to be a valuable tool in the selection of surgical candidates and in pre-operative planning [5].

The menisci play an important role in joint stabilisation and reduction of compressive forces influencing the articular cartilage [5]. Meniscal injuries may be associated with a history of twisting, squatting or cutting [9]. Abnormal shear forces that may occur as a result of knee compression–rotation are known to lead to meniscal damage [5].

Knee MRI has been shown to have a superior accuracy in the diagnosis of meniscal tears [12, 13]. In previous studies, the sensitivity and specificity for medial meniscal tears have been noted to range from 87% to 97% and from 87% to 98%, respectively, whereas the same values have been reported to range from 72% to 93% and from 89% to 99%, respectively, for the lateral meniscal tears [14]. The differences between the sensitivity and the specificity might be secondary to the preferred sequences, observer variation or sample size [4]. The medial meniscus displays a higher sensitivity, whereas the lateral meniscus exhibits a higher specificity [4]. In our study, sagittal and axial images were also found to be highly sensitive and specific for the detection of meniscal tears. In particular, using thin-slice axial images further increases the diagnostic capability. This may be owing to the use of thinner sections for axial images. In the current study, sensitivity for the detection of tears was higher in the medial meniscus in both planes than in the lateral meniscus.

Meniscal fluid interface and morphology are best visualised on TSE images [5]. The most frequently used sequences are spin echo or TSE PDW with or without FS and gradient echo [15]. Although meniscal structure can be revealed by axial images, routine axial images of 4–5 mm thickness are not sensitive to meniscal pathologies because of excessive thickness [5]. The versatility of MRI in the evaluation of meniscal tears has been shown by three-dimensional (3D) volumetric techniques and thin-section two-dimensional images. In our study, we preferred to use two-dimensional thin section MRI. Thinner sections can better reveal the signal–surface contact and tear morphology [16, 17].

Although sagittal and coronal planes have been found to be valuable in the diagnosis of meniscal tears by MRI, they are known to be of no such value in the classification of these tears since the course of meniscal tears on coronal images follows a superior–inferior route, similar to that of the sagittal views [18, 19].

Pre-operatively, surgeons need to acquire information not only on the presence of the meniscal tears but also on

Table 3. Axial classification of the tears in the medial and lateral menisci and the tear subgroups with corresponding arthroscopic findings

	Arthroscopy findings					
Axial PDW images	No tear	Longitudinal tear	Flap tear	Radial tear	Horizontal tear	Bucket-handle tear
No tear (%)	45 (97.8)	0	0	1 (2.2)	0	0
Longitudinal tear (%)	7 (29.2)	14 (58.3)	1 (4.2)	1 (4.2)	1 (4.2)	0
Flap tear (%)	5 (22.8)	0	16 (72.7)	1 (4.5)	0	0
Radial tear (%)	1 (10)	0	0	9 (90)	0	0
Horizontal tear (%)	2 (18.2)	0	0	0	9 (81.8)	0
Bucket-handle tear (%)	0	0	0	0	0	7 (100)

PDW, proton density weighted.

Table 4. The tear type performance of axial proton density-weighted images for meniscal tears

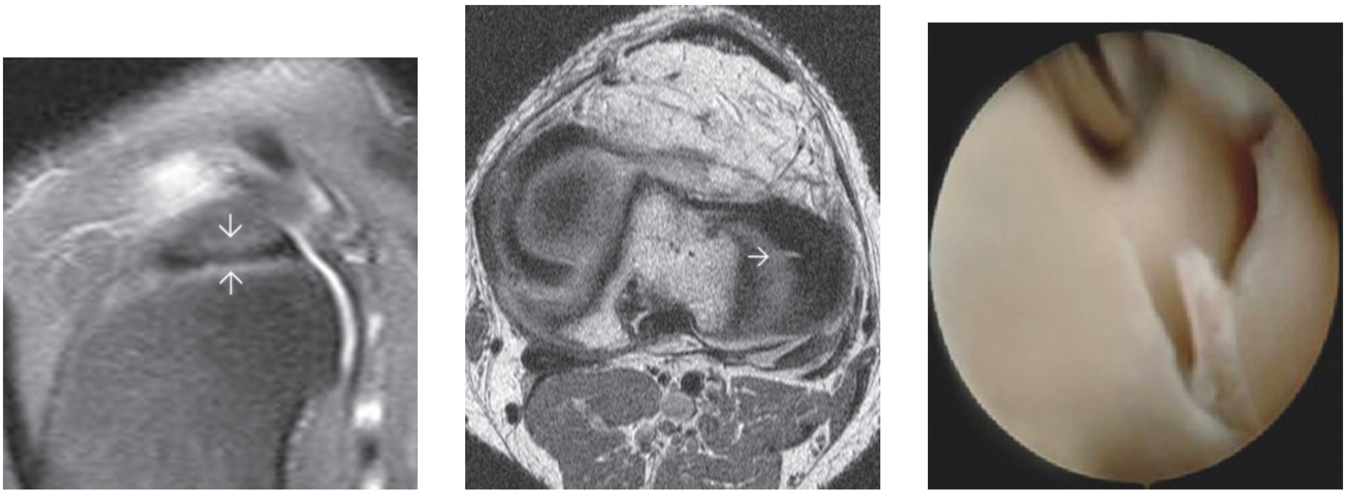
Axial plane	Sensitivity (%)	Specificity (%)	*p*-value	AUC value
Medial meniscus				
Longitudinal tear	90.91	88.00	0.625	0.89
Flap tear	81.82	92.00	0.625	0.87
Radial tear	66.66	96.87	1.000	0.81
Horizontal tear	75	96.87	1.000	0.85
Bucket-handle tear	100	96.55	1.000	0.98
Lateral meniscus				
Longitudinal tear	100	100	1.000	1.00
Flap tear	100	100	0.125	1.00
Radial tear	100	100	1.000	1.00
Horizontal tear	100	100	1.000	1.00
Bucket-handle tear	–	–	–	–

AUC, area under the receiver operating characteristic curve.

their morphological characteristics, in order to decide the most appropriate surgical method (resection or suturing of the torn menisci) [4, 7, 8, 20]. Axial images of the menisci may help in identification and confirmation of the meniscal tear patterns [18].

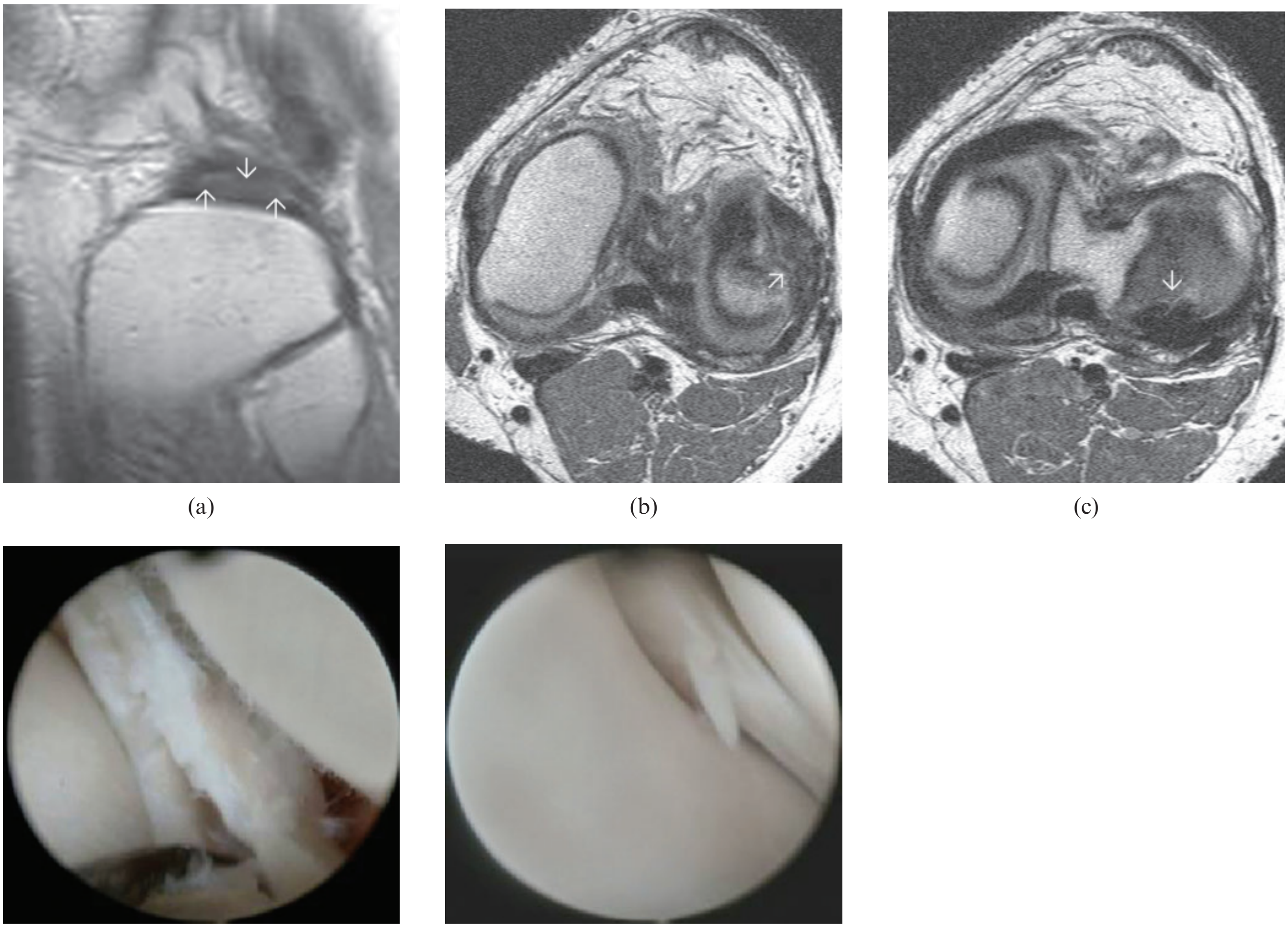
In our study, axial images showed no difference from arthroscopy findings with regard to classification of the tears. Therefore, in cases in which classification of tears is planned to be performed by routine knee MRI, inclusion of axial views will be useful. Moreover, our study showed that vertical and vertical–horizontal tear types on sagittal images could be classified accurately in the axial plane. In this study, vertical and vertical–horizontal tears in the sagittal plane were classified as radial, flap and longitudinal tears. Arthroscopy and axial PDW images demonstrated no significant difference in terms of classification of the tears, and both were found to be highly sensitive and specific in this regard.

The number of studies focusing on the classification of tears on axial images is limited [6, 14, 16, 18, 20, 21]. Tarhan et al [18] showed that axial images improved the sensitivity and specificity in lateral meniscal tears. Lee et al [6] showed that, although axial FS fast spin echo images effectively revealed vertical tears and displaced meniscal fragments, horizontal tears were indistinct. However, their results were not compared with arthroscopy results. Both of the above mentioned studies used a section thickness of 4–5 mm, and menisci were visualised on one or two images. Axial reconstruction images were generated by applying 3D volumetric methods in order to show meniscal tears. Yoon et al [14] performed TSE PDW MRI with 1 mm thickness and observed inadequate tissue contrast because of the presence of a certain degree of image degradation during the multiplanar reconstruction process owing to non-isotropic images. Jung et al [22] acquired isotropic axial multiplanar reconstruction images by 3 T MRI. However, 3D volume techniques have some limitations, such as the presence of a higher signal intensity in normal menisci than that on the spin-echo sequence and more widespread signal increase in the degenerated menisci [4]. This raised meniscal signal intensity can confuse the



(a) (b) (c)

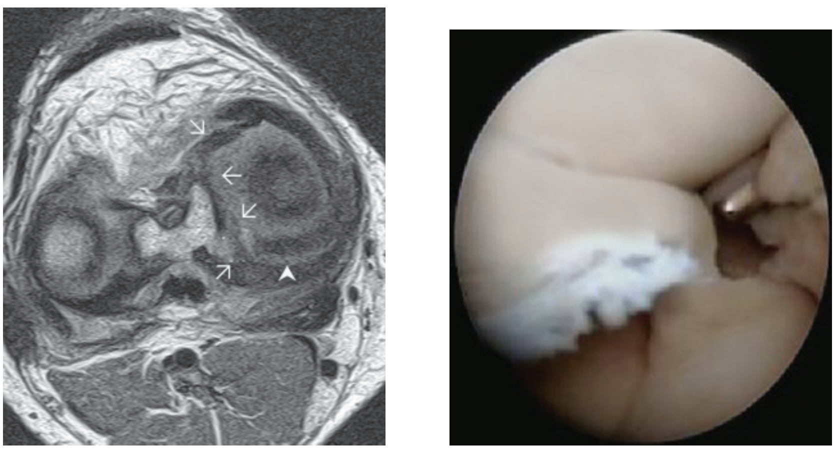
Figure 2. A 41-year-old male with right knee pain demonstrated a radial tear in the lateral meniscus on both arthroscopy and MRI. (a) Sagittal (slightly oblique) proton density-weighted (PDW) MR image showing no tear in the lateral meniscal corpus (arrows) (0 points, definitely absent). (b) Axial PDW MR image showing a radial tear in the corpus of the lateral meniscus (arrow) (4 points, definitely present). (c) Arthroscopy confirmed the radial tear and the patient was treated by partial meniscectomy.



(a) (b) (c)

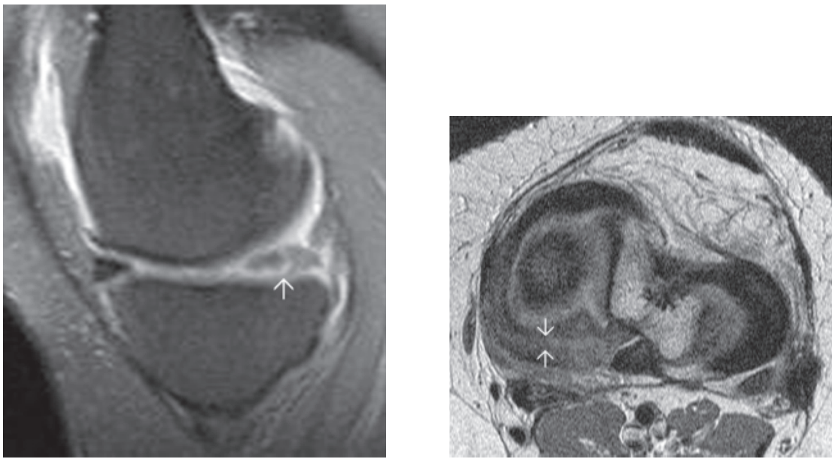
(d) (e)

Figure 3. A 53-year-old male with right knee pain demonstrated horizontal and flap tears in the lateral meniscus on both arthroscopy and MRI. (a) The linear increased signal intensity in the corpus of the lateral meniscus on the sagittal fat-suppressed proton density-weighted (PDW) MR image was evaluated as a horizontal tear (cleavage tear, arrows) (4 points, definitely present). (b)The irregular increased signal in the corpus of the lateral meniscus on the axial PDW MR image was evaluated as a horizontal tear (arrow) (4 points, definitely present). (c) Axial PDW MR image showing flap tears over the posterior horn of the lateral meniscus (arrow) (4 points, definitely present). Arthroscopy revealed (d) horizontal and (e) flap tears and the patient was treated by partial meniscectomy.



(a) (b)

Figure 4. A 32-year-old male with left knee pain demonstrated flap and bucket-handle tears in the medial meniscus on both arthroscopy and MRI. A bucket-handle tear was shown on the sagittal fat-suppressed proton density-weighted (PDW) MR image (4 points, definitely present). (a) Axial PDW MR image displaying a bucket-handle tear (arrows) in the medial meniscus along with a flap tear (arrowhead) in the posterior horn (4 points, definitely present). (b) Arthroscopy confirmed bucket-handle and flap tears (not shown) and the patient was treated by partial meniscectomy.



(a) (b)

Figure 5. A 35-year-old female with right knee pain demonstrated a longitudinal tear in the medial meniscus on both arthroscopy and MRI. (a) Sagittal fat-suppressed proton density-weighted (PDW) MR image showing a vertical tear associated with the inferior and superior articular surface (arrow), contour irregularities and increased signal intensity in the posterior horn of the medial meniscus. (b) Axial PDW MR image displaying a longitudinal tear in the posterior horn of the medial meniscus that is apparent on several subsequent sections (arrows). Arthroscopy confirmed the longitudinal tear and the patient was treated by partial meniscectomy.

examiner in deciding whether the abnormal signal actually extends into the articular surface or not and reduces the specificity [4].

Ohishi et al [20] used axial reconstructed images obtained by 3D MRI data sets in morphological diagnosis of meniscal tears. While axial images acquired from 3D MRI data sets were observed to be helpful in the diagnosis of radial tears, the rate of false-positive findings in the medial meniscus was relatively high and horizontal tears were indistinct. In the current study, although sensitivity and specificity values for the detection of horizontal tears in the medial meniscus on axial images were higher, they were still lower than those of the other tear types. Moreover, the sensitivity of axial images was found to be reduced in the detection of radial tears. This may be secondary to the fact that the number of radial tears in the medial meniscus was not high. However, axial images were observed to have high sensitivity and specificity for all the tear types in the lateral meniscus (100%).

Our study had some limitations. First, acquisition of thin-slice PDW images takes a long time (6 min). This can be avoided by using 3 T MRI, which shortens the duration of acquisition, and application of parallel imaging methods. The second limitation was the inadequacy of arthroscopy in the evaluation of the posterior horn of the medial meniscus in some cases. However, arthroscopy is regarded as the gold standard for assessment of meniscal tears. The third limitation was the use of thick slice sagittal images because of long acquisition times in thin-slice sequences. However, the aim of our study was not to determine the sensitivity of sagittal and axial images in the detection of meniscal tears, but to classify the meniscal tears on axial images.

In conclusion, since axial images present an additional plane for visualisation alongside sagittal and coronal planes, they increase the sensitivity and specificity of the imaging results. Axial images proved to be very useful, particularly with regard to classification of the vertical and vertical–horizontal tears. Integration of axial imaging with the routine sagittal and coronal images will facilitate the identification and classification of meniscal tears.

References

1. Ryzewicz M, Peterson B, Siparsky PN, Bartz RL. The diagnosis of meniscus tears: the role of MRI and clinical examination. Clin Orthop Relat Res 2007;455:123–33.
2. Kornick J, Trefelner E, McCarthy S, Lange R, Lynch K, Jokl P. Meniscal abnormalities in the asymptomatic population at MR imaging. Radiology 1990;177:463–5.
3. Wright DH, De Smet AA, Norris M. Bucket-handle tears of the medial and lateral menisci of the knee. AJR Am J Roentgenol 1995;165:621–5.
4. Fox MG. MR imaging of the meniscus: review, current trends, and clinical implications. Radiol Clin North Am 2007;45:1033–53.
5. Stoller DW, Li AE, Anderson LJ, Cannon WD. The knee. In: Stoller DW, ed. Magnetic resonance imaging in orthopaedics and sports medicine. Philadelphia, PA: Lippincott Williams & Wilkins; 2007. pp. 305–731.
6. Lee JH, Singh TT, Bolton G. Axial fat-saturated FSE imaging of knee: appearance of meniscal tears. Skeletal Radiol 2002;31:384–95.
7. Jee WH, McCauley TR, Kim JM, Jun DJ, Lee YJ, Choi BG, et al. Meniscal tear configurations: categorization with MR imaging. AJR Am J Roentgenol 2003;180:93–7.
8. White LM, Kramer J, Recht MP. MR imaging evaluation of the postoperative knee: ligaments, menisci, and articular cartilage. Skeletal Radiol 2005;34:431–52.
9. Deutsch AL, Mink JH, Fox JM, Arnoczky SP, Rothman BJ, Stoller DW, et al. Peripheral meniscal tears: MR findings after conservative treatment or arthroscopic repair. Radiology 1990;176:485–8.
10. Zanetti M, Pfirrmann CW, Schmid MR, Romero J, Seifert B, Hodler J. Patients with suspected meniscal tears: prevalence of abnormalities seen on MRI of 100 symptomatic and 100 contralateral asymptomatic knees. AJR Am J Roentgenol 2003;181:635–41.
11. Quinn SF, Brown TF. Meniscal tears diagnosed with MR imaging versus arthroscopy: how reliable a standard is arthroscopy? Radiology 1991;181:843–7.
12. Magee T, Williams D. 3.0-T MRI of meniscal tears. AJR Am J Roentgenol 2006;187:371–5.
13. Grossman JW, De Smet AA, Shinki K. Comparison of the accuracy rates of 3-T and 1.5-T MRI of the knee in the diagnosis of meniscal tear. AJR Am J Roentgenol 2009;193:509–14.
14. Yoon YC, Kim SS, Chung HW, Choe BK, Ahn JH. Diagnostic efficacy in knee MRI comparing conventional

technique and multiplanar reconstruction with one-millimeter FSE PDW images. Acta Radiol 2007;48:869–74.
15. Helms CA. The meniscus: recent advances in MR imaging of the knee. AJR Am J Roentgenol 2002;179:1115–22.
16. Araki Y, Ootani F, Tsukaguchi I, Ootani M, Furukawa T, Yamamoto T, et al. MR diagnosis of meniscal tears of the knee: value of axial three-dimensional Fourier transformation GRASS images. AJR Am J Roentgenol 1992;158:587–90.
17. Aubel S, Heyd RL, Thaete FL, Wozney P. MR knee imaging: axial 3DFT GRASS pulse sequence versus spin-echo imaging for detecting meniscal tears. Magn Reson Imaging 1992;10:531–9.
18. Tarhan NC, Chung CB, Mohana-Borges AV, Hughes T, Resnick D. Meniscal tears: role of axial MRI alone and in combination with other imaging planes. AJR Am J Roentgenol 2004;183:9–15.
19. Reeder JD, Matz SO, Becker L, Andelman SM. MR imaging of the knee in the sagittal projection: comparison of three-dimensional gradient-echo and spin-echo sequences. AJR Am J Roentgenol 1989;153:537–40.
20. Ohishi T, Takahashi M, Abe M, Tsuchikawa T, Mori M, Nagano A. The use of axial reconstructed images from three-dimensional MRI datasets for morphological diagnosis of meniscal tears of the knee. Arch Orthop Trauma Surg 2005;125:622–7.
21. Aubel S, Heyd RL, Thaete FL, Wozney P. MR knee imaging: axial 3DFT GRASS pulse sequence versus spin-echo imaging for detecting meniscal tears. Magn Reson Imaging 1992;10:531–9.
22. 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.