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FULL PAPER

Can a single isotropic 3D fast spin echo sequence replace three-plane standard proton density fat-saturated knee MRI at 1.5 T?

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Objective: To assess whether a single isotropic three-dimensional (3D) fast spin echo (FSE) proton density fat-saturated (PD FS) sequence reconstructed in three planes could replace the three PD (FS) sequences in our standard protocol at 1.5 T (Siemens Avanto, Erlangen, Germany).

Methods: A 3D FSE PD water excitation sequence was included in the protocol for 95 consecutive patients referred for routine knee MRI. This was used to produce offline reconstructions in axial, sagittal and coronal planes. Two radiologists independently assessed each case twice, once using the standard MRI protocol and once replacing the standard PD (FS) sequences with reconstructions from the 3D data set. Following scoring, the observer reviewed the 3D data set and performed multiplanar reformats to see if this altered confidence. The menisci, ligaments and cartilage were assessed, and

statistical analysis was performed using the standard sequence as the reference standard.

Results: The reporting accuracy was as follows: medial meniscus (MM) = 90.9%, lateral meniscus (LM) = 93.7%, anterior cruciate ligament (ACL) = 98.9% and cartilage surfaces = 85.8%. Agreement among the readers was for the standard protocol: MM kappa = 0.91, LM = 0.89, ACL = 0.98 and cartilage = 0.84; and for the 3D protocol: MM = 0.86, LM = 0.77, ACL = 0.94 and cartilage = 0.64.

Conclusion: A 3D PD FSE sequence reconstructed in three planes gives reduced accuracy and decreased concordance among readers compared with conventional sequences when evaluating the menisci and cartilage with a 1.5-T MRI scanner.

Advances in knowledge: Using the existing 1.5-T MR systems, a 3D FSE sequence should not replace two-dimensional sequences.

INTRODUCTION

Knee MRI is the most commonly used cross-sectional imaging modality for the evaluation of knee injury and pain with the common indications being the diagnosis of abnormality to the menisci, ligaments and articular cartilage. Arthroscopy is the recognized gold standard for the evaluation of internal knee derangement, but knee MRI has been proven to significantly influence clinicians' diagnoses and management plans and has been shown to improve health-related quality of life.¹ Given these findings, the demand for knee MRI has increased dramatically over the past decade and will continue to do so.

Fast spin echo (FSE) sequences are used in a variety of MRI applications with the advantage of faster acquisition times in comparison with conventional spin echo (SE) sequences. At Leeds Teaching Hospitals Trust, the standard knee MRI protocol employed is based on FSE sequences including proton density (PD) fat-saturated (FS) sequences, but

recent advances in MRI technology now allow the acquisition of a three-dimensional (3D) SE sequence with the advantage of being able to perform multiplanar reformats (MPRs) owing to the acquisition of isotropic voxels. Up until now, the majority of studies assessing 3D SE sequences in the knee have been undertaken on 3-T MRI systems.^{2–11} However, in common with many centres, our institution employs a 1.5-T system for the majority of its routine knee MRI studies. With acquisition time being a key factor in knee imaging protocols, our aim was to assess whether reconstructions obtained from a single isotropic 3D FSE PD (FS) sequence could replace the 3 PD (FS) sequences in our standard protocol on a 1.5-T system (Siemens Avanto, Erlangen, Germany). We aimed to assess whether the isotropic sequences could reproduce the reporting accuracy of our standard sequences and whether the facility to perform MPRs in non-orthogonal planes would increase reader concordance and raise diagnostic performance.

Table 1. Scan parameters

Sequence	Plane	Repetition time (ms)	Echo time (ms)	Acquisition time (min : s)	Slice thickness (mm)
PD FS	Axial	5590	13	3 : 33	3
PD FS	Cor	4470	13	4 : 24	3
PD FS	Sag	5190	13	5 : 07	3
T2 FS	Sag	4920	89	2 : 53	3
T1	Cor	512	11	4 : 12	3
PD water excitation SPACE	Three dimension	1800	19	7 : 55	0.7 isotropic voxel

Cor, coronal; FS, fat saturation; PD, proton density; Sag, sagittal.

METHODS AND MATERIALS

Patient population

The study protocol was approved by the local ethics committee, and the need for individual written patient consent was waived. 100 knee scans were undertaken consecutively in 99 patients who were initially included in the study. However, in five cases, it was not possible to analyse the data owing to incomplete examinations (excessive movement artefact on one or more sequences in four patients and failure to complete the examination in one patient). This resulted in 95 complete studies being included. All patients were referred for routine MRI knee studies (mean age, 31 years; range, 11–72 years; 66 males; 29 females). Our aim was to replicate standard MRI reporting lists as closely as possible; therefore, patients were not excluded from the study on clinical grounds. Three patients had previous surgery with two having anterior cruciate ligament (ACL) reconstructions and one having a posterior cruciate ligament reconstruction.

MRI technique

Imaging was performed on a 1.5-T MR system with an eight-channel receive-only knee extremity coil. All patients underwent imaging according to the institution's standard knee protocol: sagittal PD FS and T2 FS, coronal PD FS and T1, and axial PD FS. In addition, a 3D FSE PD water excitation (WE) SPACE sequence was employed in the sagittal plane, and this was obtained with a 0.7-mm isotropic voxel as was previously found optimal for 3D sequences by Gold *et al*¹² for allowing multi-planar reconstruction. The 3D FSE PD WE sequence had an acquisition time of 7 min 55 s, and the three PD (FS) sequences in our standard protocol had a total acquisition time of 13 min 4 s. The scan parameters are detailed in [Table 1](#).

MRI analysis

The images were reconstructed at 2.5 mm in axial, coronal and sagittal planes and presented as individual sequences. The reconstructed images were created offline by a radiologist who was not involved in scoring the images for the study. It was not possible to match the slice thickness to that in our standard protocol on the reformatting system used, but the slice thickness of 2.5 mm is as close as possible to that of our standard sequences at 3 mm.

The images were assessed by two experienced fellowship trained musculoskeletal consultant radiologists each with more than 15 years' experience. One observer scored the conventional sequences first and replaced the three PD sequences with the reconstructed 3D sequences for the second scores. The second observer scored the studies in opposite order. To avoid recall bias, the second set of images was reviewed after at least a 3-week interval, and on each occasion, the studies were viewed in a different random order. Following scoring, the observer was allowed to review the 3D data set and perform MPRs to see if this altered confidence.

Meniscal tears were diagnosed according to the recognized criteria as intrameniscal high signal extending to one or both articular surface, abnormal meniscal morphology or displaced meniscal material.¹³ All ligaments were assessed for the presence of tears and articular cartilage for abnormality. The menisci were graded in the posterior, body and anterior areas, and the cartilage was assessed in the medial and lateral tibiofemoral and patellofemoral compartments. Cartilage abnormality was scored using the modified Outerbridge

Table 2. Meniscal and cruciate ligament grading system and Outerbridge grading system for articular cartilage

Meniscal and cruciate ligament grading		Articular cartilage grading	
1	Definitely no tear	0	Normal
2	Probably no tear	1	Abnormal signal intensity, normal surface
3	Indeterminate	2	Superficial partial thickness lesion <50%
4	Probably tear	3	Deep partial thickness lesion >50%
5	Definitely tear	4	Full thickness lesion

Figure 1. Sagittal images of a tear of the posterior horn of the medial meniscus seen on both the spin echo sequence (a) and the three-dimensional fast spin echo sequence (b).

grading system.¹⁴ The menisci, cruciate ligaments and collateral ligaments were scored for tear on a five-point grading system to provide a measure of the observer's confidence (Table 2).

Accuracy, sensitivity and specificity were calculated using the standard protocol as the reference standard. The concordance between the two observers was assessed using the kappa statistic.¹⁵ For further analysis, the discordant scores were resolved by consensus agreement.

RESULTS

Evaluation of the 3D FSE PD FS sequence showed reduced accuracy in both medial and lateral meniscal tears in comparison with the standard sequences: 93.7% lateral and 90.9% medial (Figures 1 and 2). Accuracy of articular cartilage evaluation was also reduced in all three knee compartments: 87.5% medial, 89.5% lateral and 80% patellofemoral. The accuracy of the ACL tear evaluation remained excellent using the reconstructed 3D images at 98.9% (Figure 3). The analysis of the sensitivity and specificity for the different structures assessed is presented in Table 3.

Agreement between the observers for menisci and articular cartilage assessment was reduced using the 3D sequence compared with the standard sequence, although there was little difference in the agreement between the observers for the ACL using the two protocols (Table 4).

Confidence was increased following the viewing of the 3D data set and MPRs in 10 of 95 cases by Observer 1 and in 32 of 95 cases by Observer 2. Observer 1 commented on the improved confidence in cartilage reporting in 7 cases and Observer 2 in 14 cases. Increased confidence in meniscal reporting was commented upon by Observer 1 in 3 cases and by Observer 2 in 13 cases. Observer 1 did not comment on any alteration in the confidence in ACL reporting, whereas Observer 2 commented on the increased confidence in 3 cases.

DISCUSSION

This study suggests that current technology does not allow a 3D sequence to be obtained for the evaluation of knees for internal derangement at 1.5 T without significant reduction in diagnostic accuracy for the evaluation of both meniscal tears and articular cartilage abnormality. This finding is in keeping with the

Figure 2. Coronal images of a tear of the body of the medial meniscus showing a horizontal component on the standard spin echo sequence (a), which was not seen on the three-dimensional fast spin echo sequence (b).

Figure 3. Sagittal and coronal images of an intact anterior cruciate ligament. This was a false-positive result demonstrated as intact on the standard spin echo sequences (a, b) and reported as a tear on the three-dimensional fast spin echo sequence (c, d).

preliminary results from previous studies undertaken using 3-T systems, which demonstrated lower or similar diagnostic performance in comparison with conventional two-dimensional (2D) imaging.^{2–4} However, other 3-T studies have shown promising results for the evaluation of menisci by a 3D sequence with no statistical difference in the evaluation of surgically confirmed meniscal tears.^{5,6} A larger study by Kijowski and associates demonstrated that a 3D SPACE sequence had a similar sensitivity and specificity for evaluating medial meniscal tears compared with a routine MRI protocol and a similar specificity in evaluating the lateral meniscus but a significantly reduced sensitivity.⁷ Studies at 3 T have shown that optimized 3D SPACE provides significantly higher signal and contrast than conventional 2D FSE, particularly for fluid and cartilage.^{8,12}

All of the above studies have been performed at 3.0 T, but with the majority of European hospitals using 1.5-T magnets for their routine work it is important to evaluate 3D sequences using these systems. A small study by Ai *et al*¹⁶ demonstrated that their

3D sequence at 1.5 T had similar or superior sensitivity, specificity and accuracy to a conventional 2D imaging protocol. This is contradictory to the findings in the present study, but there are several important differences between these two studies. Ai *et al* showed that their standard imaging protocol had a sensitivity of 77.1% and specificity of 91.4% for meniscal tears in comparison with arthroscopy. Our standard sequence has been shown using unpublished and published data¹⁷ to have sensitivity and specificity of >90% using the same observers as employed in this study. Ai *et al*¹⁶ evaluated only 29 patients using a 1.5-T MR scanner, and reviewers were given access to the data set, allowing the reviewers to reformat the original image data for both the 3D sequence and conventional MRI protocols; there was no assessment of the increased accuracy or reporting confidence from performing MPRs. In our study, the reformatting was performed by a third party not reviewing the images, and we found that subsequent access to the data set for multiplanar reformatting did increase the confidence. It was felt that if the 3D sequence was to be employed in the clinical

Table 3. Results of statistical analysis comparing three-dimensional fast spin echo proton density (fat saturated) with standard sequences as the gold standard

Measure	Lateral meniscus	Medial meniscus	Anterior cruciate ligament	Medial compartment cartilage	Lateral compartment cartilage	Patellofemoral compartment cartilage
True positive	25	67	23	14	9	31
True negative	242	192	71	153	161	121
False positive	13	15	1	12	16	17
False negative	5	11	0	11	4	21
Sensitivity (%)	83.3 (64.5–93.7)	85.9 (75.7–92.4)	100 (82–100)	56 (35.3–75.0)	69.2 (38.9–89.6)	59.6 (45.1–72.7)
Specificity (%)	94.9 (91.2–97.1)	92.8 (88.1–95.7)	98.6 (91.5–99.9)	92.7 (87.3–96.0)	91 (85.5–94.6)	87.7 (80.7–92.5)
Positive-predictive value (%)	65.8 (48.6–79.9)	81.7 (71.3–89.0)	95.8 (76.8–99.7)	53.8 (33.7–72.9)	36.0 (18.7–57.4)	64.6 (49.4–77.4)
Negative-predictive value (%)	98 (95.0–99.3)	94.6 (90.2–97.1)	100 (93.6–100)	93.3 (88.0–96.4)	97.6 (42.6–81.2)	85.2 (78.0–90.4)
Accuracy (%)	93.7	90.9	98.9	87.9	89.5	80

Table 4. Kappa scores of interobserver agreement for each of the study sequences

Anatomical area assessed	Standard protocol	Three-dimensional sequence
Medial meniscus	0.91	0.86
Lateral meniscus	0.89	0.77
Anterior cruciate ligament	0.98	0.94
Cartilage	0.84	0.64

setting, the provision of previously reconstructed data would be needed to avoid adversely impacting on reporting time.

One of the major advantages of a 3D sequence is the ability of the radiologist to be able to perform MPRs in non-orthogonal planes. In our study, this was shown to increase the subjective confidence in a number of cases but did not compensate for the disadvantages of the reduced reporting accuracy of the 3D sequence. Other advantages of the 3D sequence include decreased acquisition time, 7 min 55 s for the 3D sequence vs 13 min 4 s for the standard 3 PD sequences. The reduction in scan time has the potential to improve patient experience and also to reduce costs with a time saving of 5 min 9 s per scan.

One disadvantage of a 3D sequence is that the whole sequence must be repeated if there is excessive movement artefact; in our study, this occurred in 4% of cases, and this has a greater time cost than that of repeating a single sequence.

This study is limited as a standard knee protocol was used as the reference standard not arthroscopy. The reason for this was that we were conscious that all of our patients would not go on to have arthroscopy performed and that our standard sequence has been previously evaluated extensively against arthroscopy in published and unpublished studies and has been shown to have an excellent accuracy.¹⁷ Ultimately, we were keen to specifically compare the 3D protocol against our

current protocol. A further limitation is that we did not formally evaluate all features that would normally be assessed by the radiologist reporting a knee MRI study. For instance, we did not evaluate the relative accuracy of the 3D sequence for assessing the presence, absence and morphology of bone marrow lesions.

In conclusion, the present study demonstrates that at 1.5 T, a 3D FSE sequence has reduced diagnostic performance in the evaluation of meniscal tears and articular cartilage lesions in comparison with standard 2D imaging in the three planes. For 1.5-T scanners currently common in routine practice, this study does not support the replacement of standard 2D MR sequences with images reconstructed from a single 3D sequence. At this time, we continue to use 2D PD sequences as part of the standard imaging protocol.

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