CHARACTERIZATION OF MENISCAL TEAR MORPHOLOGY ON RECONSTRUCTED MR AXIAL IMAGES AND CORRELATION WITH ARTHROSCOPY

Prabhu Radhan Radhakrishnan[1], Biji Babu[2], Arumugam S[3], Prakash A[4], Praveenkumar V[5]

[1]*Associate Professor, Department of Radiology and Imaging Sciences, Sri Ramachandra University, Porur, Chennai, Tamil Nadu.*
[2]*Resident, Department of Radiology and Imaging Sciences, Sri Ramachandra University, Porur, Chennai, Tamil Nadu.*
[3]*Professor, Department of Arthroscopy and Sports Medicine, Sri Ramachandra University, Porur, Chennai, Tamil Nadu.*
[4]*Associate Professor, Department of Arthroscopy and Sports Medicine, Sri Ramachandra University, Porur, Chennai, Tamil Nadu.*
[5]*Assistant Professor, Department of Radiology and Imaging Sciences, Sri Ramachandra University, Porur, Chennai, Tamil Nadu.*

ABSTRACT

BACKGROUND
MRI is a highly accurate imaging modality for diagnosing meniscal tears. Pre-operatively, surgeons need information not only on the presence of the meniscal tears but also on their morphological characteristics, in order to decide the most appropriate surgical method. MR Axial images of the menisci have been observed to help in identification and characterization of the meniscal tear, though they are under-used.

MATERIALS AND METHODS
A prospective observational study of 73 menisci in 63 patients, with prior MRI examination and who underwent arthroscopic surgery of knee over a period of 2 years was conducted. Images were reviewed by an MSK radiologist for the identification of meniscal tears, who was blinded to the arthroscopic findings. The routine MRI sequences along with reconstructed axial images acquired from sagittal PDFS images were used for the evaluation. The images were analysed in 5 different groups which included Coronal, Sagittal, Coronal and Sagittal, Axial, and Axial and Sagittal. A 3-point scale was used to report the confidence level for the diagnosis of meniscal tear in each imaging group.

The results were then statistically analysed using McNemar test to calculate the sensitivity, specificity and accuracy for detection and characterization of meniscal tears in the different imaging planes, considering the arthroscopic findings as the gold standard.

RESULTS
The specificity, sensitivity, and accuracy in the characterization of meniscal tears were increased with the inclusion of reconstructed axial images in combination with other imaging modalities. This imaging plane did not need added image acquisition time, but the interpretation of the tear morphology was little difficult due to poor image quality and needed regular practice. The axial plane was extremely helpful in the correct diagnosis of radial tears and root tears. We saw no statistically significant difference between the imaging groups of medial and lateral menisci in the diagnosis of tears ($p>0.05$).

CONCLUSION
The detection and characterization of meniscal tear morphology is more accurate using the reconstructed axial imaging plane, alongside the sagittal and coronal planes.

KEYWORDS
MRI, Meniscus, Reconstructed Axial Images, Arthroscopy, Tear, Knee.

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Corresponding Author:
Dr. Biji Babu,
#835, Sobha Serene,
Senneerkuppam P. O.,
Poonamallee High Road,
Chennai-46, Tamil Nadu.
E-mail: dr.bijibabu35@gmail.com
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BACKGROUND

The meniscus is composed of fibrous cartilage and contributes to the static stability of the knee joint.[1] Meniscal tears refers to the derangement of the fibrocartilaginous menisci of the knee. Acute meniscal tears usually occur after rotatory trauma of the knee, while chronic degenerative meniscal tears are often seen in the elderly after minimal stress on the knee.[2] MRI has been considered the best diagnostic method for the evaluation of internal derangements of the knee. A clinically suspicious meniscal tear is one of the commonest indications for the MR examination of the knee joint.[3] Injury of the menisci can be divided into four grades as seen with sagittal or coronal planed MRI sequences (Figure 1).

Grade I and II meniscal tear are probably treated conservatively, while Grade III and IV tears require surgical intervention. This classification does not include the anatomy of various meniscal tear path which is determined during arthroscopic knee surgery.[4] There are two primary MR criteria for the diagnosis of meniscal tears: (1): contact of intrameniscal high signal with the superior or the inferior surface of a meniscus (or with both surfaces). (2): distortion of the normal appearance of a meniscus.[5] In the past few years, there has been advances in the imaging of various types of meniscal tears and its normal variants which includes use of appropriate imaging techniques.[6] In the MR imaging for meniscal tears, sagittal and coronal planes were proved to be of higher diagnostic value.[7] The use of axial planes in the characterization of meniscal tears has been investigated to a lesser degree.[8]

With the use of Axial imaging planes, we get a good assessment of tear type and trajectory, extension, and morphology, because the axial plane helps to classify tear's trajectory relative to meniscus collagen bundles, which in turn helps in determining therapeutic method. However, axial imaging of menisci has reduced sensitivity to discriminate horizontal tears from other types of meniscal tears. But the advantage of axial imaging for the assessment of vertical and vertical-horizontal tears are to be considered as, clinically the horizontal tears are usually not easily repairable while longitudinal tears are often repairable and radial tears may be repairable depending on its location.[9]

In our study, we are assessing the value of axial MR reconstructed images, alone and in combination with other imaging planes, for the diagnosis of meniscal tears of the knees, keeping arthroscopy as the gold standard for the diagnosis of the same.

MATERIALS AND METHODS

A prospective observational study was conducted in department of radiology at Sri Ramachandra Medical College over a period of 2 years from April 2015 to August 2017 in 63 patients who were diagnosed to have meniscal tear by MR imaging of knee and who also underwent arthroscopic examination in our institution. The time interval between the MRI examination and arthroscopy ranged between 1 day to 15 months. Institutional Ethics committee approval was obtained for the study proposal in April 2015 and informed consent was obtained in all patients.Patients who had absolute contraindications to MR imaging and patients with previous meniscal repair were not included in the study.

All patients who were referred for MRI Knee were first explained about the MR procedure, detailed clinical history was taken, previous medical records checked and then written informed consent was obtained. Patient was then screened with a metal detector and positioned.MRI of knee were performed with 1.5T MRI machines using knee coil/extremity coil and following the routine protocol (Table 1). The patients were then followed up for the arthroscopic findings. Later, the images were analysed as detailed below.

Image Analysis

During the image analysis, the imaging sequences were separated into 5 evaluation groups: Coronal (I), sagittal (II), coronal and sagittal (III), axial (IV) and axial and sagittal (V). The axial images used for the analysis were the reconstructed images from the routine Sagittal PDFS (3.5 mm slice thickness).The image groups were independently reviewed by an experienced musculoskeletal (MSK) radiologist (9 years of experience as a MSK radiologist) who was blinded to the arthroscopic findings.

The imaging groups were evaluated for the presence or absence of meniscal tears with the observer determining the confidence level for the diagnosis of meniscal tear in all the above-mentioned imaging groups using a 3 - point scale; with 0 indicating a completely uncertain tear and 3 indicating very certain of tear. The medial and lateral menisci were evaluated as separate entities. These findings were then compared with those of Arthroscopy.

Statistical Analysis

Statistical analysis considered medial and lateral menisci separately. Sensitivity, specificity and accuracy for the detection and characterization of meniscal tears were then calculated, considering the arthroscopic findings as the gold standard. Statistical analysis was performed using McNemer test to interpret the differences in the identification and characterization of meniscal tears between the 5 imaging planes.

Abbreviations

MRI - Magnetic resonance imaging, 1.5T-1.5 Tesla, 3T- 3 Tesla, FSE- Fast Spin Echo, FOV- Field of view, TR- Repetition time, TE- Echo time, ACL- Anterior Cruciate Ligament, PCL- Posterior Cruciate Ligament, 3D- Three Dimensional, 2D- Two Dimensional, TSE- Turbo Spin Echo, T1WI- T1 Weighted Image, T2WI- T2 Weighted Image, FS- Fat-suppressed, PD- Proton Density, FRFSE- Fast- Recovery Fast Spin Echo, GRE- Gradient Echo, MSK- Musculo-Skeletal, SAG- Sagittal, COR- Coronal, AX- Axial, NEX- Number of Excitations

RESULTS

63 patients (49 male &14 female) with a clinical suspicion of meniscal tear underwent Routine MRI knee. 73 menisci in 63 patients, whose ages were distributed between 15 to 58 years with a mean age of 31 years, were evaluated using 5 imaging planes (using Sagittal PDFS, Coronal PDFS, and reconstructed Axial images from Sagittal PDFS). The patients were then followed up for their arthroscopic findings.

In our study, we saw almost equal percentage of prevalence of the meniscal injury in the right (52%) and left knee (48%). Among the 73 menisci studied in 63 patients, 58% of the patients presented with medial meniscal injury while 42% of patients had lateral meniscal injury.

The morphology of meniscal tear could be appreciated in 64 of the 73 menisci on MRI. The morphologies seen were classified into complex tear, Radial tear, Longitudinal tear, Horizontal tear, Bucket-handle tear, Parrot-beak tear, Flap tear, Root tear and Wrisberg rip tear. Most of the tears we encountered were bucket-handle tears (22%) followed by complex tear (20%).

On correlation with the Arthroscopic findings, the characterization and identification of various types of tears in the different imaging planes were observed. The various imaging planes used for assessment were Sagittal plane (I); Coronal plane (II); Sagittal and coronal plane (III); Sagittal and axial (IV) and Axial (V).

*For the identification of meniscal tear in medial meniscus, the highest sensitivity and accuracy were seen with imaging groups III and IV (92.3% and 88.09% respectively) followed by imaging group V(89.74% and 85.71%). (Table 2)

*For the identification of meniscal tear in lateral meniscus, the highest sensitivity and accuracy were seen with imaging groups I, III and IV (85.71% and 80.64% respectively) followed by imaging group V(78.57% and 74.19%). (Table 2)

*For the characterization of meniscal tear morphology in medial meniscus, the highest sensitivity and accuracy were seen with imaging group IV (92.3% and 88.09% respectively) followed by imaging group V(89.74% and 85.71%). (Table 3)

*For the characterization of meniscal tear morphology in lateral meniscus, the highest sensitivity and accuracy were seen with imaging group IV (85.71% and 80.64% respectively). (Table 3)

Erroneous Interpretation

In our study, at arthroscopic correlation, 60 of the 73 menisci were correctly diagnosed as torn.

4 menisci (2 medial meniscus; 2 lateral meniscus) were diagnosed to be torn in MRI but was not visualized at Arthroscopy.

One patient was diagnosed to have complex tear of anterior horn of medial meniscus on MRI evaluation. On arthroscopy, it was identified as hypoplastic anterior horn with thick intermeniscal ligament which mimicked the tear.

Another patient who presented with instability of knee underwent MRI of knee and was found to have Anterior cruciate ligament injury with high signal intensities in the anterior horn of lateral meniscus which was identified as meniscal tear on MRI. Upon arthroscopic examination, there were no meniscal tear identified.

7 menisci (3 medial meniscus; 4 lateral meniscus) were diagnosed to have been torn at arthroscopy, which was not reported at MRI.

Among these patients, one patient had a radial tear and one had a Wrisberg rip tear at arthroscopy.

One patient who underwent MRI of knee with complaints of knee pain showed focal vertical global signals in the posterior horn of medial meniscus which was not continuous and was not seen in coronal images, hence did not fulfill the criteria for meniscal tear on MRI. On arthroscopic examination, this altered signals were identified as meniscal tear. There was another similar scenario, where the altered signal intensities in the posterior horn of the lateral meniscus did not fulfill the criteria for tear at MRI but was identified as a tear at Arthroscopy.

In two patients, discoid lateral meniscus could not be appreciated at MRI.

Representative Cases:

Case 1

A 19-year-old soccer player in Germany came for MRI of left knee with complaints of pain while kicking football. MRI done elsewhere, 10 days back was reported as normal study. MRI was repeated in our institution and a radial tear was identified in the anterior horn-body junction of the lateral meniscus. Axial reconstructed images proved to be helpful in identifying the tear trajectory. (Figure 2). Arthroscopy was performed 2 days later, which identified the tear and partial lateral meniscectomy was performed. (Figure 2d).

Case 2

A 30-year-old male patient came with alleged history of a twisting injury to his right knee while climbing stairs and sustained pain and instability of his knee. MRI of right knee was done which showed a complex root tear of the posterior horn of the medial meniscus. The tear morphology was very subtle in Sagittal and Coronal imaging planes while axial reconstructed images could demonstrate the tear better. (Figure 3). Arthroscopic examination was done 1 month later, which revealed the tear and partial lateral meniscectomy was done. (Figure 3d).

Sequence	TR (ms)	TE (ms)	ETL	Slice Thickness (mm)	Spacing (mm)	FOV (cm)	Nex	Matrix
Sag PDFS	2500	30	8	3.5	0.5	16	2	320x256
Cor PDFS	2160	30	8	3.5	3.5	16	2	320x256
Ax PDFS	3300	42	8	3.5	1	14	2	320x256
Sag T2	2820	85	15	3	0.2	16	3	320x224
Cor T1	680	11.5	2	3.5	0.5	16	2	320x256
Sag GRE	475	13.3	Flip angle: 25	3.5	0.5	16	2	384x192

Table 1. Protocol for the MRI Knee Study

	Medial Meniscus			Lateral Meniscus		
Plane	Sensitivity	Specificity	Accuracy	Sensitivity	Specificity	Accuracy
Sagittal (I)	89.74	33.33	85.71	85.71	33.33	80.64
Coronal (II)	76.92	66.67	76.19	53.57	66.67	54.83
Sagittal+ Coronal (III)	92.3	33.33	88.09	85.71	33.33	80.64
Sagittal + Axial (IV)	92.3	33.33	88.09	85.71	33.33	80.64
Axial (V)	89.74	33.33	85.71	78.57	33.33	74.19

Table 2. Comparison of Sensitivity, Specificity and Accuracy of Various Imaging Planes in the Identification of Meniscal Tear in Medial and Lateral Meniscus

	Medial Meniscus			Lateral Meniscus		
Plane	Sensitivity	Specificity	Accuracy	Sensitivity	Specificity	Accuracy
Sagittal (I)	87.17	33.33	83.33	82.14	33.33	77.41
Coronal (II)	61.53	66.67	61.90	46.42	100	51.61
Sagittal + Coronal (III)	87.17	33.33	83.33	82.14	33.33	77.41
Sagittal + Axial (IV)	92.3	33.33	88.09	85.71	33.33	80.64
Axial (V)	89.74	33.33	85.71	75	33.33	70.96

Table 3. Comparison of Sensitivity, Specificity and Accuracy of Various Imaging Planes in the Characterization of Meniscal Tear in Medial and Lateral Meniscus

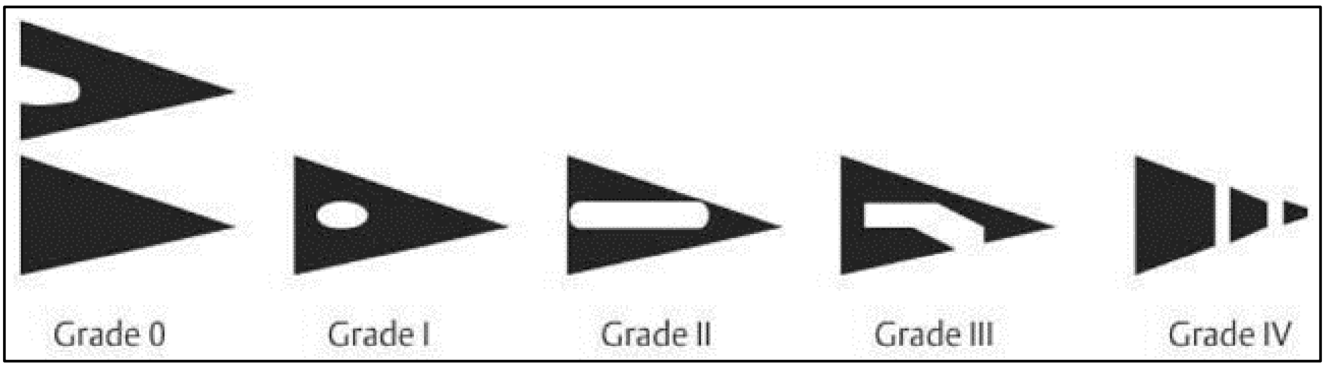

Figure 1

Figure 1. Grading of meniscal tears as seen on a sagittal / coronal planed MRI sequence.

(**Grade I:** a small focal area of increased signal intensity, that does not extend to the articular surface; **Grade II:** linear trajectory of increased signal intensity without extension to the joint surface. **Grade III**: area of increased signal intensity that extends to the articular surface. **Grade IV:** meniscal tears characterized by more than one lesional paths, with fragmentation of the meniscus).

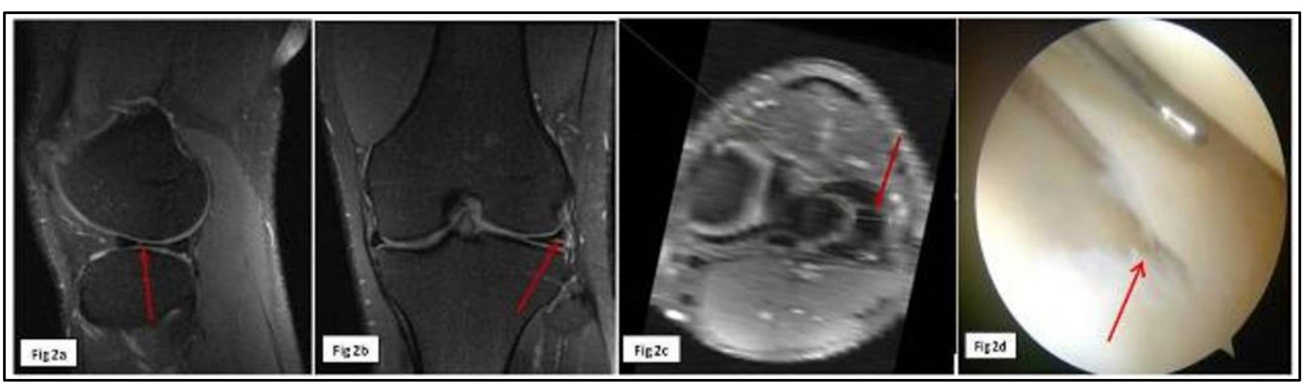

Figure 2

Figure 2. MRI left knee Sagittal PDFS (2a), Coronal PDFS (2b) and Axial reconstructed images (2c) from the Sagittal PDFS images showed a radial tear (Arrows) involving the anterior horn-body junction of lateral meniscus. The tear trajectory was better delineated in the axial image. Figure 2d: Arthroscopic picture showing radial tear of lateral meniscus.

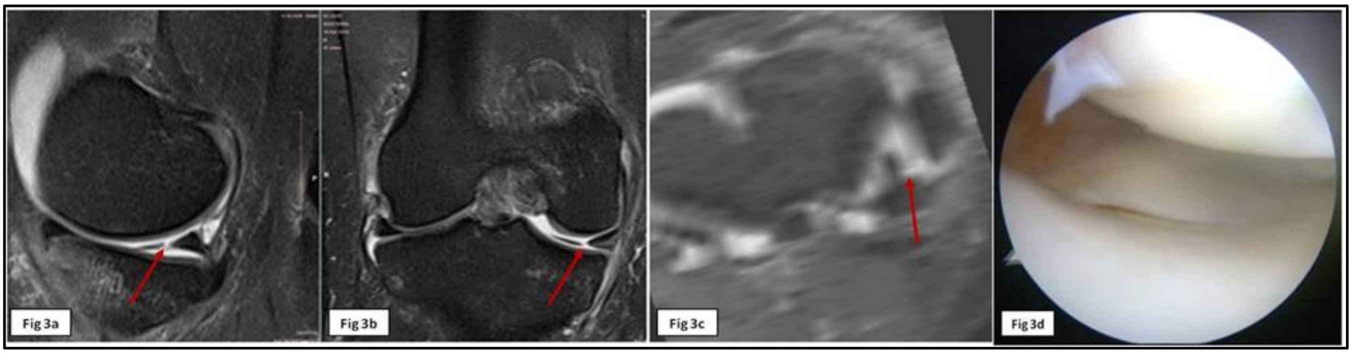

Figure 3

Figure 3. MRI left knee Sagittal PDFS (3a), Coronal PDFS (3b) and Axial reconstructed images (3c) from the Sagittal PDFS images showed a complex root tear (Arrows) of the posterior horn of medial meniscus. The tear trajectory was better delineated in the axial image. Figure 3d: Arthroscopic picture showing complex root tear of medial meniscus.

DISCUSSION

The menisci are the important primary stabilizers and weight transmitters in the knee.[1] Accurate and timely diagnosis of a meniscal tear is necessary for reducing morbidity as well as for planning the treatment. Meniscal damage predisposes the adjacent articular cartilage to increased axial and sheer stress, resulting in early degenerative osteoarthritis.[2]

MRI has evolved into the preferred non-invasive imaging modality for the evaluation of the internal derangement of the knee, with arthroscopy being the gold standard of reference.[2] There are very few studies which emphasizes on the accuracy of axial planes in the diagnosis of meniscal tears.[3]

In our study, we evaluated 73 menisci in 63 patients who were diagnosed to have meniscal tear in MR imaging of knee and for whom arthroscopic examination was also performed in our institution. The common presenting complaints were knee pain/ instability/restricted movements following trauma. Routine MRI was performed in these patients followed by arthroscopic examination. The MRI images of these patients were then re-evaluated in 5 different imaging planes i.e, Sagittal, Coronal, Sagittal and coronal; reconstructed Axial, Axial and Sagittal, by an experienced MSK radiologist, who was blinded to the arthroscopic findings.

Our study showed an increased risk for injury to the body and posterior horn of menisci as per the evaluation using MRI (49%) and arthroscopy (56%). The commonest morphology of tear encountered was Bucket handle tears (23%), followed by flap tears (20%) and radial and longitudinal tears (14% each).

In our study, meniscal tear morphologies were defined as follows:

1) Longitudinal/vertical tear: tear perpendicular to the tibial plateau in the sagittal plane.
2) Horizontal tear: tear parallel to the tibial plateau in the sagittal and axial plane that slices the meniscus into top and bottom portions.
3) Radial tear: tear perpendicular to the free edge of the meniscus in the axial plane.
4) Complex tear: combination of all or some of horizontal, longitudinal and radial tears.
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) Parrot –beak tear: displaced radial tear in a pattern similar to that of Parrot beak.
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.
8) Root tear: radial type of tear located at the root of meniscus.
9) Wrisberg rip tear: longitudinal meniscal tears at the junction of the ligament of Wrisberg and the posterior horn of lateral meniscus, commonly associated with ACL tear.

The sensitivity, specificity and accuracy of findings in all the imaging planes for the identification and characterization of meniscal tears were assessed for medial and lateral meniscus separately. (Table 2 & 3). There was no significant statistical difference between the imaging plane groups of both menisci in the identification and characterization of meniscal tears ($p>0.05$). It was observed that the axial plane increased the accuracy of Sagittal and coronal planes in the characterization of tears in both menisci.

Our results were comparable to those of a study by Tarhan et al in 2004 on the role of axial MRI alone and in combination with other imaging planes where they used axial fat-saturated FSE proton density images with 4-5 mm slice thickness. For the medial and lateral meniscal tears, the accuracy(79% and 71% respectively) of axial imaging plane alone were comparable to that of other imaging planes, in their study which was similar to ours with an accuracy of 85.7% and 70.96% for the medial and lateral menisci, respectively.[4]

Our study, on comparison to a similar study conducted by Ohishi et al in 2005 on use of axial images from 3D MRI datasets for the diagnosis of meniscal tears in comparison to 2D sagittal and coronal images, where they studied 74 menisci in 37 patients, showed a sensitivity, specificity and Accuracy of 96.8%, 79.1% and 86.5% respectively for the detection of tear on axial images from 3D MRI, which is comparable to that of ours.[5]

Similarly, all the meniscal root tears were correctly diagnosed using reconstructed axial images while only 83% of these tears could be correlated using sagittal and coronal images.

Of the 9 peripheral longitudinal tears studied, reconstructed axial images in combination with the sagittal images enabled the correct diagnosis in 8 patients (89%) while sagittal and coronal images together could diagnose the tear correctly in only 7 patients (78%).

These findings were in par with the study conducted by Tarhan et al[4] which concluded that the extent and severity of meniscal tears were better delineated with thin section axial 3D gradient echo sequences compared with coronal and sagittal images, especially when the disease existed in the periphery of the meniscus.

Meniscal fluid interface and morphology are best visualised on TSE images.[6] The most frequently used sequences are spin echo or TSE PDW with or without FS and gradient echo.[7] Although meniscal structure can be revealed by axial images, routine axial images of 4–5mm thickness are not sensitive to meniscal pathologies because of excessive thickness.[8]

In 2011, a study by G. Gokalp et al. on the contribution of thin-slice(1 mm) axial proton density MR images for the identification and classification of meniscal tears in correlation with arthroscopy, showed that thinner sections can better reveal the signal–surface contact and tear morphology.[9]

Yoon et al[10] performed TSE PDW MRI with 1mm thickness and observed inadequate tissue contrast because of the presence of a certain degree of image degradation during the multi-planar reconstruction process owing to non-isotropic images.

Limitations of acquiring thin-slice axial images included longer acquisition time (6 min). This could be avoided by using 3 T MRI, which shortens the duration of acquisition, and application of parallel imaging methods.

The versatility of MRI in the evaluation of meniscal tears has been shown by 3D volumetric techniques and thin-section two-dimensional images. Axial reconstruction images were generated by applying 3D volumetric methods in order to show meniscal tears.[11]

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.[12] This raised meniscal signal intensity can confuse the observer in deciding whether the abnormal signal actually extends into the articular surface or not and reduces the specificity.[12]

In our study using 1.5T MRI, we acquired routine MRI knee for all patients with 3 plane PDFS. Sagittal T2, Coronal T1 and Sagittal GRE were optional sequences which varied in different patients. In the evaluation of meniscal tear, we used axial images reconstructed from the sagittal PDFS images (3.5 mm thickness) for interpretation in axial plane along with sagittal and coronal PDFS images.

We observed that, with these reconstructed images, we were able to evaluate the tear morphology better according to our region of interest, in comparison to sagittal/ coronal images. Both menisci could be evaluated simultaneously in the same plane using the reconstructed images, which was poorly appreciated in routine axial images (including both 3D and thin slice images). The total scan time was also reduced for the patient, as this did not require additional acquisition time.

However, the images acquired were of poor image quality/ noisy thereby making the interpretation of the tear morphology little difficult and required regular practice.

A study by Neil Kruger in 2016 concluded that Uni-planar 3D reconstruction from 3T MRI knee scan sequences are useful in identifying normal menisci and menisci with bucket-handle tears. Advances in MRI sequencing and reconstruction software are awaited for accurate identification of the remaining meniscal tear configurations.[13]

Perspective

Axial images present an additional plane for visualization, alongside sagittal and coronal planes, as they increase the sensitivity and specificity of the imaging results. Integration of axial imaging with the routine sagittal and coronal images will facilitate the identification and characterization of meniscal tears better.

We get a good assessment of lesion type and trajectory, as the axial plane helps to classify lesion's trajectory relative to meniscus collagen bundles. The extent and severity of meniscal tears were better delineated with axial images compared with coronal and sagittal images especially in the assessment of peripheral tears and small radial tears of the free edge.

CONCLUSION

In our study, by including the reconstructed axial images acquired from the sagittal PDFS images in combination with other imaging planes, the characterization of meniscal tear morphology were more accurate and this imaging plane did not require additional image acquisition time although the interpretation of the tear morphology was little difficult due to poor image quality and required regular practice.

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