Original Research Article

MRI evaluation of knee cartilage injury: Comparison of 3D FIESTA with the fat suppressed 3DSPGR imaging

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Abstract

Background: To compare the sensitivity, specificity and accuracy of 3-dimentional fast imaging employing steady state acquisition (3DFIESTA) sequence with that of 3 - dimensional spoiled gradient echo (3DSPGR) sequence in the assessment of articular cartilage in patients with multiple ligament knee injury using arthroscopy as the reference standard. **Materials and methods** A total of 300 surfaces of 50 knees were evaluated by using sagittal 3D FIESTA and sagittal fat-suppressed 3D SPGR sequences. Articular cartilage lesions were graded on MRI and arthroscopy using a modified Noyes scoring system. Sensitivity, specificity, and accuracy were assessed. An interobserver agreement was determined with rho(r) values. **Results:** The performance of 3D FIESTA sequences, sensitivity, specificity, and accuracy were ranged from 54-80%, 88-98%, and 86-92%, respectively was similar to that of fat-suppressed 3D SPGR sequences, sensitivity, specificity, and accuracy were 62-98%, 90-98% and 88 to 98%, respectively in the detection of knee articular cartilage lesions. The interobserver agreement varied from good to excellent (rho values ranged from 0.63-0.99). **Conclusion:** 3D FIESTA has good diagnostic performance, comparable with fat-suppressed 3D SPGR in the evaluation of knee cartilage injury, and can be integrated into routine knee MRI protocols due to the short acquisition time.

Key words: MRI: Magnetic resonance imaging, 3D FIESTA:3- Dimensional fast imaging employing steady state acquisition, 3D SPGR:3-Dimensional spoiled gradient echo sequence, ACL: Autologous chondrocyte implantation.

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INTRODUCTION

Detection and characterization of joint cartilage lesions have become increasingly important in routine work due to the high prevalence of osteoarthritis and post-traumatic cartilage abnormalities. Traumatic cartilage injuries of the knee are common in physically active individuals; however, the accurate numbers and localizations are not well known. Magnetic resonance imaging (MRI) of the knee joint is routinely used to detect traumatic cartilage injuries. MRI has good sensitivity and specificity in the

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examination of menisci and ligament injuries to the knee. However, for cartilage injuries, past literature (1,2,3) has produced varying results compared to arthroscopy, with a sensitivity ranging from 60 to 100%, a specificity ranging from 70 to 100 percent and an accuracy ranging from 81 to 98%. The integrity of its articular cartilage is the most crucial prerequisite for an adequate long-term joint function. Many studies (1,2,3,4) have shown that the prevalence of joint chondral trauma is high and cartilage damage is generally recognized as an early factor in the irreversible joint degeneration process. Recent developments in new surgical procedures and tissue engineering, such as autologous chondrocyte implantation (ACL) have had promising results in the formation of hyaline cartilage repairs. MRI is a widely accepted noninvasive technique for the assessment of cartilage lesions. A variety of MRI sequences for the assessment of articular cartilage have attracted considerable interest and have been the subject of numerous research studies in recent years(2,3). With conventional spin-echo sequences, sensitivities for the detection of hyaline cartilage lesions have been reported as low as 29 percent to 53 percent (2,3). Better results have been published using cartilage-specific sequences including T2 or intermediate weighted fast spin-echo sequences (4,5), 3-Dimensional spoiled gradient-echo sequence (3D SPGR), or 3- Dimensional fast imaging employing steady-state acquisition (3D FIESTA) sequences. The objective of the present study is to compare the sensitivity, specificity, and accuracy of 3-dimensional fast imaging employing steady-state acquisition (3DFIESTA) sequence with that of 3 - dimensional spoiled gradient echo (3DSPGR) sequence in the assessment of articular cartilage in patients with multiple ligament knee injury using arthroscopy as the reference standard.

MATERIALS AND METHODS

This is a prospective study conducted in the Department of Radiodiagnosis and Imaging, Kasturba Medical College, Manipal, from October 2010 to September 2012. The research procedure was accepted by our Institutional Ethics Board and informed consent were obtained from all patients before the MRI examination. The study was approved by the Ethics Committee of the institute, EC Reg NO: IEC423/2011 and taken permission from an appropriate authority. Informed consent was obtained from all patients before the MRI study. All patients with traumatic knee injury referred for MR evaluation were scanned on a 1.5T GE HDxt MRI system using a dedicated quadrature phased array knee coil with 3- dimensional fast imaging employing steady-state acquisition (3DFIESTA) and 3-dimensional spoiled gradient echo (3DSPGR) sequences. Imaging parameters for sequences performed during the MRI examination are listed in Table 1

Table 1: Imaging parameters for sequences performed during the MRI examination

	3DSPGR	3DFIESTA
TR	40ms	6ms
TE	6ms	3ms
Flip angle	10	30
VBW	15	41
ETL	1	1
FOV	12	20
SL(mm)	2	2
GAP	0	0
MATRIX	320x256	320x320
NEX	3	3
TIME (min)	7 – 8	4 - 5

Patients with a definite history of external trauma to knee and Knee with a multiligamental injury were included. Patients with Previous h/o knee surgery, Contraindications for MR imaging, Knee with isolated meniscal or cruciate ligament injury, and Non-availability of arthroscopy record were excluded from the study. 300 surfaces of 50 knees have been tested for cartilage injuries. The following six articular surfaces were tested for cartilage signal and morphology. Medial patellar facet, Lateral patellar facet, Medial femoral condyle, Medial tibial condyle, Lateral femoral condyle, and Lateral tibial condyles using a modified version of the Modified Noyes classification system (6,7) (Table 2) for articular cartilage defects. All patients in this study underwent conventional knee arthroscopy by an orthopedic surgeon who was blinded to the MRI grading results of cartilage lesions. All MRI scans were evaluated by a single senior radiologist who is blind to the arthroscopy results.

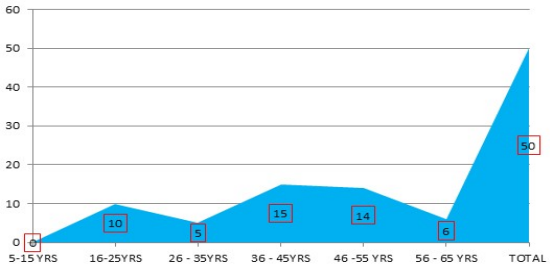
Table 2: Modified Noyes classification system for articular cartilage defects

Grade 0	Intact cartilage with normal signal and uniform thickness.
Grade 1	Focal abnormal signal without surface abnormalities.
Grade 2A	Superficial ulceration or fissuring, with a depth less than 50% of cartilage thickness.
Grade 2B	Deep ulceration or fissuring with a depth greater than 50% of cartilage thickness.
Grade 3	Full-thickness cartilage defect with normal or erosion of sub chondral bone.

All patients in this study underwent conventional knee arthroscopy by an orthopedic surgeon who was blinded to the MRI grading results of cartilage lesions. All MRI scans were evaluated by a single senior radiologist, who is blind to the arthroscopy results. Correlation of grades between arthroscopy and MR imaging for different articular surfaces were calculated by using spearman's rho correlation (r). Spearman's rho correlation ranges from -1 to + 1. -1 –Negative correlation,0 - No correlation, +1-Positive correlation. The more positive the r, the stronger the correlation.

RESULTS AND OBSERVATIONS

The study group consists of 50 subjects, of whom 38 had a history of RTA, 6 had a history of fall and the remaining 6 had a history of blunt trauma. All patients had been injured in the last six months before the MRI examination.43 (86%) were below 50 years of age and 17 (14%) were above 50 years of age (graph 1)



Graph 1: Age distribution of the subjects in the study

Grading and distribution of cartilage defects: A total of 300 surfaces of 50 knees were evaluated, of which 221(72%) were normal(Fig 1) surfaces and 79(27%) had cartilage defects.9(3%) were grade 1 lesions(Fig 2) 24(8%) were grade 2A(Fig3),10(3%)were grade 2B (Fig 4)and 36(12%) were grade 3(Fig 5) arthroscopic lesions. Chondral lesions were most often seen on the medial patellar surface and medial femoral surface (Graph 2). The distribution of grading of articular lesions for different articular surfaces was calculated and compared with arthroscopic grading. More than 85% of lesions showed a maximum difference of one grade between arthroscopy and MR imaging for different articular surfaces (Graph 3).

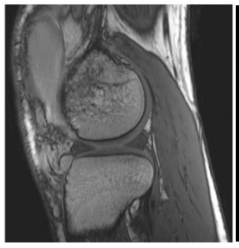
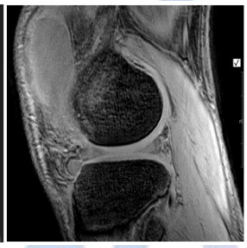


Figure 1(a)



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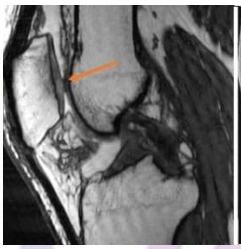


Figure 2(a)

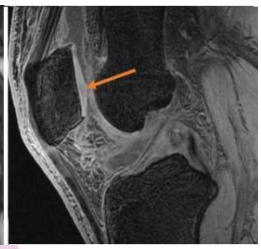


Figure 2(b)

Figure 3

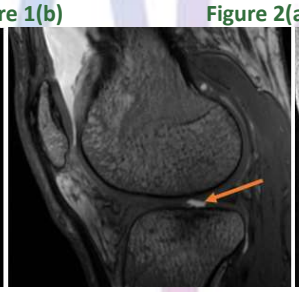


Figure 4(a)

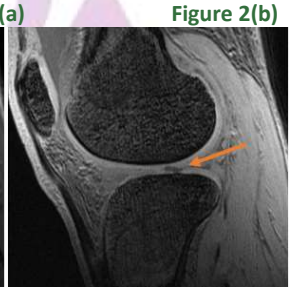


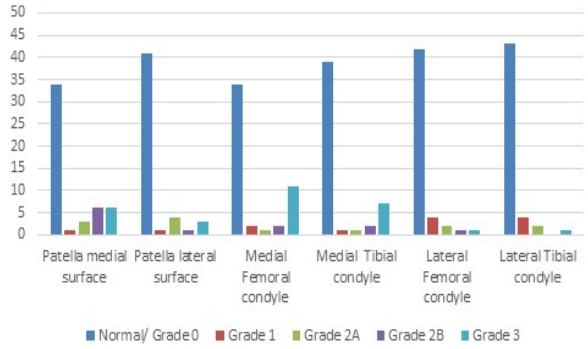
Figure 4(b)

Figure 5(a)

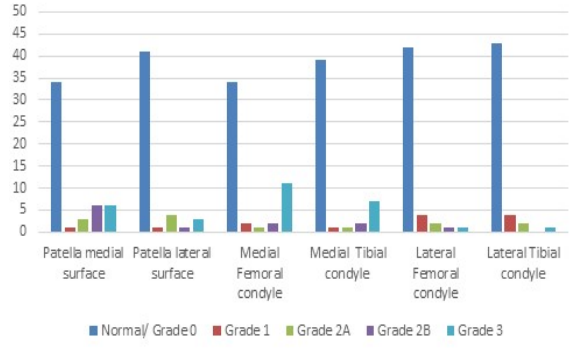
Figure 5(b)

Figure 1: Normal appearing cartilage (a) 3D FIESTA (b)3D SPGR; **Figure 2:** MRI images of a 35-year-old man with arthroscopic grade 1 cartilage change of medial patellar surface after acute trauma. (a)Sagittal, 3D FIESTA image shows focal cartilage swelling with intermediate signal intensity with an intact cartilage surface (arrow).(b) Sagittal, fat-suppressed, 3D SPGR image shows a focal decreased cartilage intensity with an intact cartilage surface (arrow); **Figure 3:** MRI image of a 42 yrs. old male trauma patient with arthroscopic grade 2A cartilage grading. Sagittal, 3D FIESTA image shows a focal cartilage defect (less than 50% of the depth of total cartilage surface; arrow) at the medial femoral condyle. Note that the defect is lined with relatively hyperintense effusion; **Figure 4:** MRI images of a 33 -year-old woman with arthroscopic grade 2B cartilage change of the lateral femoral and tibial condyles after twisting of the knee while playing basketball. (a) Sagittal FIESTA image shows a focal cartilage defect (more than 50% of the depth of total cartilage surface but without exposure of the subchondral bone; the arrow at the lateral femoral and tibial condyles. (b) Sagittal, fat-suppressed, 3D SPGR image shows a focal cartilage defect (more than

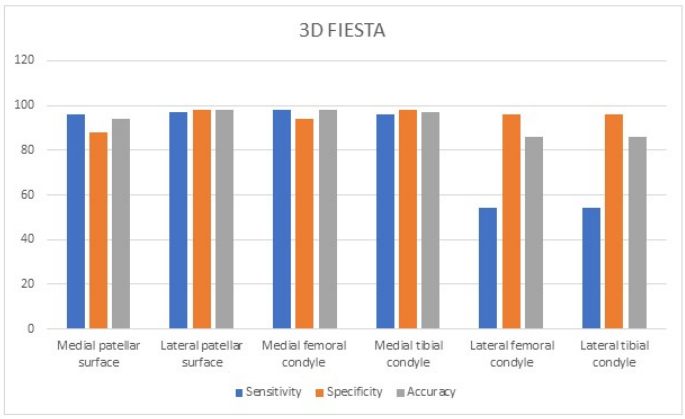
50% of the depth of total cartilage surface but without exposure of the subchondral bone; arrow) at the lateral femoral and tibial condyles. **Figure 5(a)(b):** MRI images of two men (42 years and 48 yrs. old) with arthroscopic grade 3 cartilage change (a) Sagittal FIESTA image shows cartilage defect (arrow) at the lateral tibial plateau. (b) Sagittal, fat-suppressed, 3D SPGR image shows a solitary, large cartilage defect (with exposure of the subchondral bone) (arrow) at lateral femoral condyle.



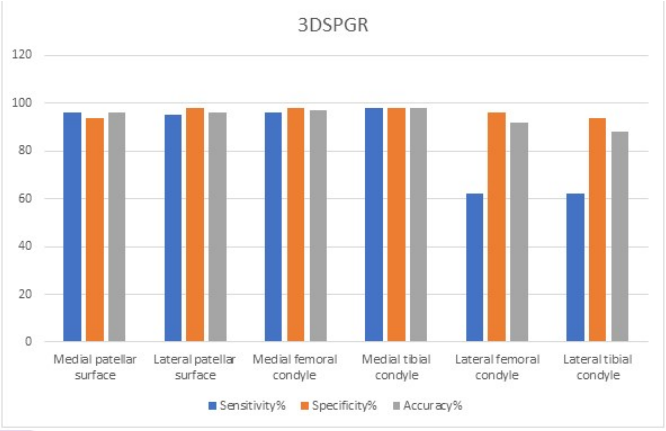
Graph 2



Graph 3



Graph 4



Graph 5

Graph 2: Distribution of different grades of cartilage injury along the different articular surfaces. Arthroscopy; **Graph 3:** Distribution of different grades of cartilage injury along the different articular surfaces 3D FIESTA: In the present study, 3D FIESTA sensitivity ranged from as high as 98% for Medial femoral condyle to as low as 54% for lateral femoral and tibial condyles. The specificity was ranging from 88% to 98% and the accuracy ranged from 86% to 98% respectively (Graph 4); **Graph 4:** Sensitivity, specificity, and accuracy of 3D FIESTA imaging by cartilage surface; **Graph 5:** Sensitivity, specificity, and accuracy of 3D SPGR imaging by cartilage surface

Sensitivity for 3D SPGR ranged from 98% for medial tibial condyle to 62% for lateral femoral and tibial condyles. Specificity was greater than 90% and accuracy ranged from 88% to 98%respectively (Graph 5).

In the present study, r values ranged from as high as 0.97 for medial femoral condyle cartilage to as low as 0.63 for lateral tibial articular cartilage in 3DFIESTA imaging and as high as 0.99 for medial tibial condyle cartilage to as low as 0.68 for lateral tibial articular cartilage in 3D SPGR MR imaging.

DISCUSSION

The knee joint is one of the most commonly involved in external injuries due to human bipedal nature (2,8). Injuries include acute, chronic, and repetitive trauma. Even minor injuries can disrupt the complex structure and function of the articular cartilage (2,9,10). Hyaline cartilage deficiency in the knee is a significant cause of symptoms for the patient(11,12). With the recent development of chondrocyte transplantation and other advanced surgical techniques, the presurgical identification and characterization of these defects have become increasingly significant (11,12). The detection of hyaline cartilage defect in the knee is critical because symptoms and indications associated with such defects may be clinically confused with meniscal tears. Meniscal tears are easily repaired, but the treatment of chondral defect is a controversial and limited prognostic value because hyaline cartilage does not regenerate but rather repairs with fibrocartilage growth from subchondral mesenchyme. Surgical grading of the 324 cartilage surfaces studied by Sonin *et al.*. (13) shows “normal”

(grades 0 and 1) in 241 surfaces (74.4%); partial-thickness defects (grades 2 and 3) in 56 (17.3%); and full-thickness defects (grade 4) in 27 surfaces (8.3%). Of the partial-thickness defects, 29 (9.0% of the total) were grade 2 and 27 (8.3% of the total) were grade 3. In the research performed by LI Xiao-ming *et al.*. (2) the occurrence of cartilage changes of all the evaluated surfaces was 41% (339/828), grade 3 lesions were 3% (25/828), and grade 4 lesions was 3% (26/828).In the present study, the frequency of cartilage defects in all the studied surfaces was 27% (79/300), grade 1 lesions were 3%, grade 2 lesions were 8 %, grade 3 lesions were 3% and grade 4 lesions was 12%. The incidence of cartilage lesions of different grades in the present study was slightly lower than that of studies in the literature; however, these differences may be partly due to the relatively smaller sample size as patients with nontraumatic knee pain and those with degenerative osteoarthritis were excluded from our research3D SPGR imaging is one of the most commonly used sequences for cartilage assessment in clinical practice (2,3,4,6,7). In the present study, cartilage lesions of the knee were shown to be accurately detected on 3D SPGR imaging, with sensitivity ranging from 62-96%, the specificity of 96%, and accuracy of 93%. Sensitivity, specificity, and accuracy of 3D SPGR imaging in our study are almost similar to the studies by David G Disler (3,4) *et al.*. and lixiao-ming (2) *et al.*. (Table3).

Table 3: Sensitivity, specificity, and accuracy of 3D SPGR imaging among different studies

3D SPGR	Sensitivity %	Specificity %	Accuracy %
David G Disler *et al.*.	85-95	97	94
Lixiao-ming *et al.*.	64	87	82
X.Li *et al.*.	82	90 -92	88 -90
Present study	62-96 (79)	96	93

Because fat-suppressed 3DSPGR effectively suppresses all stationary tissue, it is not useful to test the ligaments, or soft tissues of the knee (2,14) and is not sensitive for marrow edema, which is often a sign of overlying cartilage defects (2). The main drawback of the 3DSPGR sequence in clinical application is its long scanning time. With increased scan time, the potential for motion artifact also increases, which is deleterious to the interpretation of the image. Another drawback of this sequence is the weak contrast between the cartilage and synovial fluid, which can reduce the conspicuousness of superficial cartilage lesions (15,16). More recently, SSFP imaging, with a relatively short period of acquisition, has been applied to experiments and clinical practice (17,18). This high SNR technique has also been referred to as "true fast imaging with SSFP' (TrueFISP), "balanced fast field echo' (Balanced FFE) and "fast imaging with the steady-state acquisition (FIESTA), which generates signal contrast based on the ratio of T2 to T1 in tissues (19).In 3D FIESTA imaging, the signal intensity of the cartilage is intermediate to low and that of the joint fluid is bright, which can provide an arthrographic effect that shows the subtle defects of articular cartilage(15).In the present study, cartilage lesions of the knee detected on 3D FIESTA images were confirmed on surgical examination with sensitivity ranging from 54-96%, the specificity of 88%, and accuracy of 90%, which is almost similar to that of 3D SPGR (Table 4). X. Li *et al.*. (15) reported that the performance of 3DFIESTA sequences (sensitivity, specificity, and accuracy were 80, 94, and 92 percent, respectively)was close to that of fat-suppressed 3D GSPR sequences (sensitivity, specificity, and accuracy were 82, 92, and 90 percent, respectively)for the identification of knee joint cartilage lesions. Interobserver agreements ranged from fair to good to strong (kappa values from 0.43 - 0.83).Hargreaves *et al.* (19) reported that SSFP sequences have a higher SNR and contrast between the cartilage and synovial fluid compared with SPGR. Duc *et al.* (17) found a sensitivity ranging from 52 to 65%, a specificity varying from 80 to 94%, and an accuracy from 71to 76% with 3D water-excitation True FISP sequences.

Table 4: Sensitivity, specificity, and accuracy of 3D FIESTA imaging among different studies.

3D FIESTA	Sensitivity %	Specificity %	Accuracy %
Lixiao-ming *et al.*.	59	88	79
X.Li *et al.*.	82	92	90
Present study	54 – 96 (75)	88	90

Compared with 3D SPGR, 3D FIESTA MR imaging provides a contrast between synovial fluid and cartilage while preserving signal from the cartilage itself and maybe more useful in the detection of cartilage defects. In the present study, some superficial cartilage defects were undetectable on 3D FIESTA images, which may be partly due to a lack of fat suppression. We also noticed that 3D FIESTA imaging was more sensitive to bone edema or bruise in wounded knees compared to 3D SPGR, and this advantage allowed some contribution to the identification and assessment of cartilage lesion for proper grading. In the present study, the acquisition time of 3D FIESTA was 4 to 5 min, which is decreased significantly compared to 6.5 to 7 min of 3D SPGR. However, the use of this sequence in the diagnosis of meniscal, tendon, or ligament

disease may not be as effective as FSE MR imaging and will be the focus of future studies. The main drawback of SSFP is the extreme banding artifacts caused by local inhomogeneity of the magnetic field when the TR is long. With the development of MRI gradient hardware, which allows lower TRs, the probability of banding artifacts caused by field inhomogeneity has decreased. In the present study, TR was kept minimum (4 to 6 ms) to reduce banding artifacts.Magnetic resonance imaging showed a relatively low sensitivity to the detection of chondral lesions of the lateral tibial plateau; partially due to the relatively small number of chondral lesions that were identified in this region in arthroscopy. It should be noted, that the Disler *et al..* (3,4) also described the lateral tibial plateau as a difficult region to identify chondral lesions. This difficulty may also be due to the convex surface of the plateau, which, when subjected to sectioning into tomographic coronal and sagittal images, may cause more partial volume effects and imaging artifacts. Magnetic resonance imaging, on the other hand, showed a higher sensitivity (> 90%) to detect defects involving patellar facets and medial femoral and tibial condyles that are relatively thick and smooth, and this result was consistent with those of other studies (3,4,15).

Limitations

There were some drawbacks in the present study. The first was that the orthopaedists had access to the clinical MRI results, which was a possible source of bias in grading during arthroscopy. Second, the size of the sample was fairly small. Third, arthroscopy was an incomplete reference norm since it is based on the operator. Orthopedicians visualized only cartilage surfaces unless the subchondral bone was exposed. Fat saturation was not possible with the 3D FIESTA series, which affected the dynamic range of images. At present, more modern devices with higher field and gradient strengths have been commonly used in the clinical setups (20). Imaging time and image quality could also be enhanced by the updated SSFP sequences used in the recent study (21).

CONCLUSION

Both 3D FIESTA and three 3D gradient echo (3D SPGR) imaging had a similar performance in detecting the chondral lesions. In conclusion,3D FIESTA is a sequence with a good diagnostic performance that is comparable to the 3D SPGR sequence for the assessment of knee cartilage lesions. It is proposed that due to its short acquisition time, it to be incorporated into standard knee MRI protocols.

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