Diagnostic value of 3D FSE CUBE MRI sequence at 1.5 T in internal knee injuries compared to arthroscopy

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Aims and objectives

3D acquisition is now a current MR imaging tool providing MultiPlanar Reformation images by using isotropic voxels and no gap. Complex structures such as ligaments or menisci can be more easily studied with oblique plane reformations.

Until recently, 3D gradient-recalled echo (GRE) acquisitions were used to limit acquisition time \(^1\) \(^2\) and clinical applications were mainly focused on cartilage study \(^3\) \(^4\). Indeed, these sequences have lower contrast resolution for detecting ligaments and meniscal injuries and vulnerability to susceptibility artifacts \(^5\) \(^6\) \(^7\). More recently, 3D Fast Spin Echo (FSE) sequences were introduced through the use of parallel imaging and by refocusing flip angle modulation techniques \(^8\) \(^9\).

 Few clinical studies at 3.0 T have demonstrated that 3D FSE sequences had similar diagnostic performances in evaluation of cruciate ligament tears and meniscal or cartilage lesions \(^10\) \(^11\) \(^12\).

To our knowledge, no report has been published at 1.5 T on symptomatic knees, and reproducibility of the analysis between senior and junior readers has yet to be evaluated.

Thus, the aim of this study was to assess diagnostic performance of a 3D FSE sequence called CUBE for knee exploration at 1.5 T in comparison with arthroscopy. Variability according to the experience of the reader was also evaluated.
Methods and materials

Study group

A retrospective study was conducted on all patients who underwent arthroscopy at our institution between March and October 2011. Among the 386 patients, 108 had a MRI examination of the knee, in 94 cases including a 3D FSE cube sequence. We excluded 16 patients because of an overly long delay between MRI and arthroscopy (up to 6 months) and 4 patients for MRI or lost arthroscopic data. Finally we retrospectively included 74 patients. The local independent research ethics committee approved the study and all patients gave their informed consent to undergo a MRI examination and an arthroscopy.

MR Imaging

MRI examinations were carried out on the same 1.5 T MR unit (Sigma HDx 1.5T, Discovery MR 450; GE Healthcare, Milwaukee, USA) with an eight-channel phased-array knee coil (Invivo, Orlando, Florida, USA).

Protocol varied due to the retrospective pattern of the study: all patients had a 3D FSE Cube sequence, with a T1-weighted sequence (mostly sagittal) but some also had conventional T2-weighted 2D sequences.

The FSE-Cube sequence characteristics were: sagittal acquisition, TR=1600ms, TE=40ms, FOV=18 cm; matrix size=352X520 reconstructed in 520x520; section thickness=0.7 mm; bandwidth=60 kHz; echo train length=32; acceleration factor=2.8. Total acquisition time was 7 minutes. There was no contrast injection.

MRI and reading

MR imaging was independently reviewed by two radiologists: one senior with an experience of 7 years in exclusive musculoskeletal radiology (reader 1) and one junior with 1 year of experience (reader 2). Each was blinded to the clinical diagnosis, first MRI diagnosis (performed at the same time as MRI examination) and arthroscopic report.

Interpretation was carried out on the Advantage Windows Volume Share (GE Healthcare, Milwaukee, USA) workstation. Native images and coronal, sagittal and axial reformatted images with a 1.5 mm partition thickness were read.
The following structures were evaluated: the anterior and posterior cruciate ligaments (ACL and PCL), the medial and lateral menisci (MM and LM), the knee cartilage with its 6 compartments (medial and lateral femoral condyles, medial and lateral tibial plateaus, trochlea and patella).

The ACL and PCL were classified as normal or torn (partial or complete tear).

The meniscal tears were described according to the Crues and Stoller classification (13); Grade 1: Hyperintense punctiform or nodular intrameniscal signal; Grade 2: Linear hyperintensity sometimes extended to the joint capsule but always respecting the meniscal articular surfaces; Grade 3: Hyperintense linear interrupting at least one articular surface (Simple linear lesion or complex morphology). Presence or absence of complex lesion (« bucket handle » or flap) was also noted.

For analysis, meniscal tears were classified as « negative » or « positive » (grade 1 to 3), and dedicated analyses were performed for grade 3, the significant arthroscopic lesions.

ICRS classification (International Cartilage Repair Society) was used for staging each articular surface of the knee (fig 1).

Grade 0: normal; Grade 1: nearly normal (soft indentation and/or superficial fissures and cracks); Grade 2: abnormal (superficial partial-thickness extending down to <50% of cartilage depth); Grade 3: severely abnormal (deep partial-thickness >50% of cartilage depth); Grade 4: full-thickness (through the subchondral bone).

For analysis, the cartilage grades assigned at MR were sorted into 2 classes « no-defect » (grades 0, 1) and « defects » (grades 2, 3, 4) for each area and into « non-high-grade » (grades 0, 1, 2) and « high-grade » (grades 3, 4) for all surfaces combined.

**Arthroscopic knee surgery**

Arthroscopic exploration of the knee was our gold standard. The knee arthroscopies were performed by an experienced orthopedic surgeon (more than 1 000 acts per year) and carried out at our institution. The operator knew the results of the MRI examination when he carried out the surgery. The surgical report was used to obtain final lesion staging.

**Statistical analysis**

Mc Nemar’s tests and Binomial Proportion were used for statistical analysis.
Using arthroscopy as the reference standard, the sensitivity, specificity and accuracy of FSE-Cube in detection of anterior and posterior cruciate ligament tears, medial and lateral meniscal tears and cartilage lesions of each compartment were calculated for each reader.

# tests were used to measure interobserver agreement between reader 1, senior and reader 2, junior, in determination of presence or absence of anterior cruciate ligament tears, medial and lateral meniscal tears and cartilage lesions.

Interobserver agreement was assessed according to the recommendations of Landis and Koch(14), in which a # value of 0.00-0.20 indicates slight agreement; a # value of 0.21-0.40, fair agreement; a # value of 0.41-0.60, moderate agreement; a # value of 0.61-0.80, substantial agreement; a # value of 0.81 to less than 1.00, almost perfect agreement; and # value of 1.00, perfect agreement.

For all statistical tests, differences were considered to be significant if the $p$ value was less than 0.05.
Images for this section:

Figure 1:
Cartilage defects grading with 3D CUBE reformations
(a) grade 0
(b) grade 1 on tibial lateral plateau
(c) grade 2 on patella
(d) grade 3 on medial condyle and tibial plateau
(e) grade 4 on medial condyle and grade 3 on lateral condyle

Fig. 1
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Results

Among the 74 patients included, there were 52 men and 22 women (age range, 17-70 years; mean age, 34.2 years) including 41 right knees and 33 left knees.

According to arthroscopy there were 44 complete ACL tears, 0 PCL tear, 35 medial meniscal tears including 16 complex lesions including 14 "bucket-handle", 11 lateral meniscal tears with 2 complex forms (meniscal flap).

Table 1 gives the results for ligaments and menisci.

Sensitivity was higher in detection of ACL and MM tear with respectively 100% and 97% for reader 1 and 97.7% and 91.4% for reader 2.

Sensitivity for LM tears was 54.5% for reader 1 and 63.6% for reader 2, who was more sensitive but less specific than reader 1.

Sensitivity was better in diagnosis of presence or absence of meniscal tears than in staging the lesion grade, as sensitivity for MM tears, MM grade 3 lesions and LM tears, MM grade 3 lesions was respectively 97%, 88.2% and 54.5%, 54.5% for reader 1 and 91.4%, 82.3% and 63.6%, 45.4% for reader 2.

Sensitivity for diagnosing complex MM tears was better than for complex LM tears with no lesion found.

According to arthroscopy there were 98 cartilage lesions among the 444 articular surfaces analyzed.

Table 2 shows the number of identical gradings between MR Imaging and arthroscopy, all surfaces combined for each reader.

Among the 98 cartilage lesions there were 89.8% low-grade lesions (grades 1, 2 combined) and 10.2% high-grade lesions (grades 3 and 4 combined), corresponding to 2.3% of the 444 knee articular surfaces.

Diagnostic performance in detection of high-grade lesions was better than for low-grade ones for both readers, with sensitivity, specificity and accuracy respectively: 90%, 97.2%, 97% for reader 1 and 90%, 97.7%, 97.5% for reader 2 whereas sensitivities for low-grade lesion were 30.7% for reader 1 and 35.2% for reader 2.

Table 3 reveals that reader 1 reported better sensitivity for detecting cartilage lesions in medial femoral condyle, trochlear and patellar surfaces with respectively 86.7%, 100% and 77.8% than reader 2 with 53.3%, 50% and 55.6%. Both readers reported
low sensitivities for the lateral tibial plateau but higher specificities and accuracy with respectively: 20%, 100% and 94.6% for reader 1 and 40%, 97.1% and 93.2% for reader 2.

There was no significant difference between the two readers in sensitivity, specificity and accuracy for detecting ACL, meniscal tears and high-grade cartilage lesions. There were significant differences in detection of cartilage defects in lateral and medial femoral condyle, medial tibial plateau and patella with $p$ value respectively: $p=0.021$, $p<0.001$, $p=0.002$, $p=0.021$.

Table 4 and 5 gives the interobserver agreement between the two readers for ligaments, meniscal and cartilage lesions. # value was almost perfect in determination of presence or absence of ACL tear, complex and grade 3 MM tear; substantial in detection of presence or absence of MM and LM tear. # value was fair to moderate (0.31 to 0.51) in detection of all cartilage defects and increased for high-grade lesions (#=0.58).
Fig. 1:

Cartilage defects grading with 3D CUBE reformations
(a) grade 0
(b) grade 1 on tibial lateral plateau
(c) grade 2 on patella
(d) grade 3 on medial condyle and tibial plateau
(e) grade 4 on medial condyle and grade 3 on lateral condyle

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Table 1: Sensitivity, Specificity and Accuracy of FSE-Cube in detection of Knee Joint Abnormalities for Each Reader

<table>
<thead>
<tr>
<th>Joint Abnormality*</th>
<th>sensitivity</th>
<th>specificity</th>
<th>accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reader 1</td>
<td>Reader 2</td>
<td>Reader 1</td>
</tr>
<tr>
<td>ACL tear (n=44)</td>
<td>100.0 (92-100)</td>
<td>97.7 (88-99.9)</td>
<td>100.0 (88.4-100)</td>
</tr>
<tr>
<td>MM tear (n=35)</td>
<td>97.0 (85-99.9)</td>
<td>91.4 (77-98)</td>
<td>66.7 (49.8-80)</td>
</tr>
<tr>
<td>MM grade 3</td>
<td>88.2 (72.5-96.7)</td>
<td>82.3 (65.5-93.2)</td>
<td>72.5 (59-87)</td>
</tr>
<tr>
<td>MM complex lesion (n=16)</td>
<td>68.8 (43-91.5)</td>
<td>62.5 (36-85.5)</td>
<td>98.3 (90.6-99.9)</td>
</tr>
<tr>
<td>LM tear (n=11)</td>
<td>54.5 (23.4-83.3)</td>
<td>63.6 (31-89)</td>
<td>95.1 (86.3-98.9)</td>
</tr>
<tr>
<td>LM grade 3</td>
<td>54.5 (23.4-83.3)</td>
<td>45.4 (16.7-76.6)</td>
<td>98.6 (92.5-99.9)</td>
</tr>
<tr>
<td>LM complex lesion (n=2)</td>
<td>0.0</td>
<td>0.0</td>
<td>98.6 (92.5-99.9)</td>
</tr>
</tbody>
</table>

Note. All data are percentages. Numbers in parentheses are lower and upper bounds of binomial Wald 95% confidence intervals.

ACL = anterior cruciate ligament, MM = medial meniscus, LM = lateral meniscus

Fig. 2

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Table 2:

3D-FSE-Cube MR Imaging Grading of Cartilage Surfaces for all surfaces combined compared to Arthroscopy for each reader

<table>
<thead>
<tr>
<th>Arthroscopy</th>
<th>Grade 0</th>
<th>Grade 1</th>
<th>Grade 2</th>
<th>Grade 3</th>
<th>Grade 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reader 1</td>
<td>300</td>
<td>7</td>
<td>34</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Reader 2</td>
<td>41</td>
<td>*1</td>
<td>9</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>0</td>
<td>*17</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>*0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>*5</td>
<td></td>
</tr>
</tbody>
</table>

*The numbers on the diagonal are the numbers of identical grading between MRI and Arthroscopy
On the right of the diagonal are the numbers of over-graded interpretations, on the left are the numbers of under-graded interpretations

Fig. 3

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Table 3:

<table>
<thead>
<tr>
<th></th>
<th>MR Imaging</th>
<th></th>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MFC</td>
<td>MTP</td>
<td>LFC</td>
<td>LTP</td>
<td>T</td>
</tr>
<tr>
<td>arthroscopy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sensitivity</td>
<td>86.7 (59.5-98.3)</td>
<td>60.0 (26.3-87.8)</td>
<td>66.6 (94.4-99.2)</td>
<td>20.0 (0.5-71.6)</td>
<td>100.0 (40-100)</td>
<td>77.8 (40-97.2)</td>
</tr>
<tr>
<td>specificity</td>
<td>72.9 (59.7-83.6)</td>
<td>100.0 (92.5-100)</td>
<td>85.9 (75.6-93)</td>
<td>100.0 (94.8-100)</td>
<td>94.2 (85.8-98.4)</td>
<td>70.3 (57.6-81.1)</td>
</tr>
<tr>
<td>accuracy</td>
<td>75.6</td>
<td>72.9</td>
<td>85.1</td>
<td>94.6</td>
<td>94.5</td>
<td>70.0</td>
</tr>
</tbody>
</table>

reader 2

<table>
<thead>
<tr>
<th></th>
<th>MFC</th>
<th>MTP</th>
<th>LFC</th>
<th>LTP</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>sensitivity</td>
<td>53.3 (26.6-78.7)</td>
<td>70 (34.7-93.3)</td>
<td>66.6 (94.4-99.2)</td>
<td>40.0 (5.3-85.3)</td>
<td>50.0 (6.8-93.2)</td>
<td>55.6 (21.2-86.3)</td>
</tr>
<tr>
<td>specificity</td>
<td>91.5 (81.3-97.2)</td>
<td>87.3 (76.5-94.3)</td>
<td>97.2 (90.2-99.7)</td>
<td>97.1 (89.9-99.6)</td>
<td>92.7 (83.9-97.6)</td>
<td>82.8 (71.3-91.1)</td>
</tr>
<tr>
<td>accuracy</td>
<td>83.8</td>
<td>83.8</td>
<td>89.2</td>
<td>93.2</td>
<td>90.5</td>
<td>78.0</td>
</tr>
</tbody>
</table>

Note. All data are percentages. Numbers in parentheses are lower and upper bounds of binomial Wald 95% confidence intervals.
MFC = medial femoral condyle, MTP = medial tibial plateau, LFC = lateral femoral condyle, LTP = lateral femoral plateau
T = trochlea, P = patella

Fig. 4

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<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ACL</td>
<td>0.97</td>
</tr>
<tr>
<td>PCL</td>
<td>1.00</td>
</tr>
<tr>
<td>MM tear</td>
<td>0.66</td>
</tr>
<tr>
<td>MM grade 3</td>
<td>0.84</td>
</tr>
<tr>
<td>MM complex lesion</td>
<td>0.89</td>
</tr>
<tr>
<td>LM tear</td>
<td>0.65</td>
</tr>
<tr>
<td>LM grade 3</td>
<td>0.45</td>
</tr>
<tr>
<td>LM complex lesion</td>
<td>0.66</td>
</tr>
</tbody>
</table>

**Note.** Data are k-values.  
ACL = anterior cruciate ligament, PCL = posterior cruciate ligament, MM = medial meniscus, LM = lateral meniscus.
Table 5:

Interobserver Agreement for Detecting Cartilage Defects in each compartment

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial Femur</td>
<td>0.31</td>
</tr>
<tr>
<td>Medial Tibia</td>
<td>0.51</td>
</tr>
<tr>
<td>Lateral Femur</td>
<td>0.32</td>
</tr>
<tr>
<td>Lateral Tibia</td>
<td>0.39</td>
</tr>
<tr>
<td>Trochlea</td>
<td>0.48</td>
</tr>
<tr>
<td>Patella</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Note: Data are κ-values.

Fig. 6

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Conclusion

Our study showed that at 1.5 T, a 3D FSE Cube sequence had high sensitivity, specificity and accuracy in detection of the most frequent knee traumatic lesions (ACL and MM tears) with excellent reproducibility whatever the experience of the readers.

MM and ACL tears have appeared to be perfectly assessed by a 3D FSE sequence; Kijowski et al (10) using a 3D FSE Cube sequence (but at 3.0 T) showed an excellent performance with 100%, 98.4% and 99% for respectively sensitivity, specificity and accuracy in detection of ACL injuries and 98.1, 70.8% and 85% for MM tears. These results were similar to those obtained with the "standard" 2D FSE protocol including T1 and T2 imaging, and also with another 3.0 T device for Jung an al. (11). These authors pointed out the interest of MPR reconstructions; 1- compared to conventional sequences, the same performance for diagnosing ACL and meniscal tears can be obtained by using isotropic resolution (fig 2); 2- acquisition time was shorter than for 2D sequences (15). Our results confirmed these data and it should be highlighted that this study was the first one performed in symptomatic knees at 1.5 T.

For Van Dyck et al. in contrary, using 3D SPACE sequence at 3 T is a valuable component but can not be used as a single sequence in the MR evaluation of the knee (16).

If 3D becomes the standard protocol in the knee study (17), 3D FSE should be preferred to 3D GRE sequences, which have shown lower diagnostic performance: sensitivity for diagnosis of ACL tears was only 80% for the 3D WE True Fisp sequence (1) and 91.1% for VIPR-SSFP (2).

However, 3D FSE sequence has appeared to be more limited in diagnosis of LM tears according to our results in which sensibility was lower even if specificity and accuracy remained high. These results confirmed the previous data of several studies demonstrating that LM tears were more difficult to detect: both 3D (10) and conventional 2D sequences were less sensitive(2)(1)(11). Causes of these false negatives were complex and have been discussed; for Smet et al (18) lesion localization and size appeared to have a major impact, indeed they showed that MRI was significantly more sensitive in depiction of lateral meniscal tears when the tear involved more than one third of the meniscus and was significantly less sensitive in depiction of tears in the posterior horn.

It should be underlined that our results were lower than those of previous reports, but also that three of the five missing lesions were found in a retrospective review of these cases (fig 3).
MR diagnosis of a cartilage lesion remains a challenge nowadays. In our study sensitivity, specificity and accuracy of MRI examination were better for high-grade lesions (grade 3 and 4 combined) than for low-grade ones. This has already been observed with conventional 2D sequences (19) and with 3D FSE MR imaging protocol (10) (20). A study on experimental models of porcine knees (21) showed an improvement in detection of low-grade lesions at 3.0 T but this has not been confirmed with either conventional 2D sequences (22) or with FSE-Cube (10).

In our study, a relatively lower sensitivity was observed by both readers in lateral tibial condyle cartilage analysis. Many studies have already described this limit, which is probably related to its thin and convex surface, and the development of new sequences has not altered existing conclusions on this point (23) (24) (25).

Agreement between the 2 readers was good or very good in diagnosis of ACL, MM, LM tears but only moderate in diagnosis of grade 3 of LM tears and there was no significant difference between the readers. From our experience, the oblique reformations allowed by 3D acquisition were of a significant help in diagnosis of some knee lesions, particularly « bucket handle » of the menisci (fig 4). The poor interobserver variability observed in this study is probably partially due to the possibility of reformation. Also, agreements were comparable to the reproducibility between senior readers given in the literature using 2D conventional sequences, 3D FSE at 3.0 T and 3D GRE (20) (10) (11) (1) except for grade 3 of LM tears due to the lower sensitivity of the juniors to this lesion, which is more difficult to diagnose.

In assessment of cartilage, there were significant differences between the two readers and interobserver agreement was fair to moderate. Concerning high-grade lesions, reproducibility was better, and our study with a majority of low-grade cartilage injuries was in accordance with other studies that showed difficult imaging diagnosis of low-grade cartilage lesions (25).

Our study had several limitations. First of all, the relatively small patient population led to a correspondingly small number of cartilage defects and some meniscal lesions, limiting the power of the results. However, this study was comparable to other publications on this point (10) (2) (11) (26). Its retrospective design was clearly another limitation since it introduced a selection bias in the population studied and the design explained why the surgeon was aware of the MRI diagnosis before surgery. However, this protocol complied with the current way of doing; a surgeon usually plans an arthroscopy according to clinical data and to MRI results. In addition, 3D FSE Cube was not compared to standard 2D protocol because knee MRI protocol was variable according to the radiologist in charge of the examination. A large percentage part of MRI examinations were therefore carried
out with only the 3D FSE Cube sequence and a T1 weighted imaging. Lastly, it should be pointed out that arthroscopy is an operative-dependent method.

Our study has shown that FSE-Cube had high diagnostic performance in diagnosing the most frequent knee traumatic lesions (ACL, MM tears) and high-grade cartilage defects without significant difference between an experienced and a less experienced reader, a good specificity and accuracy but lower sensitivity in diagnosis of LM tears and low-grade cartilage defects.

The junior reader had lower sensitivity in detection of cartilage defects than did the experienced reader, with significant differences.

Therefore, 3D FSE could be proposed as an alternative to conventional 2D MRI protocol.
Images for this section:

Figure 2: complete anterior cruciate ligament injuries
(a) standard Fat Sat PDW sagittal; (b, c) 3D- CUBE reformations, (b) oblique sagittal, (c) oblique coronal

Fig. 7

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Fig. 8

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Figure 4: Complex lesion type «bucket-handle» of medial meniscus with 3D-CUBE axial reformation

Fig. 9

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References


