MR Imaging of the Knee using Fat Suppression Technique: A Preliminary Report

Jin Suck Suh, M.D., Mi Hye Kim, M.D., Yong Soo Kim, M.D., Jae Hyun Cho, M.D., Chang Yun Park, M.D., Yeon Hee Lee, M.D.

Purpose: The purpose of this study is to evaluate the usefulness of fat suppression technique for MR imaging of the knee.

Materials and Methods: Twenty-eight knees of 26 patients were imaged at a 1.5 T MR system. Sagittal and coronal T2-Weighted spin echo images (SET2) and sagittal fat suppression SET2 (FSSE) were obtained in all cases. We used a chemical shift imaging method for fat suppression. We compared FSSE with SET2 in terms of the conspicuity of lesions of menisci, cruciate ligaments, cartilage, bone and soft tissue of the knee.

Results: Meniscal lesions were detected on FSSE and SET2 as well. FSSE depicted the lesion more conspicuously in 6 cases. For the depiction of ACL tear, SET2 was superior to FSSE in 5 cases. FSSE was better for the visualization of the normal structure of cartilage and it also depicted the cartilaginous lesions more conspicuously in 3 cases. Though bone bruise could be detected on both techniques, FSSE was better.

Conclusion: FSSE could provide the improved delineation of menisci, cartilage, bone bruise and other soft tissues except the injuries of anterior cruciate ligament. Although FSSE is a reliable method, it can not replace SET2. It may be used as a complementary method in the imaging of the knee.

Index Words: Knee, injuries
Knee, MR studies
Magnetic resonance (MR), comparative studies
Magnetic Resonance (MR), pulse sequences
Magnetic Resonance (MR), technology

INTRODUCTION

Magnetic resonance (MR) imaging has become a useful tool for imaging the musculoskeletal as well as cranial system. Conventional spin-echo (SE) imaging has been most commonly applied for injuries of the evaluation of the knee (1–6) with a 3-dimensional gradient-echo imaging (7–9). Chemical shift imaging technique has also been proposed to be helpful for that purpose with the development of the techniques (10–20).

We prospectively designed this study to compare the clinical efficacy of chemical shift selective (CHESS) presaturation technique with conventional SE technique in the evaluation of the knee.

MATERIALS and METHODS

Materials and imaging methods
A total of 26 patients 28 knees with suspected internal derangement of the knee underwent MR examinations. Arthroscopy was performed in 5 patients within one month after the MR examination. All patients underwent plain radiography whereas only one did arthrography.

All patients were examined prospectively according to a designed protocol with a 1.5 T MR imager (Signa; GE Medical System, Milwaukee USA). All examinations were performed often positioning the knee naturally in the magnet with using a dedicated transmit-receive extremity coil. For a localizer we acquired an
axial SE T1-weighted image (WI) with a repetition time (TR) of 500 msec and echo time (TE) of 30 msec. SE T2-WI (SET2) consisting of TRs of 2500–3000 msec and TEs of 20–80 msec (TR/TE=2500–3000/20–80) was used to obtain sagittal images, followed by SE T2WI with fat suppression (FSSE). Coronal images were obtained by SET2 sequence.

All images were obtained with a matrix size of 256 by 192 or 256 by 256, a field of view of 14–16 cm, and one excitation. The slice thickness was 3 mm, with a interslice gap of 1 mm. For the sagittal plane, we switched the phase and frequency encoding directions to avoid chemical shift artifacts.

For the FSSE we used chemical shifting selective (CHESS) imaging technique which has the component of the frequency selective preparation pulse, followed by a conventional SE sequence. We obtained images of the exactly same plane for comparing FSSE with SET2 sequences. The imaging time with FSSE is equal to that with SET2 when we use an equivalent TR.

**Image Interpretation**

We compared two techniques using the SET2 as a standard reference because it has the known sensitivity and specificity of the menisci and ligaments injuries (1, 2). For the comparison of SET2 and FSSE on the sagittal plane, both images were reviewed by two of the authors (a bone radiology specialist and a resident) at a separate session and they made consensus if the initial interpretation were different. First of all, we undertook an interpretation for the first and the second echo images together, obtained by SET2 sequence on the same plane. And then we did it again for the images by FSSE sequence. We tried to evaluate the quality of

---

**Fig. 1.**

a. The first echo SET2 shows the low signal intensity of cortex and meniscus and tendon. Cartilage has an intermediate signal in contrast to fat (Rectangular cursors are marked for the measurement of the signal intensity).

b. In the second echo FSSE, Cartilage becomes bright and muscle is of intermediate signal.

c. In the first echo FSSE the ACL has become brighter.

---

**Fig. 2.**

The signal difference of the ACL and PCL.

a and b. In the second echo SET2, the PCL is seen having a dark signal uniformly, but the ACL is seen as a broad band having variable signal intensities.

c. In the first echo FSSE the ACL has become brighter.
signal and the clean visualization of structures of the knee. They are medial meniscus (MM), lateral meniscus (LM), anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), cartilage, bone marrow, and soft tissues. When they were pathologic in appearance or signal, we categorized them into two groups, an obvious abnormality and an undetermined lesion. Thereafter we tried to determine which pulse sequence is better for the delineation of lesions and normal structures by comparing both pulse sequences. Meniscus tear was diagnosed when the increased signal in the meniscus extended to the articular surfaces or there was a deformity of meniscus itself. Cruciate ligaments were evaluated for tears. We consider it a tear when the signal of ligaments was not identified (non-visualization) or disrupted, or when the signal in the ACL was highly increased, and when ACL showed anterior concavity with irregular surface (1). The criteria of abnormal cartilage was irregularities on the surface. The bone and bone marrow were considered abnormal when T2WI revealed high signal intensities and alteration of shape at the cortical margin. Soft tissue structures of the knee joint are tendons, bursae, muscles. They were considered abnormal when they had an alteration of normal signal characteristics.

Image analysis
No statistical analysis was underwent because the number of the patients was small.

Calculation of ratio of signal to noise (SNR) and of contrast to noise (CNR).
We also measured the signal intensity (SI) of each structure which was considered normal so as to objectively compare the contrast of the signals from meniscus, ligament, cartilage, joint fluid, and bone between the two pulse sequences. For the measurement we placed a of square shaped region of interest (ROI) and obtained signal intensities using a built-in routine of the MR scanner. And then, SNR of each structure was
calculated by the formula $\text{SNR} = \frac{\text{SI(ROI)}}{\text{the standard deviation of SI (background)}}$. CNR was obtained and transformed it to an absolute value by the formula, $\text{NR} = \frac{\text{SI (ROI 1) } - \text{SI (ROI 2)}}{\text{the standard deviation of SI (background)}}$. 

**RESULTS**

For the detection of signal abnormalities, it is necessary to have a high SNR of each structure and a high CNR of one to adjacent structures. The contrast of one to other structures is different between SET2 and FSSE. The signal and contrast of the FSSE were optimal for the demonstration of the knee. The first echo FSSE showed the high signal intensity of articular cartilage and joint effusion, and the low signal intensity of menisci, tendons, ligaments (except anterior cruciate ligament of intermediate signal intensity), fat and medullary bone (Fig. 1, 2). The muscles showed the intermediate signal intensity. The second echo FSSE was not as good as the first echo FSSE because the former revealed reduced SNR with a poor visualization of the normal structure except distinguishing articular cartilages from joint fluid which had a bright signal.

The results of a SNR and CNR were shown in normal structures (Fig. 3–7). The SNR was high in cartilage, fluid, and ACL on the first echo FSSE (Fig. 3). The contrast between menisci and adjacent cartilage and fluid was better in the first echo FSSE than the other images.

**Fig. 7.** The CNRs between fluid and the ACL and PCL are represented. The second echo SET2 is the highest.

**Fig. 8.** Lateral meniscus tear with incomplete discoid appearance in the patient having the intermittent knee pain which has began during the volleyball.

- a. In the first echo SET2, meniscal tear is well disclosed.
- b. Excellent contrast between tear containing fluid and meniscus is observed in the FSSE.

**Fig. 9.** Abnormal signal in the medial meniscus.

- a. In the first echo SET2, the meniscus looks like having a type 2 signal.
- b. In the first echo FSSE, this linear signal is abutting the inferior articular surface of the meniscus. This abnormality has not yet confirmed by arthroscopy.
Jin Suck Suh, et al.: MR Imaging of the Knee using Fat Suppression Technique

(Fig. 5). The contrast between cartilage and either medullary bone or meniscus was superior in the first echo FSSE to that of SET2 (Fig. 6). The CNR of fluid to cruciate ligaments is high in the SET2 (Fig. 7).

A total of 28 knees was included for comparing FSSE with SET2 sequences. Twenty-one patients had one or more history of trauma before the MR examination, with a duration of ranging from 24 days to several years.

A summary of the results is provided in Table 1. There were 18 meniscal tears, 10 involving medial meniscus and 8 involving lateral meniscus. Three lateral menisci which had a tear were discoid appearance. For the meniscal tear, FSSE revealed a tear ap-

Fig. 10. ACL partial tear in the patient, who is a basketball player, with knee injury two months before the MR examination.

a. In the second echo SET2, ACL tear can be well identified, surrounded by bright signal of the joint fluid.
b. In the first echo FSSE the signal of the ACL is not distinguished from the fluid as well as SET2.

Fig. 11. A Partial tear with hematoma in the PCL. (a) In the second echo SET2 and (b) in the second echo FSSE, high signal is seen well in contrast to the dark signal intensity of the PCL.

Fig. 12. Well visualization of hyaline cartilage in the patient with complaint of intermittent knee pain.

a. In the first SET2, intermediate signal is seen in hyaline cartilage.
b. In the first echo FSSE, the signal of articular cartilage is very high, resulting in excellent contrast between the articular cartilage and bone and meniscus.
Table 1. Summary of the SET2 and FSSE in 28 Knees

<table>
<thead>
<tr>
<th>Findings</th>
<th>SET2</th>
<th>FSSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>17</td>
<td>18</td>
</tr>
<tr>
<td>Undetermined</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Tear</td>
<td>37</td>
<td>36</td>
</tr>
<tr>
<td>ACL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>Undetermined</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Tear</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>PCL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>27</td>
<td>26</td>
</tr>
<tr>
<td>Undetermined</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Tear</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Cartilage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>14</td>
<td>23</td>
</tr>
<tr>
<td>Poor</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Abnormal</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Soft tissue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Undetermined</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Abnormal</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Bone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>25</td>
<td>21</td>
</tr>
<tr>
<td>Undetermined</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Abnormal</td>
<td>0</td>
<td>6</td>
</tr>
</tbody>
</table>

Apparently in 6 cases better than SET2 did because a tear had better contrast in the former than in the latter (Fig. 8). One showed a tear with FSSE but it appeared in the undetermined category with SET2 (Fig. 9). In the remaining 5, we already read as to meniscal tears with agreement. As we use the arthroscopic findings as a gold standard in 5 cases, 2 tears and 3 normal of the medial meniscus, they were well correlated with the MR interpretation. For the lateral meniscus we did not find a radial tear (false negative). Of the remaining 4 there were one normal and 3 tears confirmed arthroscopically (Table 2).

Of the 28 ACLs, 20 were normal, 5 had tears, and 3 were undetermined. SET2 gave more confidence than FSSE in the diagnosis of normal ACLs in 5 of 20 normal ACLs. Among 5 tears, only one showed better delineation of tear with SET2 than FSSE (Fig. 10). There was only one PCL lesion which had a hematoma or fluid collection within the PCL (Fig. 11). Both ACL and PCL were correctly disclosed on MR images in the 5 cases confirmed arthroscopically. There was only one partial tear of ACL, whereas others were normal.

We made an agreement that femoral cartilages were normal in 23 knees and abnormal in 4 and 1 was in gingly. The cartilage was normal in 12 cases (Fig. 12) and there were 3 cartilaginous abnormalities. The images with fat suppression was better than those without fat suppression. Five cases of arthroscopically confirmed abnormality were normal on MR images. We did not try to evaluate MR images for patella and tibial cartilages.

We found soft tissue abnormalities such as a pes anserinus bursitis (Fig. 13), patellar tendon injury, prepatellar soft tissue thickening, ganglion, and popliteal cyst. Two of these were distinct in nature of the lesion on FSSE.

Six of the 28 knees showed abnormally in increased signal within the bone on FSSE (Fig. 14), whereas only 3 showed equivocal change in signal intensities on SET2. Although these signal changes of medullary bone in contrast to the adjacent normal looking signal have been not proven histologically or by the follow-up studies, these were considered to be either hemorrhage or edema which were probably related to previous trauma or chronic stress. MR imaging has an advantage for detecting the abnormal soft tissue and bone abnormalities over the arthroscopy.

**DISCUSSION**

Chemical shift imaging may allow an improved contrast between lesions and normal structures by way of...
Table 2. Comparison of SET2 and FSSE with Arthroscopic Findings in Five Patients

<table>
<thead>
<tr>
<th>Findings</th>
<th>Arthroscopy</th>
<th>( T^- )</th>
<th>( F^- )</th>
<th>( T^+ )</th>
<th>( F^+ )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial meniscus tear</td>
<td>SET2</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>FSSE</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Lateral meniscus tear</td>
<td>SET2</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>FSSE</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>ACL</td>
<td>SET2</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>FSSE</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>PCL</td>
<td>SET2</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>FSSE</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

\( T^- \) = True Negative, \( F^- \) = False Negative, \( T^+ \) = True Positive, \( F^+ \) = False Positive

ABBREVIATIONS:
- BM: bone marrow
- CART: cartilage
- FAT: fat
- MS: meniscus
- MC: muscle
- FL: fluid
- ACL: anterior cruciate ligament
- ACL1: anterior cruciate ligament upper half
- ACL2: anterior cruciate ligament lower half
- PCL: posterior cruciate ligament
- FAT2: fat signal near the cruciate ligaments
- SNR: signal-to-noise ratio
- CNR: contrast-to-noise ratio
- BG: background
- PWI: proton density weighted image
- T2WI: T2-weighted image
- PWI + FS: proton density weighted image with fat suppression
- T2WI + FS: T2-weighted image with fat suppression
- ET2: T2-weighted spin echo image
- SSE: fat suppression T2-weighted image

Eliminating high signal of fat in the anatomic regions where abundant fat appears. Various techniques of fat suppression have been applied in clinical use. It is possible to eliminate the signal from fat because fat and water have slightly different resonant frequencies. Methods using a phase sensitive implementation are Dixon method, a chopper fat suppression, and three-point Dixon technique(11-15). By the Dixon method both in-phase and out-of-phase images can be obtained. But the disadvantage is a long post-processing time. With a chopper fat suppression, the limitation of prolonged post-processing time can be solved. A technique saturating one chemical component before pulse sequence is a chemical shifted selective (CHESS) presaturation method(16). This technique is simple and widely used in clinical imaging even though it has a disadvantage of inhomogeneous suppression of fat signal inspite of either the careful shimming of magnet or modification of presaturation pulse, or both(17). Sometimes, hybrid techniques have been proposed for complete suppression of fat(18, 19). Another technique is a short tau inversion recovery(STIR) pulse sequence in which the appropriate inversion time is applied to null out fat signal(20). The drawback is a small number of slices we can get in a given TR time.

Since MR imaging has been used for the evaluation of knee pathology, its roles have been described(3, 4). The overall agreement between MR and arthroscopic findings has been reported to be over 90%(5). Various grading systems of meniscal injury have been reported(6, 7). Pseudotears in lateral menisci on sagittal images were demonstrated with emphasis on the orientation of the meniscofemoral ligaments(21). In asymptomatic volunteers, the grade 2 signal of the menisci were well correlated with the age of patients, and early appearance of the signal abnormalities began during the second decade(22). The signal change of the menisci can occur with uncertain significance after repetitive impulsive loading caused by jogging(23). The efficacy of MR imaging of ACL injuries including MR criteria of ACL tear was described in detail(1).
MR imaging after ACL reconstruction was well correlated with arthroscopic results. MR imaging is useful in the assessment of the status of the osteochondral lesions, occult subcortical osteochondral fractures, and lateral tibial rim (Segond) fractures.

Some investigators compared different imaging techniques to determine which one was better or worse. There were no difference between T1- and T2-weighted SE imaging for the meniscal evaluation. Some prefer 3D MR imaging to 2D SE imaging for the detection of meniscal or ligamentous injuries or both because the former has an advantage of the thin, contiguous section as well as high patient throughput. Others thought that 2D SE and 3D gradient echo imaging had a complementary role for the evaluation of the internal derangement of the knee.

Little have been reported about the knee MR imaging using fat suppression techniques. The fat suppression techniques can provide good contrast resolution in the region where high signal of the abundant fat obscures lesions, and can eliminate the chemical shift misregistration problems at tissue interfaces. The chemical shift selective (CHESS) imaging technique, as we had used, can simply be applied to almost all imaging techniques commercially available. Hyaline cartilage invariably appears bright on both T1- or T2-weighted images with fat suppression so that articular cartilage is ready to be distinguished from cortical bones, fat, and muscles. Although other authors had difficulties in distinguishing muscle and hyaline cartilage or fluid and cartilage, we didn’t met any problems to distinguish cartilage disorders from fluid. That was because we used a longer TR than that they used. There is no difference between two techniques for the meniscal lesions, but in our experience, the contrast between menisci and articular cartilage is superior on fat suppression images. We could have a confidence in the detection of bone bruises and subcortical lesions which could not be disclosed on conventional SE images. We have to be cautious to tell the ACL tear, because even normal ACL may appear bright.

Our study has some limitations: the number of cases included was small; arthroscopic findings were available in only 5 cases; as we reviewed SET2, this could give rise to potential interpretation bias.

In summary, FSSE provides us the improved delineation of menisci and cartilaginous abnormalities as well as soft tissue abnormalities. However, FSSE did not revealed significant abnormalities of anterior cruciate ligament because this ligament had a lower CNR than the adjacent structures. Fat suppression images proved to be excellent to reveal the bone marrow changes. So, we concluded that FSSE sequence was a reliable complimentary method, but not a method of choice replacing SET2 sequence for the evaluation of knee.

REFERENCES

지방 신호 억제방법을 이용한 슬관절의 자기공명영상: 예비보고

서진석 · 김미혜 · 김용수1 · 조재현 · 박창윤 · 미연희

연세대학교 의과대학 진단방사선과학교실
1인제대학교 의과대학 방사선과학교실

목적: 자기공명영상 방법을 사용하여 슬관절의 병변을 진단하려고 할때 통상적인 스피어스코 방법과, 지방신호억제를 병행한 스피어스코 방법의 차이점을 알아보고자 하였다.

대상 및 방법: 슬관절의 병변이 의심되는 26명의 환자 (28슬관절)에게 1.5T 자기공명영상 장치를 사용하여 시상면을 따라 통상적인 스피어스코 방법과, 지방신호억제를 병행한 스피어스코 방법을 시행하여 영상을 얻었다. 지방억제 방법은 화학이동 선택공명(CHESS)방법을 사용하였다. 두 방법의 동일면 영상을 비교할때, 반월판 연골, 십자인대, 관절연골, 골 및 연부조직의 병변 유무와 확실성(Conspicuity)에 중점을 두었다.

결과: 지방신호억제 방법을 이용한 영상에서 반월판 연골, 관절연골, 골 및 연부조직의 병변을 좀더 잘 관찰할 수 있었다. 그러나 전 십자인대의 병변관찰에는 통상적인 스피어스코 방법이 좋았다.

결론: 저자들은 지방신호억제를 병행한 스피어스코 방법과 통상적인 스피어스코 방법은 슬관절의 병변을 진단하는데 상호 보완적인 역할을 할 것으로 사료 된다.
1994년도 국제 학술대회 일정표 [Ⅲ]

1994년 06월 05일 ~ 09일
**Cirse '94 — Cardiovascular and Interventional Radiological Soc. of Europe**
venue: Aghia Pelagia Crete, Greece.
contact: Mrs. B. Läublia, Ex. Dir. C.I.R.S.E.,
P.O. Box 201, 8028 Zurich, Switzerland.
(tel: 41 - 1 - 2622404; fax: 41 - 1 - 2610578) [DD4697]

1994년 06월 12일 ~ 14일
**European Congress on Medical Radiology**
venue: Kongressent. Folkets Hus Oslo, Norway.
contact: Christine B. Askim, Help Arrangement — Service,
P.O. Box 597, 1301 Sandvika, Norway.
(tel: 47 - 2 - 519012; fax: 47 - 2 - 540058)

1994년 06월 15일 ~ 19일
**27th Annual Conf. and Postgraduate Course in Head and Neck Radiology**
venue: Washington D.C., USA.
contact: Ms. Beth A. Filip, Am. Soc. Head & Neck Radiol,
2210 Midwest Road, Oak Brook, IL 60521, USA.
(tel: 1 - 708 - 5740660; fax: 1 - 708 - 5740661)

1994년 07월 12일 ~ 14일
**Esdir Seminar — Neuroradiology and Neuroscience**
venue: Marseille, France.
contact: Prof. L. Passariello, University “La Sapienza”,
Policlinico Umberto I, 00199 Rome, LI, Italy.
(tel: 39 - 6 - 445602; fax: 39 - 6 - 490243) [DD0865]

1994년 07월 17일 ~ 22일
**7th Triennial congress World fed. For Ultrasound in Medicine and Biology**
venue: Sapporo Park Hotel Sapporo, Japan.
contact: Dr. Morimichi Fukuda, MD, Sapporo Medical College,
(tel: 81 - 11 - 6112111; fax: 81 - 11 - 6128443) [DD4075]

1994년 08월 06일 ~ 12일
**13th Annual Meeting of the Society of Magnetic Resonance in Medicine**
venue: San Francisco Hilton & T. San Francisco, CA, USA.
contact: SMRM Business office, Suite 3C,
1918 University Avenue, Berkeley, CA 94704, USA.
(tel: 1 - 510 - 8411899; fax: 1 - 510 - 8412340)

1994년 08월 14일 ~ 19일
**16th Intern. Conf. on Magnetic Resonance Biological Syst.**
venue: Koningshof Veldhoven, The Netherlands.
contact: Mrs. A. Manders, Koningshof,
P.O. Box 140, 5500 AC Veldhoven, The Netherlands.
(tel: 31 - 40 - 537475; fax: )