Visualization of the Knee Using MRI: Evaluation of Double-Echo Steady-State Sequence

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1. INTRODUCTION

In recent years, magnetic resonance imaging (MRI) has become a powerful tool for evaluating disorders of the knee. The major advantage of MRI is that it is a totally non-invasive procedure with superior soft tissue contrast resolution and multiplanar capabilities. Therefore, the use of MRI to diagnose internal derangements of the knee joint has been well documented in a number of articles dealing with normal anatomy1, 2), osteochondritis dissecans3), and injuries of the menisci4-10) and ligaments11-19).

The two-dimensional (2D), multisection, spin-echo (SE) pulse sequence is a well-established, highly accurate technique for evaluating disorders of the knee. However, this type of sequence requires a relatively long period of data acquisition. Therefore, the 2D fast spin-echo (FSE) sequence has recently been used as a successful alternative to the SE pulse sequence, permitting, at least in principle, the acquisition of images with contrast similar to that on SE images. It is based on rapid acquisition with the repeated echoes (RARE) sequence, first described by Henning, et al20). However, it is known that each sequence produces a different magnetic transfer contrast21, 22) and different image quality due to blurring, which is caused by T2 decay attenuation of the later echoes used for the collection of high-spatial-frequency data at the edges of the K-space23).

The gradient-echo (GE) sequence is also frequently used. This sequence in particular generates images that exhibit both high contrast among articular tissues and high spatial resolution. We have been using the FISP (fast imaging with steady-state precession) sequence for knee joints.

The double-echo steady-state (DESS) sequence, a technique for contrast improvement for differentiating fluid from tissue in the knee, has recently been implemented on commercial MRI systems manufactured by Siemens (Germany).

Summary

The double-echo steady-state (DESS) sequence is a technique for contrast improvement for differentiating fluid from tissue in the knee. This study was designed to evaluate the performance of the DESS sequence in detecting structures in the knee in comparison with other sequences. The same asymptomatic knees were imaged in both the sagittal and coronal planes using various pulse sequences: T1-, T2- and proton density-weighted spin echo, T2-weighted fast spin echo, three-dimensional FISP and three-dimensional DESS. Our results suggest that DESS imaging provides good visualization and satisfactory diagnosis for the any structure in the knee, and is especially useful for evaluation of cartilage and joint effusion. Furthermore, as this sequence provides three-dimensional acquisition, it is possible to generate the required planes using the multiplanar reformation technique.

Key words: Magnetic resonance imaging, Asymptomatic knee, Double-echo steady-state (DESS), Visualization
In the present study, we compared the visualization and interpretation of several structures in the knee using the SE, FSE, FISP and DESS sequences, and then determined the value of the DESS sequence for the visualization of tissue in the knee joint.

2. DESS SEQUENCE

The primary purpose of this technique is to increase the signal-to-noise ratio (SNR) and T2* contrast for 3D knee imaging without increasing scanning time in the FISP sequence. Each steady-state sequence generates two signals with different contrast behavior, the FISP signal and the PSIF signal, within one repetition time interval. Usual steady-state sequences like FISP or PSIF use either one of these signals, while the other is suppressed. However, it is possible using an additional compensating gradient to rephase both signals. The principle of the new sequence is to use both signals within one TR time, and in this way increase the SNR and contrast. The characteristic of this contrast is that it has both FISP contrast and T2* contrast from PSIF. In addition, the increase in SNR can be up to $\sqrt{2}$. A timing diagram of this sequence is shown in Fig. 1.

3. MATERIALS AND METHODS

All imaging was performed at 1.0 T on a Magnetom impact unit (Siemens) with a transmit/receive extremity coil. The asymptomatic knees of three subjects were imaged by various pulse sequences in both the sagittal and coronal planes. Six imaging sequences were used: T1-weighted SE (spin echo), T2-weighted SE, proton density-weighted SE, T2-weighted FSE (fast spin echo), three-dimensional (3D)-FISP and 3D-DESS. The TR (repetition time), TE (echo time), FA (flip angle), ETL (echo train length), NEX (number of acquisitions) and acquisition time of each sequence are indicated in Table 1. All SE sequences were created with the same acquisition time. A section thickness of 4 mm, matrix size of 256x256 pixels and 16 cm field of view were used. The 3D images were created at 4 mm thickness using multiplanar reformation.

Each image was printed with a laser printer (Kodak) and evaluated by six radiologists. Visualization of eight structures in the knee (anterior cruciate ligament, posterior cruciate ligament, medial collateral ligament, lateral collateral ligament, meniscus, hyaline articular cartilage, joint effusion and gastrocnemius muscle) was assessed by the observers and scored on a scale of 1-4 according to the following criteria: excellent, the entire image of the structure was excellently visualized; good, the entire image of the structure was well visualized and sufficient for diagnosis; fair, the entire image of the structure was incompletely visualized but was sufficient for diagnosis; poor, no image of the structure was visualized and diagnosis was impossible. The images used in the evaluation are shown in Figs. 2 and 3.

4. RESULTS

The results of evaluation are shown in Table 2 in the form of average scores for the six observers. Evaluation of the results for the ligaments (ACL, PCL and MCL) showed that T1-weighted SE, T2-weighted SE and proton density-weighted SE images provided good visualization. DESS and FISP images of the ligaments did not

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Table 1: Timing parameters for each sequence.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>TR (ms)</th>
<th>TE (ms)</th>
<th>FA (°)</th>
<th>ETL</th>
<th>NEX</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2WI (SE)</td>
<td>500</td>
<td>15</td>
<td></td>
<td>2</td>
<td>4:20</td>
<td></td>
</tr>
<tr>
<td>T2WI (SE)</td>
<td>2500</td>
<td>80</td>
<td></td>
<td>1</td>
<td>4:24</td>
<td></td>
</tr>
<tr>
<td>PDWI (SE)</td>
<td>2500</td>
<td>20</td>
<td></td>
<td>1</td>
<td>4:24</td>
<td></td>
</tr>
<tr>
<td>T2WI (FSE)</td>
<td>4700</td>
<td>128</td>
<td>23</td>
<td>5</td>
<td>3:59</td>
<td></td>
</tr>
<tr>
<td>DESS</td>
<td>28</td>
<td>9</td>
<td>40</td>
<td>1</td>
<td>7:41</td>
<td></td>
</tr>
<tr>
<td>FISP</td>
<td>30</td>
<td>10</td>
<td>40</td>
<td>1</td>
<td>8:14</td>
<td></td>
</tr>
</tbody>
</table>

Note: SE = spin echo, FSE = fast spin echo, TR = repetition time, TE = echo time, FA = flip angle, ETL = echo train length
Fig. 2  Sagittal images used for visual evaluation.  
(a) T₁-weighted image using spin echo (SE).  
(b) T₂-weighted image using fast spin echo (FSE).  
(c) T₂-weighted image using SE.  
(d) DESS image.  
(e) FISP image.  
(f) Proton density-weighted image using SE.

Fig. 3  Coronal images used for visual evaluation.  The parameters of each image are the same as in Fig. 2.

have sufficient contrast, but allowed diagnosis. For the meniscus, T1-weighted SE and proton density-weighted SE images were excellent, and DESS, FISP and T2-weighted images provided good visualization and were satisfactory for diagnosis. For cartilage, on the other hand, DESS and FISP images provided excellent visualization, and both the T1-weighted and proton density-weighted images were good. However, T2-weighted images did not allow visualization and diagnosis was impossible. In the evaluation of joint effusion, DESS and T2-weighted images were excellent, whereas the T1- and proton density-weighted images provided no visualization. T2-weighted images gave the best visualization of muscle.

Overall, DESS images provided good visualization and were satisfactory for diagnosis of any structure in the knee.

5. DISCUSSION

MR imaging is generally accepted as an excellent, noninvasive modality for screening for internal derangements of the knee. This has helped to shift the role of arthroscopy from diagnosis toward therapeutic intervention. Several studies have reported sensitivities of greater than 90% for MR imaging in detecting tears of the anterior cruciate ligament and meniscus, arthroscopy being the gold standard\textsuperscript{13, 19}. In addition, the diagnostic ability of several sequences and their optimization has been investigated\textsuperscript{6, 24, 25}. However, no universally applicable sequence has been reported. This is perhaps due to differences in the visualization of various structures in the knee with each sequence. For example, whereas the meniscus is very well visualized on T1-weighted images, joint effusion is not revealed. Similarly, for T2-weighted images, ligaments are clearly visualized but cartilage is not.

Therefore, an attempt was made to assess the visualization of certain structures in the knee for each of these sequences.

It was found that for ligaments, T1-, T2- and proton density-weighted SE images provided high visualization. For the meniscus, T1- and proton density-weighted SE images were excellent. For cartilage, DESS and FISP images provided good visualization. For evaluating joint effusion, DESS and T2-weighted images were excellent. For muscle, T2-weighted images provided the best visualization.

### Table 2 Visualization of structures in the knee using six sequences.

<table>
<thead>
<tr>
<th>Structure</th>
<th>T1WI (SE)</th>
<th>T2WI (FSE)</th>
<th>T1WI (SE)</th>
<th>PDWI (SE)</th>
<th>DESS</th>
<th>FISP</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCL</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>△</td>
<td>△</td>
</tr>
<tr>
<td>ACL</td>
<td>○</td>
<td>○</td>
<td>△</td>
<td>△</td>
<td>△</td>
<td>△</td>
</tr>
<tr>
<td>MCL</td>
<td>○</td>
<td>○</td>
<td>△</td>
<td>△</td>
<td>△</td>
<td>△</td>
</tr>
<tr>
<td>LCL</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Meniscus</td>
<td>○</td>
<td>○</td>
<td>△</td>
<td>△</td>
<td>△</td>
<td>△</td>
</tr>
<tr>
<td>Cartilage</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Joint effusion</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Gastrocnemius</td>
<td>○</td>
<td>○</td>
<td>△</td>
<td>△</td>
<td>△</td>
<td>△</td>
</tr>
</tbody>
</table>

Note: ○ = excellent, △ = fair, × = poor
PCL = posterior cruciate ligament, ACL = anterior cruciate ligament, MCL = medial collateral ligament, LCL = lateral collateral ligament

On the other hand, certain structures were not visualized or visualized poorly by each of the sequences, for example, joint effusion using the T1- and proton density-weighted images, and cartilage using T2-weighted images. However, DESS images successfully visualized all structures in the knee, and were thus universally applicable.

Therefore, we consider the DESS sequence best for initial screening, followed by selective use of, for example, T1-, T2- and proton density-weighted images for detailed visualization. In addition, the DESS sequence provides excellent visualization of articular cartilage in the knee, and thus may be selected for patients with suspected articular cartilage disease.

Furthermore, as the DESS sequence is generated using thin-partitioned three-dimensional acquisition, it has high spatial resolution. The advantages of 3D acquisition methods are the lack of gaps between imaging planes and the ability to reformat the required data sets into arbitrarily oriented planes. Using the multiplanar reformation (MPR) technique, the operator can generate the required planes. For example, oblique planes of the angle of the anterior or posterior cruciate ligament can be produced for accurate diagnosis (Figs.4-6).

The present results show that the DESS imaging technique has three important features. First, it is able to visualize all structures in the knee, and therefore can be used for screening studies. Second, DESS is especially useful for the evaluation of cartilage and joint effusion. In addition, this technique can be used with thin-partitioned three-dimensional acquisition and offers the required planes for using the MPR technique.

In summary, this technique may improve the accuracy of MR diagnosis of the knee. The results of visualization using various MR sequences were evaluated for the
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Fig. 4  Oblique sagittal image obtained using the multiplanar reformation (MPR) technique. Axial scan image showing orientation of the slice. The whole length of the anterior cruciate ligament is well visualized.

Fig. 5  Oblique sagittal image obtained using the MPR technique. The whole length of the posterior cruciate ligament is well visualized.
normal knee. Therefore, visualization may differ with internal derangement of the knee. Clinical images of the DESS sequence are shown in Figs.7-9.

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REFERENCES

20) Henning J, Nauerth A, Friedburg H: RARE imaging: a fast...
膝関節MRIの抽出能—DESSシーケンスの有用性—

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膝関節疾患におけるMRI診断の有用性については、多くの報告があり、また有用なシーケンスもいくつか発表されている。しかしながら、それらのシーケンスの膝関節を構成する各組織に対する抽出能については、明確であるとはいいえない。今回、シーメンス旭メディテック株式会社より新しいシーケンス（DESS）がリリースされた。このシーケンスによる膝関節内の各組織間の抽出能を既存のシーケンスと比較することにより、検討を行った。正常ボランティアによる膝関節をT₁WI, T₂WI, PDWI, T₂FSE, 3D-FISP, 3D-DESSを用いて、それぞれの抽出能に対し評価を行った。結果として、靭帯や半月板の抽出能において、T₂WI, PDWIのSEはFISPやDESSよりも優れていた。しかし、関節軟骨や関節液に対してはDESSが優れていた。また、各シーケンスのみでは、抽出不可能な部位が存在したが、DESSはすべての部位組織が抽出可能であった。以上のことより、DESSは、スクリーニング目的の第1選択肢として有用であるとともに、3D撮像であることより、任意の断層面がMPRにより再構成可能であり、有用なシーケンスと考える。