90 ° -Flip-angle three-dimensional double-echo
steady-state(3D-DESS)magnetic resonance
imaging of the knee:Isovoxel cartilage imaging
at 3T

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**90°-flip-angle three-dimensional double-echo steady-state
(3D-DESS) magnetic resonance imaging of the knee:**

Isovoxel cartilage imaging at 3 Tesla

Purpose:

The purpose of this study was to investigate whether 3D-double echo steady state (3D-DESS) with improved contrast by setting the FA (Flip angle) at 90° is useful in 3D isotropic cartilage imaging of the knee at 3 T.

Materials and Methods:

Imaging was performed in 10 healthy volunteers using 3 methods: with 3D-DESS using FA of 25° and 90°, and with true fast imaging with steady-state precession (True-FISP). The signal-to-noise ratio (SNR) of the synovial fluid and cartilage, and contrast-to-noise ratio (CNR) were measured, and mean values were compared. Visual assessment of artifacts was performed with the cartilage divided into 6 regions.

Results:

There were no significant differences in synovial fluid SNR in the comparison between FA-90° 3D-DESS and True-FISP ($P=0.364$). A significantly higher cartilage SNR was observed with FA-90° 3D-DESS than with True-FISP ($P=0.031$). There were no significant differences in synovial fluid-cartilage CNR between FA-90° 3D-DESS and True-FISP ($P=0.892$). In the evaluation of artifacts, FA-90° 3D-DESS imaging showed a significantly higher score than True-FISP imaging in the patella and trochlea cartilage ($P<0.001$, $P<0.002$).

Conclusions:

FA-90° 3D-DESS is useful in 3D isotropic cartilage imaging of the knee at 3 T.

Key words: MRI, knee, cartilage, 3D isotropic imaging, artifact, 3Tesla

Introduction

Magnetic resonance imaging (MRI) is the most important modality in assessing degenerative cartilage lesions of the knees, and there are many MR imaging techniques (1). With recent advances in 3T MR scanners, various high-resolution 3D isotropic cartilage imaging techniques have been reported (2–4).

3D-double echo steady state (3D-DESS) (5–8) and true fast imaging with steady-state precession (True-FISP) (9–11) are clinically used in morphological evaluation of cartilage. These two sequences show synovial fluid with high signal intensity and cartilage with lower signal intensity. Cartilage surface lesions are detected by differences in contrast between synovial fluid and cartilage (12).

Both sequences are reported to have advantages and disadvantages. Accurate and precise analysis of cartilage morphology in the femorotibial joint is reported to be possible with 3D-DESS at 3.0 T (8). 3D-DESS is also used for long-term cartilage evaluation by the Osteoarthritis Initiative (13). However, several reports have suggested that 3D-DESS imaging has lower cartilage-synovial fluid contrast, which makes assessment of cartilage surface lesions more difficult than other sequences (6, 7, 14). True-FISP, on the other hand, is reported to have the advantage of high synovial fluid-cartilage contrast (9). It has also been investigated in comparison with other sequences commonly used for knee imaging, and is considered to have a comparable diagnostic performance for knee cartilage imaging (9). However, True-FISP has the disadvantages of susceptibility to magnetic field nonuniformity and the presence of banding artifacts, which may degrade the imaging quality for evaluation of meniscus or cartilage (3).

3D-DESS with flip angle (FA) set at 90° for 3D isotropic cartilage imaging would avoid the above disadvantages. One reason is that whereas 3D-DESS is generally used with FA set at 20° to 40°, there have been several reports showing that the cartilage-synovial fluid CNR is higher with a setting of 90° (7, 15). Another reason is that 3D-DESS imaging is considered to have fewer artifacts than True-FISP imaging (3). We hypothesized that if FA-90° 3D-DESS was shown to have a signal-to-noise ratio (SNR) and cartilage-synovial fluid contrast comparable to that of True-FISP in each tissue, and have fewer artifacts, then it would be useful in assessments of knee cartilage by 3D isotropic cartilage imaging.

In this study, 3D isotropic cartilage imaging of the knee was performed with three techniques, FA-25° 3D-DESS, FA-90° 3D-DESS and True-FISP. Image contrast and artifacts were then compared with the purpose of investigating whether FA-90° 3D-DESS is useful in cartilage assessment at 3 T.

Materials and methods

Subjects

Subjects were 10 healthy volunteers (5 men, 5 women; mean age, 32 years; range, 25–44 years). All subjects were considered to be healthy and had no pain in the knee joint or other health conditions. None had major injury in the past or a history of playing contact sports. The study protocol was designed in accordance with the Declaration of Helsinki of 1975, as revised in 1983. The study protocols were approved by the ethics committee of our clinic. Written informed consent was obtained from all subjects.

Imaging

In all subjects, the knee joints were imaged using a MAGNETOM Skyra 3.0T (Siemens, Erlangen, Germany) with a 15 channel knee coil. The imaging plane was the midsagittal plane for all subjects.

Three imaging sequences (FA-25° 3D-DESS, FA-90° 3D-DESS and True-FISP) were used for all subjects (Fig. 1). The reasons for using FA-25° 3D-DESS imaging was that the FA-25° setting is the standard imaging condition for 3D-DESS (8,13,14). The sequence parameters were similar to those used in a previous study comparing 3D-DESS and True-FISP (3). In this case, the imaging time was adjusted to be nearly equal (6 min 06 s, 6 min 03 s) in order to allow comparisons of the two sequences. Detailed imaging parameters for True-FISP and 3D-DESS are shown in Table 1.

Image evaluation

Images obtained with FA-25° 3D-DESS and FA-90° 3D-DESS and True-FISP were assessed using two different methods: 1. Cartilage SNR, synovial fluid SNR, and synovial fluid-cartilage contrast-to-noise (CNR) ratio was calculated and mean values were compared; and 2. Visual assessment of the artifacts was performed for each sequence.

Analysis of regions of interest

Regions of interest (ROIs) were set in the synovial fluid, cartilage and background, and the signal intensity of each tissue was measured with OsiriX software version 3.3.1 on a regular Mac OS X computer (Cupertino, CA). ROIs were set so that they contained

at least 100 pixels without any apparent artifacts. The location and size of the ROI were the same in each subject. The SNR of each tissue was calculated by dividing the signal intensity by 1.5 times the standard deviation of the background. The synovial fluid-cartilage CNR was defined as the difference in the SNR of the synovial fluid and cartilage. These calculation and measurement methods are the same as those used in a previous study that compared 3D-DESS and True-FISP (3).

Visual evaluation

The images obtained with FA-25° 3D-DESS, FA-90° 3D-DESS and True-FISP were subjectively scored for artifacts by 1 radiologist (16 years of experience) and 1 radiological technologist (17 years of experience). They were blinded to information on the images. The object of evaluation was the cartilage surface in each subject, with 6 areas of assessment; the medial and lateral femoral condyles (MFC, LFC), the medial and lateral surfaces of the tibial plateau (MTP, LTP), the trochlea groove and the patella. Scoring was performed on a scale of 1 to 3, as follows: 1: The whole cartilage region presented as black; 2: Some areas in which the cartilage is presented as black; 3: No regions within the cartilage are presented as black. Visual assessment was performed by the 2 readers independently. In cases of discrepancy, a consensus was attained between the two readers.

Statistical analysis

Multiple comparisons with Tukey's test were performed in order to test for differences in mean values for SNR and CNR with FA-25° 3D-DESS and FA-90° 3D-DESS and True-FISP. For subjective visual assessment, mean scores were

calculated and visual assessments in the 3 groups for each sequence were compared using Steel-Dwass test.

R version 2.15.0 (Vienna, Austria. <http://www.R-project.org>.) was used for all SNR and CNR tests and visual assessments. P values of 0.05 were considered to be statistically significant.

Results

With FA-25° 3D-DESS, the mean values for synovial fluid SNR, cartilage SNR, and synovial fluid-cartilage CNR in the 10 subjects were 182.7, 92.9 and 89.8, respectively. With FA-90° 3D-DESS, the mean values for synovial fluid SNR, cartilage SNR and synovial fluid-cartilage CNR in the 10 subjects were 247.8, 88.7 and 159.1, respectively. With True-FISP, the mean values for synovial fluid SNR, cartilage SNR, and synovial fluid-cartilage CNR in the 10 subjects were 213.4, 62.5 and 150.9, respectively. Representative images are shown in Fig. 1.

Synovial fluid SNR was not significantly different in a comparison between FA-90° 3D-DESS and True-FISP ($P=0.364$). Cartilage SNR was significantly higher with FA-90° 3D-DESS than with True-FISP ($P=0.031$). Synovial fluid-cartilage CNR was not significantly different between FA-90° 3D-DESS and True-FISP ($P=0.892$). However, synovial fluid-cartilage CNR was significantly higher with FA-90° 3D-DESS and True-FISP than with FA 25° 3D-DESS ($P=0.002$ and $P=0.006$, respectively) (Fig. 2).

Visual evaluations of artifacts are summarized in Table 2. There were no artifacts in MFC, LFC, MTP or LTP in any of the sequences. Some artifacts in which cartilage was presented as black were seen in the patella cartilage and trochlea groove cartilage on

True-FISP only, and the score with True-FISP was significantly lower than with FA-25° 3D-DESS and FA-90° 3D-DESS ($P<0.001$, $P<0.002$) (Table 2, Fig. 3).

Discussion

This study showed that FA-90° 3D-DESS has equivalent synovial fluid SNR and synovial fluid-cartilage CNR to those of True-FISP in 3D isotropic cartilage imaging of the knee at 3.0T. FA-90° 3D-DESS imaging had significantly higher cartilage SNR and significantly fewer artifacts than True-FISP imaging. There are several reports comparing images obtained with 3D-DESS in which FA is set at low flip angle of about 25°, and those with other 3D gradient sequences, including True-FISP (3, 9). However, to our knowledge, this is the first study to compare 3D-DESS with FA set at 90° and other 3D sequences.

From the results of this study, it was concluded that FA-90° 3D-DESS is a promising sequence for observing cartilage surface, cartilage visibility and less artifacts. As FA-90° 3D-DESS has higher synovial fluid-cartilage contrast than FA-25° 3D-DESS, it would be superior for observing the cartilage surface. Furthermore, as FA-90° 3D-DESS has higher cartilage SNR than True-FISP, cartilage visibility would be considered good, and as there are fewer artifacts with FA-90° 3D-DESS than with True-FISP, they would be considered good images.

The reason for the observation that synovial fluid-cartilage CNR was the same level with FA-90° 3D-DESS as with True-FISP is that images obtained with 3D-DESS, in which FA is set at 90° have higher synovial fluid-cartilage contrast than those obtained

with 3D-DESS using a conventional low FA setting (7,16). FA conventional settings of 20° to 25° have been used in previous studies using general 3D-DESS, and which has lower synovial fluid-cartilage contrast than True-FISP (3,9).

Artifacts that appeared as dark signals on cartilage degraded the image quality of knee joint cartilages in our study. This is probably because banding artifacts inevitably appear in imaging of the knee with balanced FFSP due to its susceptibility to magnetic field non-uniformity and the necessity of switching the gradient magnetic field at very high levels (17).

Magnetic Resonance Observation of Cartilage Repair Tissue (MOCART) is a method of assessing knee cartilage using True-FISP (18-20). This is a method of scoring the repaired tissue of articular cartilage after surgery with MRI. As shown in this study, artifacts are observed with True-FISP, and this may interfere with accurate scoring of MOCART. The results of this study indicate that diagnostic performance for cartilage may be improved by replacing True-FISP with FA- 90° 3D-DESS.

A limitation of the present study was that the subjects were all healthy volunteers. It is possible that the relaxation values of cartilage and synovial fluid changes under disease conditions such as arthritis, which may influence the image contrast. However, we believe that good cartilage-synovial fluid contrast and fewer artifacts in FA- 90° 3D-DESS will contribute to better assessment of knee cartilage lesions. It will be necessary to compare how cartilage lesions in patients with knee joint diseases are seen with the two sequences in comparison with the gold standards of arthroscopy and surgery in the future.

In conclusion, good images are obtained with FA- 90° 3D-DESS in which synovial fluid SNR and cartilage-synovial fluid contrast are comparable to those with True-FISP.

FA-90° 3D-DESS has higher cartilage SNR and less conspicuous artifacts on cartilage than True-FISP. FA-90° 3D-DESS is useful in 3D isotropic cartilage imaging of the knee at 3 T.

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Table 1**Scanning parameters of all 3D sequences**

Sequence name	3D-DESS (FA25°, FA90°)	True-FISP
Acquisition time (min:s)	6:03	6:06
GRAPPA factor/reference lines	2/40	2/8
Partial Fourier reconstruction in slice	6/8	6/8
Number of slices	224	224
Slice resolution	50%	51%
Oversampling in slice direction	7.1%	7.1%
FOV (mm ²)	160×160	160×160
Phase oversampling	65%	90%
Matrix	320×320	320×320
Repetition time TR (ms)	14.3	6.58
Echo time TE (ms)	5.1	2.92
Turbo factor/echo spacing (ms)	1/0	1/0
Flip angle (°)	25,90	33
Bandwidth (Hz/pixel)	256	504

Table 2**Visual evaluation of artifacts (mean scores for 10 subjects)**

Sequence	MFC	LFC	MTP	LTP	patella	trachea
3D-DESS (FA25°)	3.0	3.0	3.0	3.0	3.0	3.0
3D-DESS (FA90°)	3.0	3.0	3.0	3.0	3.0	3.0
True-FISP	3.0	3.0	3.0	3.0	1.5*	1.7**

(* $P < 0.001$, ** $P < 0.002$)

Figures

Figure 1. Comparison of images with FA-25° 3D-DESS and FA-90° 3D-DESS and True-FISP. A: FA-25° 3D-DESS; B: FA-90° 3D-DESS; C: True-FISP. In all of the sequences, cartilage is represented as gray and synovial fluid as white.

Figure 2. Synovial fluid SNR, cartilage SNR and synovial fluid-cartilage CNR with each sequence. There are no significant differences in synovial fluid SNR between FA-90° 3D-DESS and True-FISP ($P=0.364$). Cartilage SNR is significantly higher with FA-90° 3D-DESS than with True-FISP ($P=0.031$). Synovial fluid-cartilage CNR is not significantly different between FA-90° 3D-DESS and True-FISP ($P=0.892$). However, synovial fluid-cartilage CNR was significantly higher with FA-90° 3D-DESS and True-FISP than with FA-25° 3D-DESS ($P=0.002$ and $P=0.006$, respectively).

Figure 3. Comparison of artifacts with A: FA-90° 3D-DESS and B: True-FISP. With True-FISP, artifacts are seen on the patella and trochlea cartilage (arrows). Artifacts are not seen with FA-90° 3D-DESS. In this study, such artifacts were only seen on these 2 articular surfaces in 9 of the 10 subjects.