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Comparison of Three-Dimensional Double-Echo Steady-State Sequence with Routine Two-Dimensional Sequence in the Depiction of Knee Cartilage

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ABSTRACT

Introduction: There are some routine two-dimensional sequences, including short tau inversion recovery (STIR), T2-weighted fast-spin echo (T2W-FSE), and proton-density fast spin-echo for diagnosing osteoarthritis and lesions of the knee cartilage. However, these sequences have some disadvantages, such as long scan time, inadequate spatial resolution, and suboptimal tissue contrast which results in loss of image details, as well as missing the visualization of knee cartilage lesions. Three-dimensional (3D) sequences, such as the double-echo steady-state (DESS) sequence can decrease and overcome these problems to the smallest possible amount.

Material and Methods: A total of 15 volunteers with knee pain were examined by a 1.5 Tesla magnetic resonance imaging. The contrast-to-noise ratio (CNR) and thickness values of the knee articular cartilage were measured. The CNR and thickness values were compared by the Friedman test and the Wilcoxon signed-rank test.

Results: The obtained results showed significant differences between sequences in CNR and thickness values. The DESS sequence with a flip angle of 40°showed the best CNR values and 3D fast low-angle shot (FLASH) showed the worst results. In addition, the results showed no significant differences between FLASH, 3D DESS 40° and 90° in terms of cartilage thickness. However, thickness values of these sequences were much higher than that of the PD, T2, and STIR sequences.

Conclusion: The 3D DESS sequence with two flip angles of 40°and 90° are the best sequences for visualizing the cartilage and the synovial fluid. Because they provide the best contrast between the cartilage and the synovial fluid, it is recommended to use DESS sequences in the evaluation of cartilage defections.

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Introduction

Osteoarthritis and chondromalacia are chronic joint diseases that are associated with symptoms (e.g., the degeneration and loss of the knee articular cartilage) and they have some clinical signs, such as pain, rigidity, and functional impairment in moving body regions [1-3]. Generally, these diseases affect joints in various areas of the body (e.g., hip, knee, spine, and hand). Osteoarthritis has become one of the most common diseases in today's aging population[4]. Magnetic Resonance Imaging (MRI) is a non-invasive method for depicting body tissues and its ability to depict soft tissue with high contrast resolution has made the MRI more effective than the other imaging modalities (e.g., radiography, computed tomography, and arthroscopy) to assess cartilage abnormalities[5, 6].

Due to the high frequency of superficial and deep knee cartilage injuries of patients with osteoarthritis and chondromalacia and given that these injuries are main symptoms of these diseases, as a result in recent years, the evaluation of the knee articular cartilage morphology through the MRI has been increased to observe cartilage damages and related lesions. Therefore, an effective sequence should have a good contrast-to-noise ratio (CNR) in order to provide an acceptable contrast between the cartilage and synovial fluid. Furthermore, it should be able to acquire a good signal from cartilage thickness to provide a good evaluation of cartilage pathology [7, 8].

Two-dimensional (2D) sequences, including T2-weighted fast-spin echo (T2W-FSE), proton-density

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fast spin-echo (PD FSE) , and short tau inversion recovery (STIR) are commonly used in medical imaging centers to diagnose osteoarthritis. These sequences have been recommended by Osteoarthritis Research Society International [9, 10].

Three-dimensional (3D) sequences have many advantages, such as being able to obtain a collection of isotropic resolution volumetric data and to use thin sections (between 0.5 and 0.6 mm) leading to the production of continuous sections without a gap. As a result, partial volume artifact decreases to the smallest possible amount [11-13]. However, 3D techniques have some disadvantages, including long scan times which poses some problems to the application of these techniques [10, 14].

Three-dimensional double-echo steady-state (3D DESS) imaging sequence is one of the sequences of the Siemens MRI system, which increases the contrast difference between the cartilage and synovial fluid [15]. This sequence is from the steady-state sequence family; moreover, it is called fast acquisition double echo in GE MRI systems [16, 17]. The steady-state imaging sequence is based on maintaining the transverse magnetization vector, and this state is created when the value of the repetition time is less than the T2-weighted imaging value of the tissue [18].

Several studies have been conducted to evaluate the effectiveness of this sequence in comparison to the other sequences. Some studies showed the superiority of this sequence over other sequences in detecting lesions [16, 19], on the other hand, other studies have shown the failure of this sequence in detecting lesions in comparison to the other sequences [20].

For the purpose of better detection of cartilage lesions and with regard to the ability of the DESS sequence in improving the CNR between the cartilage and synovial fluid, this study aimed to measure values of CNR (between the cartilage and synovial) and the cartilage thickness in the DESS sequence with two flip angles of 40° and 90° . Moreover, the current research was conducted to compare these values with those that measured in the routine sequences, including T2W FSE, PD FSE, STIR, and 3D fast low-angle shot (FLASH) to prove the effectiveness of the DESS sequence.

Materials and Methods

Subjects

A total of 15 patients with knee pain volunteered for MRI. All of the subjects were examined by an orthopedic surgeon before the study. According to the surgeon's examination, 6 of them were candidates for surgery. Written consents were obtained from all of the participants.

MRI imaging protocols

All MRI examinations were performed using the same protocols via a 1.5-T MRI scanner (Simens, Avanto, Germany). The sequences and imaging parameters are listed in Table 1.

Image evaluation

Sagittal images of the same sections were selected for each patient and after consulting with a radiologist, the thickness of cartilage in the medial part of the patella which has the thickest cartilage of the knee joint was measured. The CNR values were acquired by drawing region of interest (ROI) in the weight-bearing part of the knee articular cartilage. The images were processed using the Radiant DICOM Viewer software (version 4.6.9 (64-bit), Medixant Company, Poland). Accordingly, the authors drew 3 ROIs in 3 parts of the images, including synovial fluid, cartilage, and background. Signal intensity for synovial fluid, cartilage, and standard deviation of noise in the background was acquired (Figure 1). The CNR was calculated using the following formula:

$$CNR = \frac{Signal\ intensity\ of\ synovial\ fluid - Signal\ intensity\ of cartilge}{standard\ deviation\ of\ background\ noise}$$

These values were compared using the Friedman and Wilcoxon signed-rank tests and the collected data were analyzed in the SPSS software (version 16.0). P-values less than 0.05 were considered statistically significant.

Table 1. Magnetic resonance imaging sequences and parameters for each sequence

Acquisition Parameters / sequence	TR (ms)	TE (ms)	Slice thickness (mm)	Number of slices	FOV (readout)	FOV (phase)	Scan time (minute)	NEX
DESS90	21.36	7.57	1.5 mm	64	180	100	6:30	1
DESS40	21.36	7.57	1.5 mm	64	180	100	6:44	1
FLASH	10	4.92	1.5 mm	64	180	100	4:09	1
STIR	3700	40	3 mm	32	180	100	2:44	1
PD	2400	41	3 mm	32	180	100	3:55	1
T2W FSE	3740	80	3 mm	32	180	100	2:27	1

FLASH: fast low-angle shot
PD: proton-density
TR: repetition time
FOV: Field-of-view
STIR: short tau inversion recovery
T2W FSE: T2-weighted fast-spin echo
TE: echo time
NEX: Number of excitations

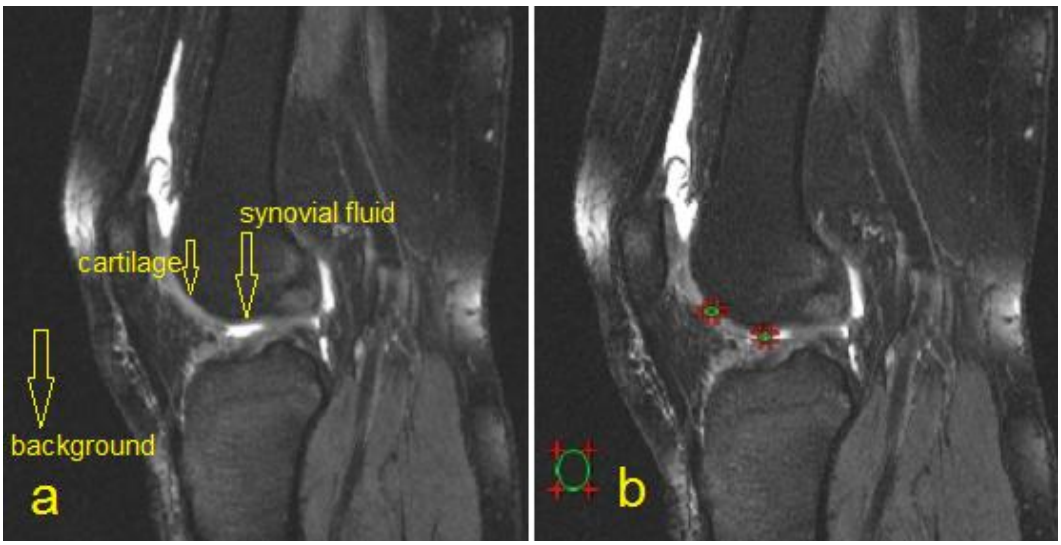

Figure 1. Signal intensities and standard deviation of background noise to calculate the contrast-to-noise ratio (CNR) were acquired by drawing region of interest (ROI) in different parts of the knee joint is depicted above. Figure 1. a shows regions of the synovial fluid, cartilage, and background which have been used to draw ROIs for acquiring signal intensities and background noise to calculate CNR values. Green circles in Figure 1. b are drawn ROIs in the regions of the synovial fluid, cartilage, and background.

Results

The Friedman test indicated a significant p-value for CNR mean values and the Wilcoxon signed-rank test showed p-values of less than 0.05 between all sequences. The best CNR mean value of 99.8000 was obtained for the DESS sequence with a flip angle of 40° . These comparative results showed that the CNR mean values for both DESS sequences were at least 3 times higher than the other sequences (Figure 2). The CNR mean values for all sequences are summarized in Table 2. In terms of thickness, 3D sequences had the best results (Figure 3) and the Wilcoxon signed-rank test showed a significant difference between the DESS sequences and the other sequences in our study.. Thickness mean values for all sequences are presented in Table 3. P values for CNR and thickness values were acquired from comparison of the DESS sequences and other sequences through the Wilcoxon signed-rank test and these values are presented in table 4 and 5 respectively.

Table 2. Contrast-to-noise ratio, standard deviation, and minimum and maximum values for all sequences

Sequence	CNR mean	Standard deviation	Minimum	Maximum
DESS40	99.8000	7.62702	85.00	111.00
DESS90	90.5333	3.33524	84.00	96.00
FLASH	5.1333	2.09989	2.00	9.00
STIR	32.0667	.96115	31.00	34.00
PD	16.0667	1.79151	12.00	19.00
T2	20.6000	2.06328	18.00	26.00

CNR: contrast-to-noise ratio
FLASH: fast low-angle shot
STIR: short tau inversion recovery
PD: proton-density
T2: T2-weighted imaging

Table 3. Thickness values in the medial part of the patella

Sequence	Thickness mean	Standard deviation	Minimum	Maximum
DESS40	5.9333	.25500	5.40	6.34
DESS90	5.8253	.28916	5.32	6.34
FLASH	5.9153	.20145	5.56	6.34
STIR	2.9267	.17915	2.60	3.20
PD	3.0333	.10040	2.90	3.20
T2	1.0547	.29631	.70	1.54

FLASH: fast low-angle shot
STIR: short tau inversion recovery
PD: proton-density
T2: T2-weighted imaging

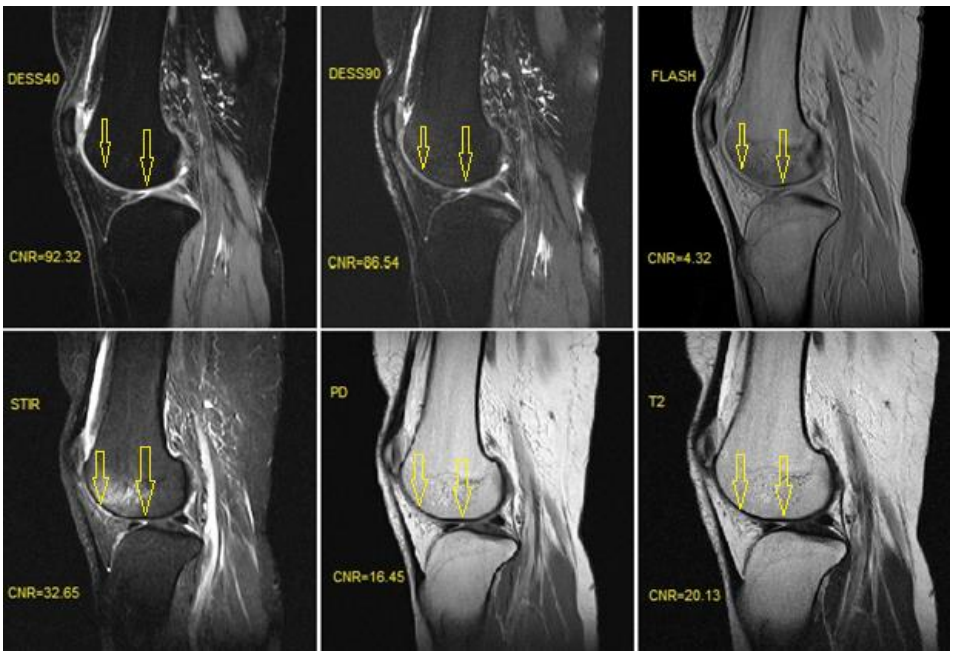

Figure 2. A 32-year-old woman with pain and rigidity in knee joint referred to us. Yellow markers indicate the regions of ROIs for acquiring signal intensities. The CNR values show a significant difference between the DESS sequences and the other sequences. It is shown that the DESS sequence with a flip angle of 40° has the best CNR value.

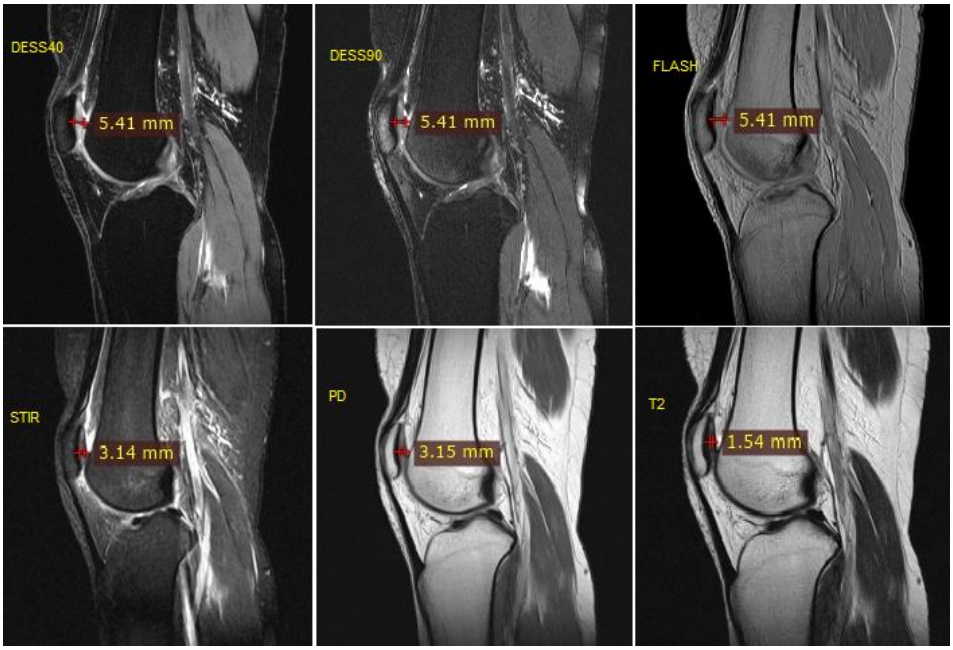

Figure 3. Thickness values in the medial part of the patella in a 32-year-old woman with pain and rigidity in the knee joint are presented. The best results were for 3D sequences; although among 2D sequences STIR and PD showed same results, both of them were superior to T2.

Table 4. Resulted P values from comparison of DESS sequences and the other sequences for CNR s.

sequence / Region	DESS90-DESS40	DESS90-FLASH	DESS90-STIR	DESS90-PD	DESS90-T2	DESS40-FLASH	DESS40-T2	DESS40-STIR	DESS40-PD
Weight bearing part of knee	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Table 5. Resulted P values from comparison of DESS sequences and the other sequences for Thickness values.

Region \ sequence	DESS90-DESS40	DESS90-FLASH	DESS90-STIR	DESS90-PD	DESS90-T2	DESS40-FLASH	DESS40-T2	DESS40-STIR	DESS40-PD
Medial part of patella	0.786	0.212	0.001	0.001	0.001	0.106	0.001	0.001	0.001

Discussion

The present study aimed to evaluate the effectiveness of the DESS sequence in comparison to routine sequences to determine which sequence can provide the best contrast between the cartilage and synovial fluid. In addition, to determine which of these sequences can acquire the best signal from the cartilage thickness. For this purpose, an orthopedic surgeon confirmed the existence of cartilage lesions in the knee of 15 subjects of the current study.

Although Current 2D magnetic resonance sequences, including T2 W FSE, PD FSE, and STIR have a high spatial resolution due to using thick sections (more than 2 mm) and the existence of a gap between slices, partial volume artifact which results in loss of image details and prevention from the visualization of lesions are shortcomings of these sequences [8, 10, 21].

The 3D DESS imaging produces two or more gradient echoes, each pair of echoes is separated by a refocusing pulse. This refocusing pulse combines image data to acquire a higher T2* weighting[8]. This imaging protocol results in high signal intensity in the cartilage and synovial fluid, which allows morphological evaluation of the cartilage. Moreover, this sequence improves the contrast between the cartilage and synovial fluid and leads to differentiating the subtle cartilage lesions [16, 18, 21-23]. The 3D DESS has some advantages, such as high Signal-to-noise ratio (SNR), high cartilage-to-fluid contrast in comparison to 3D FLASH and 2D routine sequences. This technique produces high-resolution 3D images with high cartilage SNR and provides excellent contrast between cartilage and adjacent tissues. The 3D DESS is similar to the other 3D sequences and acquires thin continuous slices without a gap from the knee joint, which decrease the effects of partial volume artifact [8, 10, 15, 16, 19].

One of the main findings of our study was better visualization of the cartilage thickness in the DESS sequence with two flip angles of 40° and 90° in comparison to the other sequences. The reason for this better visualization was due to the ability of the DESS sequence to provide the best signal from the cartilage which leads to help the radiologist to better assessment of the cartilage defects (Figure 3). Measurement of thickness in the medial part of the patella proves that the DESS sequence is the best sequence for visualizing the cartilage. Although thickness values for the FLASH sequence were as same as the DESS due to the lack of acceptable contrast between cartilage and its surrounding tissue in images acquired from FLASH sequence, the DESS sequence was the best sequence for visualizing the cartilage.

In addition, measurement of the CNR values indicated that the DESS sequence provided the best contrast between the cartilage and synovial fluid which resulted in better depiction of the image details. Furthermore, it greatly helped the radiologists to detect knee articular lesions. The CNR values for the DESS sequence with two flip angles were at least 2 times higher than that for 2D sequences (Figure 2).

In a similar study conducted by Moriya S et al. (2014), it has been indicated that the DESS sequence with a flip angle of 90° has better contrast, compared to the DESS with a flip angle of 40° [24] and our findings confirmed their findings.

Scan time in the DESS sequence is more than the 3D FLASH and 2D sequences which can result in a motion artifact and can affect the image quality; however, no result for the motion artifact was found in the present study.

Conclusion

The DESS sequence provided excellent contrast between the cartilage and synovial fluid; additionally, it provided the best signal from the cartilage and synovial fluid. Therefore, the DESS sequence resulted in better visualization of the cartilage and its surrounding tissue in comparison to the other sequences. Consequently, the DESS sequence is the best sequence for evaluating cartilage defects. According to the results of the current study, it is recommended to use the DESS sequences in the clinical assessment of knee articular cartilage lesions.

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