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Original contributions

Comparison of PD BLADE with fat saturation (FS), PD FS and T2 3D DESS with water excitation (WE) in detecting articular knee cartilage defects

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ABSTRACT

The purpose of this study, is to compare the sequences: 1) proton density (PD) BLADE (BLADE is a PROPELLER-equivalent implementation of the Siemens Medical System) with fat saturation (FS) coronal (COR), 2) PD FS COR, 3) multi-planar reconstruction (MPR) with 3 mm slice thickness and 4) multi-planar reconstruction (MPR) with 1.5 mm slice thickness, both from the T2 3D-double-echo steady state (DESS) with water excitation (WE) sagittal (SAG), regarding their abilities to identify changes in the femorotibial condyle cartilage in knee MRI examinations. Thirty three consecutive patients with osteoarthritis (18 females, 15 males; mean age 56 years, range 37–71 years), who had been routinely scanned for knee examination using the previously mentioned image acquisition techniques, participated in the study. A quantitative analysis was performed based on the relative contrast (ReCON) measurements, which were taken both on normal tissues as well as on pathologies. Additionally, a qualitative analysis was performed by two radiologists. Motion and pulsatile flow artifacts were evaluated. The PD BLADE FS COR sequence produced images of higher contrast between Menisci and Cartilage, Fluid and Cartilage, Pathologies and Cartilage as well as of the Conspicuousness Superficial Cartilage and it was found to be superior to the other sequences ($p < 0.001$). The sequences T2 3D DESS 1.5 mm and T2 3D DESS 3 mm were significantly superior to the PD BLADE FS COR and the PD FS COR sequences in the visualization of Bone and Cartilage and the Conspicuousness Deep Surface Cartilage. This pattern of results is also confirmed by the quantitative analysis. PD FS BLADE sequences are ideal for the depiction of the cartilage pathologies compared to the conventional PD FS and T2 3D DESS sequences.

1. Introduction

Magnetic Resonance Imaging (MRI) has been established as an effective technique for performing knee examination. Proton density (PD)-weighted MR imaging sequences are well-suited for the visualization of internal structures of the knee joint such as synovium, menisci, ligaments, and tendons as well as hyaline cartilage [1–5].

Although several imaging methods exist for cartilage evaluation, MRI, with its excellent soft tissue contrast, is superior in detecting cartilage abnormalities. The most widely used MRI techniques are intermediate-weighted fast spin-echo (FSE) and three dimensional (3D), fat-suppressed gradient-echo (GRE) acquisitions [6–10].

The 3D sequences have the potential of performing high resolution isotropic imaging, which may provide diagnosis and characterization

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of cartilage. One of the most frequently implemented isotropic sequences for cartilage imaging is the 3D Double-Echo Steady State (DESS) sequence, which maximizes the contrast between cartilage and joint fluid [11]. The DESS with water-excitation (WE) is used for achieving even higher contrast between cartilage and joint fluid [11,12].

Articular cartilage lesions are a common pathology of the knee joint, and many patients could benefit from cartilage repair [13]. Untreated, cartilage defects may lead to osteoarthritis (OA) [14].

BLADE sequences were applied to the patients of this study to significantly reduce motion artifacts. BLADE is a PROPELLER-equivalent implementation of the Siemens Medical System (Erlagen, Germany). In one of our previous studies, we found that the PD BLADE fat-suppressed (FS) sequences eliminate motion and pulsatile flow artifacts in knee MRI examinations. Also, it was found that they provide higher contrast between menisci and cartilage, and between bone and cartilage compared to the corresponding conventional sequences (non BLADE) [15]. The BLADE MR sequences have been reported to reduce motion artifacts and improve image quality in different anatomical sites [16–18].

In this study, we compare the 1) PD BLADE with fat saturation (FS) coronal (COR), 2) PD FS COR, 3) multi-planar reconstruction (MPR) with 3 mm slice thickness and 4) multi-planar reconstruction (MPR) with 1.5 mm slice thickness, both from the T2 3D-double-echo steady state (DESS) with water excitation (WE) sagittal (SAG), regarding their abilities to identify changes in femorotibial condyle cartilage (conspicuousness of cartilage, superficial and deep surface) in knee MRI examinations.

2. Materials and methods

2.1. Patients

From February 2010 to December 2012, thirty three consecutive patients with osteoarthritis (18 females, 15 males; mean age 56 years, range 37–71 years), who had been routinely scanned for knee examination using the image acquisition techniques described in the following section, participated in the study. This study was approved by the local institutional review board and a written informed consent was obtained from all the subjects participating in the study protocol.

2.2. MR imaging techniques

The presented knee examinations were performed on all the patients using a 1.5 T scanner (Magneton Avanto, Siemens Healthcare Sector, Erlangen, Germany) and the Siemens four-channel matrix knee coil. The parameters of the different sequences are presented in Table 1.

2.3. Quantitative analysis

A quantitative analysis was performed for the examined four sequences. In the quantitative analysis the following items were analyzed: relative contrast (ReCon) between (i) Menisci and Cartilage, (ii) Bone and Cartilage, (iii) Pathologies (cartilage abnormalities) and (iv) Cartilage Fluid and Cartilage. For calculating these values, the signal intensity (SI) of the menisci, bone marrow, hyaline cartilage and background noise was measured by placing regions of interest (ROIs). For each patient, the ROIs were identical and they were placed in the same position in the sequences under comparison. When in some cases the positions of the ROIs of one sequence were shifted due to patient motion, the ROIs were manually placed based on their relative position to adjacent tissues.

Table 1
Summary of the sequences that were applied for MR examinations.

Sequences	PD FS COR	PD BLADE FS COR	T2 3D DESS 1.5 mm	T2 3D DESS 3 mm
TR (ms)	3050	3030	20.60	20.60
TE (ms)	41	50	7.57	7.57
Matrix (Freq/Phase)	320/234	320/320	304/320	304/320
BW (Hz/pixel)	193	260	191	191
Acquisition Time (min)	3:35	3:46	4:53	4:53
Thickness (mm)	3 mm	3 mm	1.5	3
Space (%)	20%	20%	−25%	−25%
ETL	9	13	–	–
FOV (mm)	160	160	170/170	170/170
Echo spacing (ms)	12	7.12	–	–
Proportion of coverage	–	100	–	–
Number of signal averages (NSA)	1.0	1.0	1.0	1.0

The Relative Contrast was calculated by the following mathematical expression:

$$\mathrm{Re}Con_{\mathrm{AB}} = \frac{SI_{\mathrm{A}} - SI_{\mathrm{B}}}{SI_{\mathrm{A}} + SI_{\mathrm{B}}} \times 100\% \tag{1}$$

The CNR is calculated based on the following formula:

$$CNR_{\mathrm{AB}} = \frac{SI_{\mathrm{A}} - SI_{\mathrm{B}}}{N} \tag{2}$$

where SI_A and SI_B define the signal intensity of the tissues A and B, respectively. Both the ReCon and CNR are measures of contrast. Their difference is that ReCon is associated with the relative difference in contrast between two tissues, whereas CNR is associated with noise (SD in air). In this study, CNR measurements were performed in all the tissues but in a number of them (FL/CS, FL/CD, BN/CS, BN/CD, PT/CS, PT/CD) the acquired CNR values did not have any difference compared with the ReCon values in each of the sequences, separately.

The analysis of the relative contrast (ReCON) results was performed using the ANOVA (analysis of variance) statistical test.

2.4. Qualitative analysis

All the images of the four corresponding MR sequences were visually evaluated and compared independently at two separate settings with 3-week interval by two image evaluators (two radiologists), both of who were blinded to information other than the images themselves when they made their assessments.

A qualitative analysis of the images from the PD BLADE FS COR, PD FS COR, T2 3D DESS 1.5 mm and T2 3D DESS 3 mm sequences was performed by the two radiologists (a third year resident and a radiologist with 12 years of experience in musculoskeletal radiology) working in consensus.

The qualitative assessment was performed by grading: 1) two types of artifacts in cartilage imaging [19,20], namely the Pulsation Artifact and the Truncation Artifact, 2) the Conspicuousness of Cartilage, both Superficial and Deep surface, 3) Edge Sharpness, 4) Blurring, 5) General Artifacts, 6) Contrast between Menisci and Cartilage, 7) Contrast between Fluid and Cartilage, 8) Contrast between Bone and Cartilage and 9) Contrast between Pathologies and Cartilage.

The degrees of artifacts were assessed subjectively by assigning a score on a scale of 1–5: 1, unacceptable; 2, severe; 3, moderate; 4, mild; and 5, absent. Particularly, for the pulsation artifact a score of 5 meant that there was no ghost of the popliteal artery, 3 meant that

Table 2
Summary of the results of the quantitative comparison between the different sequences.

ReCON	PD BLADE FS COR	PD FS COR	T2 3D DESS 1.5 mm	T2 3D DESS 3 mm	p
MS/CS	72.5 ± 9.6	60.9 ± 9.6	35.5 ± 9.6	37.2 ± 10.1	<0.001
MS/CD	66.5 ± 13.0	52.2 ± 11.8	31.8 ± 9.7	34.5 ± 10.0	<0.001
FL/CS	47.9 ± 6.4	16.7 ± 8.2	18.5 ± 9.9	17.7 ± 10.5	<0.001
FL/CD	55.8 ± 6.8	28.7 ± 8.7	21.9 ± 10.4	20.0 ± 10.2	<0.001
BN/CS	27.3 ± 9.2	45.3 ± 7.7	75.1 ± 5.2	75.9 ± 5.3	<0.001
BN/CD	17.7 ± 10.5	34.4 ± 10.1	73.2 ± 5.6	74.5 ± 5.4	<0.001
PT/CS	38.4 ± 10.0	12.2 ± 10.9	12.8 ± 9.0	13.5 ± 11.1	<0.001
PT/CD	47.0 ± 10.0	18.2 ± 9.9	14.6 ± 9.6	14.5 ± 9.5	<0.001

MS: Menisci, FL: Fluid, BN: Bone, PT: Pathologies, CS: Cartilage Superficial, CD: Cartilage Deep surface.
The analysis of the relative contrast (ReCON) results was performed using the ANOVA (analysis of variance) statistical test.

the ghost could be readily seen over the bone marrow, and 1 meant that the ghost distorted the morphology of the adjacent cartilages.

For the truncation artifact, a score of 5 meant that there was no pseudolaminar appearance of the patellofemoral compartment, 3 meant that the pseudolaminar appearance of the patellofemoral cartilage could be readily recognized, and 1 meant that the pseudolaminar appearance was extremely conspicuous.

The cartilage conspicuousness was defined according to the visibility and sharpness of the cartilage surfaces and was graded along another subjective scale: 1, unacceptable; 2, poor; 3, fair; 4, good; and 5, excellent. A score of 5 meant that the cartilage surface could be seen clearly and sharply, distinguished from surrounding tissues; 3 meant that the surface could be seen, but the demarcation was not sharp; and 1 meant that the surface could not be distinguished from the surrounding tissues. For superficial conspicuousness, the surface contour in the posterior region of the femoral condyle cartilage was used for grading because the possible surface ambiguity was a well-established phenomenon observed in this region on the spoiled T1-weighted gradient-echo sequence [21,22].

The statistical significance of the qualitative data was determined by the Kruskal–Wallis non-parametric test. Furthermore, a comparison of the evaluations of the two radiologists was performed based on eleven parameters and the estimates with their comparison intervals were calculated using the Kruskal–Wallis test.

3. Results

3.1. Quantitative results

The results of the quantitative analysis obtained from all the patients are presented in Table 2. Specifically, the ReCON measure-

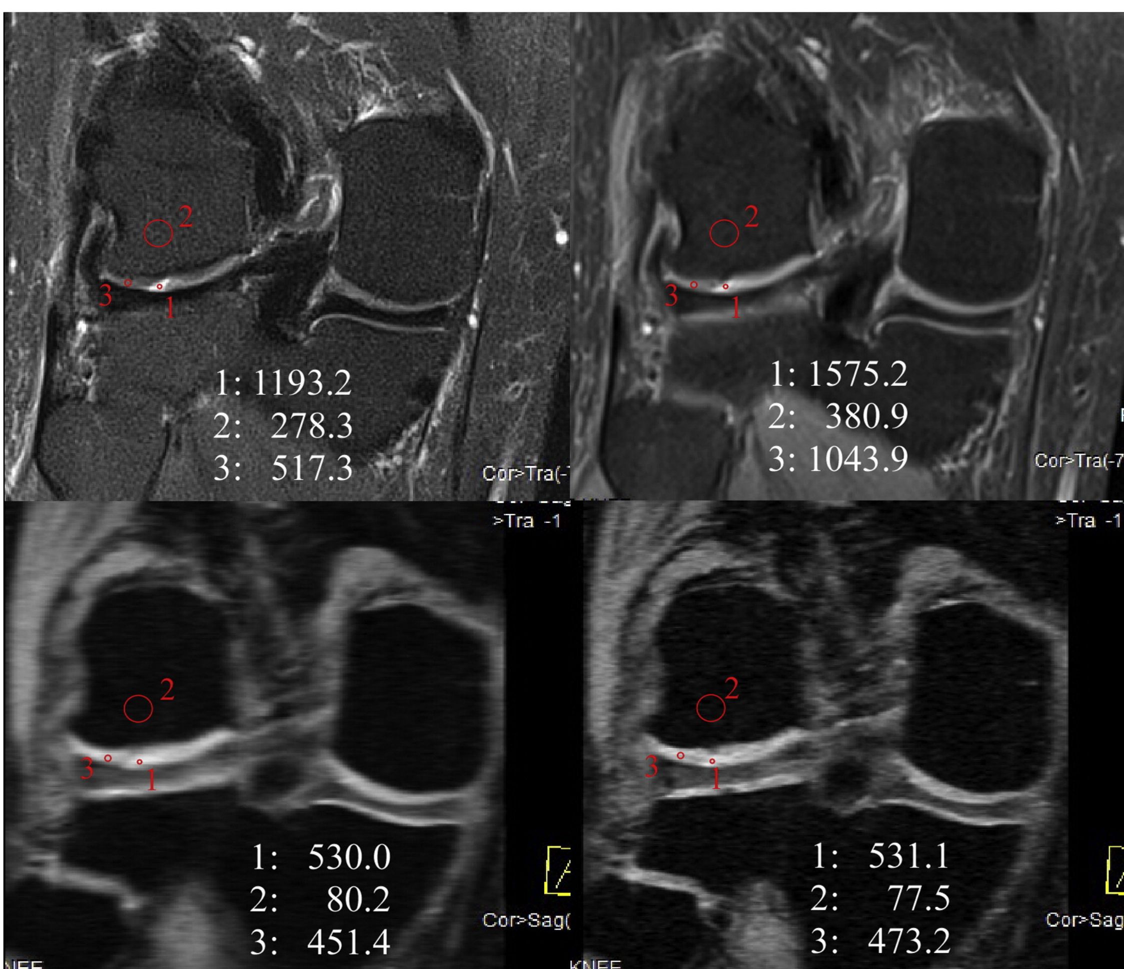

Fig. 1. Coronal PD BLADE FS (upper left), Coronal PD FS (upper right), Coronal T2 3D DESS with 3 mm slice thickness (lower left), Coronal T2 3D DESS with 1.5 mm slice thickness (lower right). Measurements of signal intensity (SI) in those four images were performed in pathology (1), bone (2) and cartilage (3). The results of ReCon in the PD BLADE FS COR sequence between the Cartilage and Pathologies were very superior to those of the other sequences. The results of ReCon between Bone and Cartilage from the T2 3D DESS 1.5 mm and 3 mm sequences were superior to those of the PD BLADE FS COR and PD FS COR sequences.

ments of the Menisci/Cartilage Superficial, the Menisci/Cartilage Deep surface, the Fluid/Cartilage Superficial, the Fluid/Cartilage Deep surface, the Pathologies/Cartilage Superficial and the Pathologies/Cartilage Deep surface (Fig. 1), in the PD BLADE FS COR sequences, were found to be superior to the PD FS COR, T2 3D DESS 1.5 mm and T2 3D DESS 3 mm sequences.

The sequences T2 3D DESS 1.5 mm and T2 3D DESS 3 mm were significantly superior to the PD BLADE FS COR and PD FS COR sequences in the ReCON of Bone/Cartilage Superficial and Bone/Cartilage Deep surface (Fig. 1).

The sequence PD FS COR was significantly superior to the T2 3D DESS 1.5 mm and T2 3D DESS 3 mm sequences in the ReCON results between Menisci/Cartilage Superficial, Menisci/Cartilage Deep surface, Fluid/Cartilage Deep surface and Pathologies/Cartilage Deep surface. No significant difference was calculated in the ReCON results between Fluid/Cartilage Deep surface and Pathologies/Cartilage Deep surface.

3.2. Qualitative analysis

The results of the qualitative analysis obtained from all the patients are presented in Table 3.

More specifically, the contrast in the PD BLADE FS COR sequence between Menisci and Cartilage, Fluid and Cartilage, Pathologies and Cartilage, and in the Conspicuousness Superficial Cartilage was found to be superior to the other sequences ($p < 0.001$) (Figs. 2–4).

The sequences T2 3D DESS 1.5 mm and T2 3D DESS 3 mm were significantly superior to the PD BLADE FS COR and PD FS COR sequences in the Bone and Cartilage and Conspicuousness deep Surface Cartilage.

The sequences T2 3D DESS 1.5 mm and T2 3D DESS 3 mm were significantly superior to the PD FS COR sequence regarding the results of the Pulsation Artifact, and Fluid and Cartilage.

Table 3
Summary of the results of the qualitative comparison between the different sequences.

ReCON	PD BLADE FS COR	PD FS COR	T2 3D DESS 1.5 mm	T2 3D DESS 3 mm	p
1st Radiologist					
TArt	4.0 ± 0.2	3.6 ± 0.5	2.1 ± 0.4	2.9 ± 0.2	<0.001
PArt	4.0 ± 0.6	2.1 ± 1.0	2.2 ± 0.4	2.4 ± 0.5	<0.001
EShr	4.2 ± 0.5	3.1 ± 0.4	2.2 ± 0.5	1.7 ± 0.7	<0.001
Blur	3.6 ± 0.8	3.4 ± 0.6	2.2 ± 0.5	3.1 ± 1.0	<0.001
Arts	5.0 ± 0.2	2.6 ± 0.5	2.2 ± 0.4	2.3 ± 0.5	<0.001
MenC	3.9 ± 0.6	3.0 ± 0.2	3.0 ± 0.6	2.4 ± 0.5	<0.001
FluC	4.4 ± 0.6	2.8 ± 0.5	3.0 ± 0.7	2.9 ± 0.9	<0.001
BonC	3.0 ± 0.5	2.5 ± 0.5	3.9 ± 0.6	3.9 ± 0.5	<0.001
PatC	4.0 ± 0.6	2.6 ± 0.8	2.5 ± 0.7	2.7 ± 0.8	<0.001
CnSC	4.0 ± 0.6	3.0 ± 0.4	2.6 ± 0.8	2.6 ± 0.7	<0.001
CdSC	2.5 ± 0.5	2.2 ± 0.4	3.6 ± 0.7	3.6 ± 0.6	<0.001
2nd Radiologist					
TArt	4.1 ± 0.4	3.6 ± 0.6	2.5 ± 0.6	2.8 ± 0.5	<0.001
PArt	4.5 ± 0.7	1.9 ± 0.7	2.2 ± 0.5	2.2 ± 0.4	<0.001
EShr	4.6 ± 0.5	3.5 ± 0.5	2.7 ± 0.5	2.0 ± 0.4	<0.001
Blur	3.7 ± 0.9	3.5 ± 0.7	2.3 ± 0.4	3.0 ± 1.1	<0.001
Arts	4.9 ± 0.3	3.0 ± 0.3	2.5 ± 0.6	2.4 ± 0.5	<0.001
MenC	4.2 ± 0.7	3.0 ± 0.2	3.1 ± 0.8	2.8 ± 0.8	<0.001
FluC	4.3 ± 0.6	2.7 ± 0.5	3.1 ± 0.6	2.8 ± 1.0	<0.001
BonC	2.5 ± 0.6	2.6 ± 0.5	4.3 ± 0.6	4.3 ± 0.5	<0.001
PatC	4.4 ± 0.6	3.1 ± 0.7	3.2 ± 0.6	3.2 ± 0.6	<0.001
CnSC	4.3 ± 0.6	3.0 ± 0.3	3.0 ± 0.9	2.9 ± 0.7	<0.001
CdSC	2.6 ± 0.5	2.2 ± 0.4	4.0 ± 0.9	3.8 ± 0.5	<0.001

The statistical significance of the qualitative data was determined by the Kruskal–Wallis non-parametric test.
TArt: Truncation Artifact, Part: Pulsation Artifact, EShr: Edge Sharpness, Blur: Blurring, Arts: General Artifacts, MenC: Menisci and Cartilage, FluC: Fluid and Cartilage, BonC: Bone and Cartilage, PatC: Pathologies and Cartilage, CnSC: Conspicuousness Superficial Cartilage, CdSC: Conspicuousness deep Surface Cartilage.

Also, in the PD BLADE FS COR sequence, the results of the Truncation Artifact, Pulsation Artifact, Edge Sharpness, Blurring, Artifacts, were superior to the other sequences ($p < 0.001$) (Figs. 3–4).

Furthermore, an inter-observer analysis was performed. More specifically, as far as the qualitative evaluations of the two observers are concerned, their evaluation scores do not show statistically significant differences ($p > 0.01$) regarding the comparison of the four sequences and the examined eleven parameters. Only, in four cases (Pulsative Artifact of PD BLADE FS COR, Edge Sharpness of T2 3D DESS 1.5 mm, Edge Sharpness of T2 3D DESS 3 mm and Pathologies Cartilage of T2 3D DESS 1.5 mm) statistically significant differences ($p < 0.005$) were found using the Kolmogorov–Smirnov test.

4. Discussion

The primary goal of the present study was not to evaluate the accuracy of the examined sequences but to quantitatively determine which of the sequences provides the best contrast between the lesion and its surroundings. For this purpose, 33 clinical cases where the existence of a lesion had been confirmed were used. In the clinical cases that were investigated, the lesion was confirmed through arthroscopic proof (11 cases), during surgery (1 case) or known history of a cartilage defect from previous radiological examinations (21 cases). Consequently, accuracy could not be measured in all the patients due to lack of grading using a Cartilage Damage Measuring System (system by which cartilage defects can be ranked).

As indicated by the supplementary figures, the results are very consistent between the observers. More specifically, there were only very minor differences in the results by the two observers, even though they had different levels of clinical experience. The reason is that both observers 1) had at least a given level of experience in this field and 2) examined very specific characteristics and only one lesion (cartilage defect).

Visualization and classification of lesions of the articular cartilage of the knee in patients without underlying degeneration type of osteoarthritis, are another field in which the magnetic resonance imaging has contributed significantly [23]. The display now in the magnetic field of 1.5 T, has shown that it is possible to enhance chondral lesions (but not always) and there seems to be no sequence that ideally highlights and categorizes osteochondral lesions. The aim of the present study is to evaluate the ability of different sequences to highlight abnormal or unstable cartilage requiring surgery. In the literature, it has become accepted that T2-Fast Spin Echo with fat suppression in three levels is a sequence of reference, with approximate values TR 4000/TE 35 and TR 3500/TE 45, respectively. PD sequences with fat suppression seem to have a slight edge, and have been adopted by several protocols in the imaging of the knee in daily clinical practice. Also, 3D sequences with fat suppression or excitation of water molecules (water excitation) can be used to achieve better contrast between cartilage–bone interface and ability to quantify the damage in the area with semi illustration algorithms.

In addition to the well-established 3D-FLASH sequence, the 3D-DESS sequence was introduced as another MRI acquisition that could measure changes in cartilage thickness and volume in a longitudinal follow up study of the OA initiative [24].

In another evaluation, the DESS sequence showed slightly superior results and reportedly permitted accurate and precise analysis of cartilage morphology in the femorotibial joint at 3 T [25].

In one of our previous studies we have found that, in the PD TSE FS COR sequences, the SNR of fatty tissues, the CNR of fat and posterior cruciate ligament and the ReCon between Menisci and Cartilage, Bone and Cartilage, and Fat and Posterior Cruciate Ligament, where

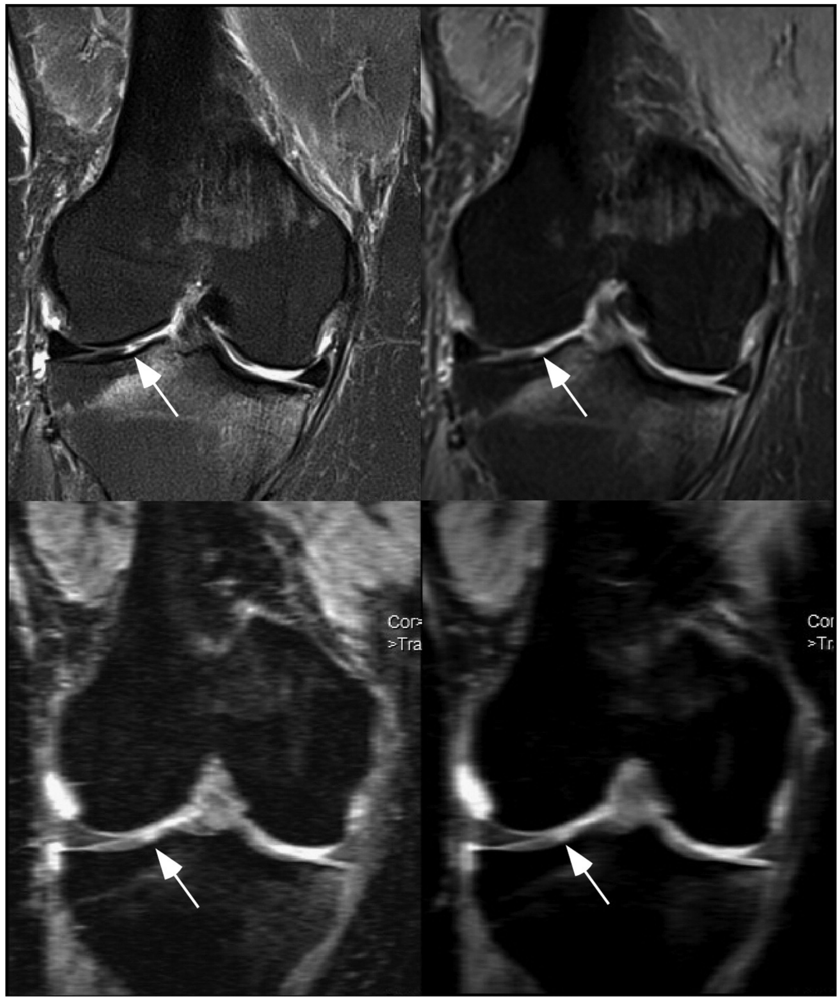

Fig. 2. Coronal PD BLADE FS (upper left), Coronal PD FS (upper right), Coronal T2 3D DESS with 3 mm slice thickness (lower left), Coronal T2 3D DESS with 1.5 mm slice thickness (lower right). The Coronal PD BLADE FS image shows tear (grade II) femoral cartilage (arrow), whereas the Coronal PD FS (upper right) and Coronal T2 3D DESS with 1.5 mm slice thickness (lower right) sequences do not show it clearly.

the differences were statistically significant, the BLADE sequences were superior to the conventional ones. More specifically, in all the comparisons, the PD BLADE FS sequences (coronal and sagittal) were significantly superior to the corresponding conventional sequences regarding the classification of their image quality. The imaging of pathologies was more distinguishable from its surrounding in bone marrow edema. In addition, BLADE sequences were found to eliminate motion and pulsation artifacts. Also, the PD BLADE FS COR image shows tear femoral cartilage, whereas the conversional PD FS COR image does not show it clearly [15].

Compared with the 3D-FLASH and 3D-DESS sequences, the preoperative detection of cartilage defects is possible with similar sensitivity, accuracy and specificity [26]. However, the capability of those techniques for assessing adjacent structures such as menisci and ligaments has not been well validated [27].

In addition, for non-fat-suppressed images, the greater separation of fat and water frequencies will lead to greater chemical shift artifacts at the cartilage–bone interface because of marrow fat. Although increasing the bandwidth of the image acquisition may reduce this artifact, the SNR of the acquisition decreases. Despite these challenges, high-field imaging shows great promise as an overall improvement in articular cartilage assessment by MRI. Currently, high-field MRI systems are not as widely available and do not have the same range of radiofrequency coils as those that are produced for 1.5 T systems [28].

In our results, it was found that the PD BLADE FS COR sequence eliminated motion artifacts in all the cases. It also improved image quality compared to the PD FS COR and T2 3D DESS sequences. More specifically, in the PD BLADE FS COR sequence, the results of the Truncation Artifact, Pulsation Artifact (Figs. 3–4), Edge Sharpness, Blurring, and General Artifacts, were superior to those of the other sequences ($p < 0.001$).

The contrast in the PD BLADE FS COR sequence between the Menisci and Cartilage, Fluid and Cartilage, Pathologies and Cartilage, and in the Conspicuousness Superficial Cartilage was superior to the other sequences ($p < 0.001$) (Figs. 1–4). In Fig. 1, the results of ReCon of the PD BLADE FS COR sequence between Cartilage and Pathologies, were very superior to the other sequences.

The sequences T2 3D DESS 1.5 mm and T2 3D DESS 3 mm were significantly superior to the PD BLADE FS COR and PD FS COR sequences in the Bone and Cartilage and the Conspicuousness deep Surface Cartilage. Regarding the results of ReCon between Bone and Cartilage, the T2 3D DESS with 1.5 mm and 3 mm slice thickness sequences (Fig. 1) were superior to the PD BLADE FS COR and PD FS COR sequences.

The values of the CNR measurements are not presented because of the large differences in the pixel size between the four sequences. Furthermore, in a previous work by this group, where PD COR FS and PD BLADE COR FS sequences were compared by normalizing the

Fig. 3. Coronal PD BLADE FS (upper), Coronal PD FS (middle), Coronal T2 3D DESS with 1.5 mm slice thickness (lower). The Coronal PD BLADE FS sequence eliminated the pulsation artifacts compared to the rest of the sequences. Furthermore, the Coronal PD BLADE FS sequence also shows tear (grade II) femoral cartilage (arrow), whereas the Coronal PD FS (middle) and the Coronal T2 3D DESS with 1.5 mm (lower) sequences do not show it clearly.

pixel size, in all the examined pairs of tissues the values of contrast in the PD BLADE COR FS sequences were significantly superior compared to those of the PD COR FS sequences [15].

The sequences T2 3D DESS 1.5 mm and T2 3D DESS 3 mm were significantly superior to the PD FS COR sequence in the Pulsation Artifact, and Fluid and Cartilage too.

One of the most important finding of the study is that the cartilage pathology is more clearly distinguished from the healthy cartilage and the contrast between Fluid and Cartilage is better visualized in the PD BLADE FS COR sequence compared to other sequences (Figs. 2–4). In Fig. 4, the PD BLADE FS COR sequence also shows the tear (grade II) femoral cartilage (arrow), whereas the PD FS COR (b) and the T2 3D DESS 3 mm (c) and 1.5 mm (d) sequences do not show it. The findings that are associated with the PD BLADE FS COR sequence agree with those of arthroscopy. In addition, in Figs. 2 and 3 the PD BLADE FS COR sequence also shows the tear (grade II) femoral cartilage (head arrow), whereas the PD FS COR and the T2 3D DESS COR 1.5 mm and 3 mm sequences do not show it clearly.

Furthermore, isotropic 3D fast spin-echo sequences have recently become available (called PD [proton-density] SPACE [sampling perfection with application optimized contrasts using different flip angle evolutions] or 3D fast spin-echo [FSE] extended echo-train acquisition [XETA]), which may, in future applications, provide greater opportunity to characterize the constitution of cartilage, bone, menisci, ligaments, and the surrounding tissue within one clinically applicable sequence [27,29].

PD BLADE FS COR sequences have also high echo-train acquisition. IDEAL, mapping and generally sequences that are used for the early detection of cartilage lesions have a high bandwidth (BW) [30,31,28]. Also, a high bandwidth reduces chemical shift artifacts. The combination of high BW and high echo-train, which are a feature of Blade sequences, is probably another reason for the very good depiction of the cartilage.

We found that the examined PD BLADE FS COR sequence is ideal for the depiction of the whole knee (ligament, menisci, cartilage, bone etc). However, further investigation is required regarding the modification and optimization of the parameters used in the PD FS BLADE sequences. Based on the findings of this study, we suggest the use of the PD BLADE FS COR sequence in 3D plane with the possibility of performing reconstruction in arbitrary planes.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.mri.2013.06.007.

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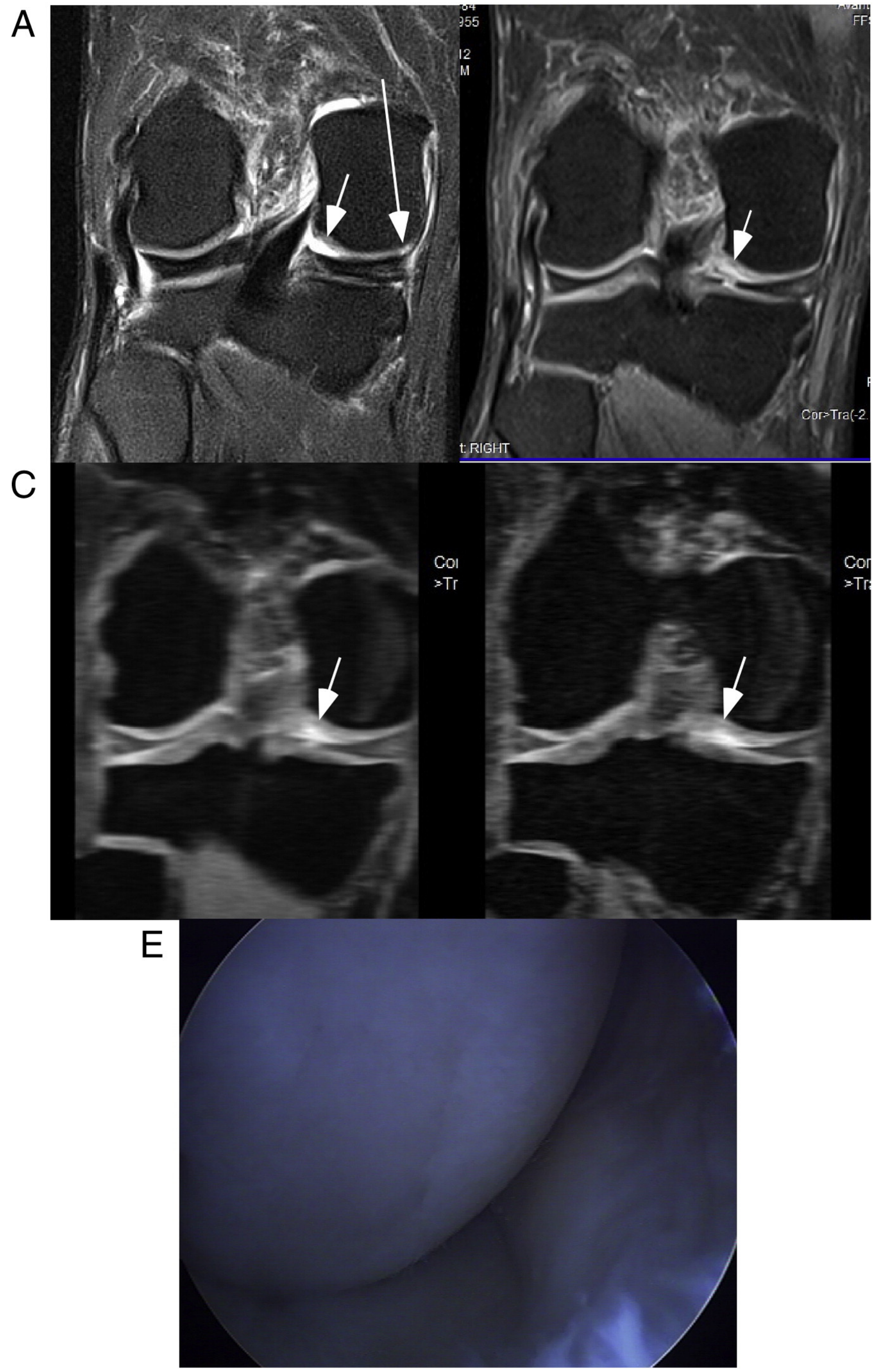

Fig. 4. (A) Coronal PD BLADE FS, (B) Coronal PD FS, (C) Coronal T2 3D DESS with 3 mm slice thickness, (D) Coronal T2 3D DESS with 1.5 mm slice thickness and (E) image from arthroscopy. The Coronal PD BLADE FS sequence eliminated pulsation artifacts compared to Coronal T2 3D DESS with 3 mm (C) and 1.5 mm (D) slice thickness sequences. The Coronal PD BLADE FS sequence also shows tear (grade II) femoral cartilage (arrow), whereas the Coronal PD FS (B) and the Coronal T2 3D DESS with 3 mm (C) and 1.5 mm (D) slice thickness sequences do not show it. In addition, the Coronal PD BLADE FS also shows tear (grade III) femoral cartilage (head arrow), whereas Coronal PD FS (B) and the Coronal T2 3D DESS with 3 mm (C) and 1.5 mm (D) slice thickness sequences do not show it clearly. The findings of the Coronal PD BLADE FS sequence agree with those of arthroscopy.

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