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FULL PAPER

Usefulness of the fast spin-echo three-point Dixon (mDixon) image of the knee joint on 3.0-T MRI: comparison with conventional fast spin-echo T_2 weighted image

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Objective: To compare the quality of two different imaging methods, three-point Dixon (mDixon) and fast spin-echo (FSE) T_2 weighted image (T2WI) [and fat suppression (FS) T2WI], and to assess the utility of mDixon for the imaging of knee joint pathology.

Methods: This retrospective study included 66 patients who underwent both mDixon and FSE T2WI (and FS T2WI) of the knee joint. Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) of the two sequences at the articular cartilage and ligament were measured. Two radiologists independently evaluated the anatomic identification score and diagnostic performances of the two sequences.

Results: The mean SNRs and CNRs of the patellar cartilage, femoral cartilage and anterior cruciate ligament (ACL) were significantly higher on T2WI and FS T2WI than on mDixon imaging, with the exception of the mean SNR of ACL on in-phase images. Most of the anatomic

identification scores did not show significant differences, except for inferiorities of the in-phase mDixon in the evaluation of the cruciate ligament. There were no significant differences in sensitivity, specificity and accuracy between mDixon and T2WI regarding diagnostic performance.

Conclusion: mDixon images have equivalent anatomic identification ability with the exception of cruciate ligament delineation on in-phase images and have a diagnostic performance comparable with that of FSE T2WI for meniscal, cartilage and ligament injuries of the knee joint. There would be a net saving in time, if mDixon was the only sequence used.

Advances in knowledge: The mDixon images have equivalent anatomic identification abilities, with the exception of cruciate ligament delineation on in-phase images and have a diagnostic performance comparable with that of FSE T2WI for meniscal, cartilage and ligament injuries of the knee joint.

INTRODUCTION

The Dixon imaging technique provides chemical shift-separated fat and water images, quantification of fat amount and an alternative to fat suppression (FS).¹ Regarding FS, the two-point Dixon method is limited by B_0 field heterogeneity and fat-water swapping and needs a relatively long sequence time.² The three-point Dixon (mDixon) technique using a three-phase difference (0, π and $-\pi$) between fat and water signals allows a flexible echo time and sequence design and compensates for B_0 field heterogeneity.³ The mDixon therefore produces homogeneous fat and water separation that is less sensitive to B_0 field heterogeneity.^{4,5} The mDixon technique provides rapid T_2 weighted imaging (T2WI) with and without FS; addition and subtraction of the separate images yields a fat-only and a water-only image.⁶ The mDixon technique is different from frequency-selective FS or short tau inversion

recovery (STIR) imaging because it relies on the separation of the water and fat signal rather than pure FS.⁶ Knee joint imaging requires multiple planes and many sequences containing FS, which inevitably prolongs the total scan time. The mDixon technique rapidly generates multiple images (including FS and T_2 -like images, in phase) in a single acquisition;⁶ thus, the use of mDixon images as substitutes for T2WI and FS T2WI would reduce the total scan time. The purpose of our study was to compare the quality of two different methods of imaging, mDixon and fast spin-echo (FSE) T2WI (T2WI and FS T2WI), and to assess the utility of mDixon for the imaging of knee joint pathology.

METHODS AND MATERIALS

Case selection

The institutional review board of Kangbuk Samsung Hospital approved this study and waived the requirement for informed

consent because of its retrospective nature. Of the patients who visited our medical centre because of various complaints of the knee joint between December 2014 and February 2015, 257 patients who consecutively underwent 3.0-T MRI with the mDixon technique were included in this retrospective study. Clinical indications for knee MRI were joint pain and impaired mobility under various clinical suspicions such as ligament injury, meniscal tear or osteoarthritis. The exclusion criteria were bone tumour and infectious disease in the knee joint. Among those 257 patients, 189 patients were also excluded because they did not undergo surgical intervention such as arthroscopy. Therefore, a total of 66 cases were enrolled in our study: 36 males and 30 females, aged 10–73 years (mean 46 ± 15.3 years).

Arthroscopic diagnosis

Arthroscopic findings were the reference standard for diagnosis. One orthopaedic surgeon (JHA) with fellowship training in knee joint surgery and 32 years' experience performed all arthroscopic procedures and treatments. The included surgical indications were meniscal injury, anterior cruciate ligament (ACL) injury and cartilage injury. The mean interval between MR and surgery was 23 ± 25 days (range 1–75 days). Anterolateral and anteromedial portals with probing and distraction of the ligament were used to evaluate the internal pathology of the knee joint. An intact ACL was diagnosed as the presence of taut and visibly intact fibres from the tibial to the femoral attachment.⁷ When the ACL bundle lost continuity and tautness, it was considered an ACL tear. The surgeon also evaluated other pathologies such as cartilage injury or meniscal tear on arthroscopy and described these in the operation notes on the electronic medical record system.

MR parameters

All MRI procedures were performed on a Achieva® 3.0-T MR scanner (Philips, Best, Netherlands) with an eight-channel knee-dedicated coil. The routine pulse sequences and imaging parameters are summarized in Table 1. The mDixon sequences

included one in-phase and two out-of-phase loops (water and fat protons), which resulted in three separate echoes.³ Fat and water phase shift for each echo was 0, π and $-\pi$. For fat–water separation, a phase-unwrapping algorithm was adopted.³ The parameters were adjusted to be as similar as possible to allow image comparison between mDixon and T2WI. The scan times of the mDixon were approximately 3 min and 40 s.

Image analysis

(1) Image contrast

Patellar and femoral condylar cartilage and ACL signals were measured by both mDixon and FSE T2WI (T2WI and FS T2WI) from 2-mm circular regions of interest on each sagittal image (Figure 1). Regions of interest were placed within the cartilage and ACL mid-portion (small circles), suprapatellar joint effusion (not shown) and anteroinferior to the patella (background noise, large circle). Each measurement was performed by two radiologists (HJP, SYL) in consensus. Both radiologists had undergone fellowship training and had 14 and 9 years' experience, respectively, in musculoskeletal radiology. We calculated the signal-to-noise ratio (SNR), according to the following equation: $\text{SNR} = \text{signal of cartilage or ligament} / \text{standard deviation of the background noise}$. Contrast-to-noise ratio (CNR) was defined as the difference between the SNR of the cartilage (or ligament) and that of the fluid and was calculated according to the following equation: $\text{CNR} = \text{SNR of fluid} - \text{SNR of tissue}$.

(2) Anatomic identification score of the images

Anatomic identification scoring of the images was performed independently by two radiologists, according to the three criteria of image sharpness, FS on water-only mDixon and FS T2WI (ACL delineation on in-phase mDixon) and cartilage evaluation and using a four-point scale (0, poor; 1, questionable; 2, adequate; and 3, excellent).⁸ First, both radiologists evaluated the subjective scorings of mDixon images only. To prevent recall bias, they evaluated the subjective scorings of the corresponding

Table 1. Imaging parameters for the MR sequences

Imaging parameter	Coronal T_1 FSE	Coronal FS PD FSE	Sagittal FS T_2 FSE	Sagittal T_2 FSE	Sagittal mDixon water only	Sagittal mDixon in phase	Axial FS T_2 FSE
TR (ms)	700–750	3000–3500	3800–4600	3500–4000	2600–2900	2600–2900	4300–4700
TE (ms)	10–30	20–40	60–90	60–90	70–90	70–90	60–90
Flip angle (°)	90	90	90	90	90	90	90
Matrix size (pixels)	350×340	320×230	330×250	360×280	360×280	360×280	320×240
Field of view (cm)	16	16	16	16	16	16	16
Slice thickness (mm)	3	3	3	3	3	3	3
Interslice gap (mm)	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Bandwidth (kHz)	270	260	250	250	270	270	290
Echo train length	5	12	14	14	14	14	15
Signal average	1	1	1	1	1	1	1
Scan time (min:s)	2:30	2:20	2:30	2:30	3:40		2:30

FS, fat suppression; FSE, fast spin echo; mDixon, three-point Dixon; PD, proton density; TE, echo time; TR, repetition time.

Figure 1. Sagittal fast spin-echo three-point Dixon image (repetition time/echo time = 2700/80 ms, field of view = 16 cm, slice = 3 mm and matrix = 360×280 pixels). Regions of interest were placed within the cartilage and anterior cruciate ligament mid-portion (medium and small circles, respectively), suprapatellar joint effusion (not shown) and anteroinferior to the patella (background noise, large circle). A, area; L, length; M, mean value; S, standard deviation.

T2WI 2 weeks later at the next session. In the evaluation of image sharpness, a score of 3 indicates the ability to evaluate more than 75% of the entire anatomic structure without image distortion due to artefacts such as susceptibility or flow artefacts, a score of 2 indicates an ability to evaluate 50–75%, a score of 1 indicates 25–50% and a score of 0 indicates <25%.⁹ Scoring of FS was determined as follows: 3, homogeneous FS in the bone and soft tissue; 2, inhomogeneous FS in the soft tissue only; 1, inhomogeneous FS

in the bone and soft tissue; and 0, little or no FS (Figure 2).¹⁰ In ligament evaluation, a score of 3 indicates the ability to evaluate >75% of the whole course of ACL and posterior cruciate ligament (PCL); 2, 50–75%; 1, 25–50%; and 0, <25%.⁹ In the cartilage evaluation section, a score of 3 indicates the ability to evaluate >75% of the entire cartilage including both the femoral and patellar cartilage; 2, 50–75%; 1, 25–50%; and 0, <25% (Figure 3).

(3) Diagnostic performance

Diagnostic performance of mDixon and FSE T2WI was evaluated, according to whether a meniscal tear, cartilage injury or cruciate ligament injury was identified (Figures 4 and 5). Each evaluation was performed several times with an interval of at least 2 weeks. Every positive finding was recorded during independent evaluation and correlated with arthroscopic findings, after overall evaluation of the three kinds of knee joint pathology.

Statistical analysis

CNR values of each anatomic region (patellar cartilage, femoral cartilage and ACL) were determined in consensus by two radiologists, and mean CNR values of mDixon and conventional FSE T2WI were compared using Wilcoxon signed rank tests. Anatomic identification scores independently assigned by two radiologists were analyzed using Wilcoxon signed rank tests. Interobserver agreement between the radiologists was analyzed using an intra-class correlation coefficient (ICC). ICC values <0.40 indicated poor agreement, whereas ICC values of 0.40–0.75 indicated fair-to-good agreement, and values >0.75 indicated excellent agreement.¹¹ Diagnostic performance was evaluated using the sensitivity, specificity and accuracy of the meniscal tear, cartilage injury and ligament tear diagnosis, as determined by the use of mDixon images and conventional FSE T2WI. The surgical findings were used as the reference standard. We used the McNemar test for the analysis of sensitivity, specificity and accuracy. Statistical analyses were performed using PASW software v. 18.0 (IBM, Armonk, NY), and p values ≤ 0.05 were considered to be statistically significant.

Figure 2. A 29-year-old female with knee pain without trauma. (a) Sagittal fat-suppressed fast spin-echo T_2 weighted image of the knee [repetition time (TR)/echo time (TE) = 4000/70 ms, field of view = 16 cm, slice = 3 mm and matrix = 330×250 pixels] showing inhomogeneous fat suppression in the subcutaneous fat layer of the posterior portion of the knee (arrow); but, fat suppression of the bone marrow appears homogeneous. The anatomic identification score of the fat suppression was 2. (b) A corresponding three-point Dixon water-only image (TR/TE = 2700/80 ms, field of view = 16 cm, slice = 3 mm and matrix = 360×280 pixels) showing homogeneous fat suppression of the bone and soft tissue (arrow). The anatomic identification score of the fat suppression was 3.

Figure 3. A 20-year-old male with instability of the knee joint after surgery owing to trauma. (a) A sagittal fat-suppressed fast spin-echo T_2 weighted image of the knee [repetition time (TR)/echo time (TE) = 4600/70 ms, field of view = 16 cm, slice = 3 mm and matrix = 330×250 pixels] showing marked image distortion and blurring of the cartilage of the femur (arrows). The anatomic identification scores of the fat suppression and cartilage evaluation were 2 and 2, respectively. (b) A corresponding three-point Dixon water-only image (TR/TE = 2900/80 ms, field of view = 16 cm, slice = 3 mm and matrix = 360×280 pixels) showing homogeneous fat suppression of the bone and soft tissue (arrows). The femoral cartilage is also well delineated. Nevertheless, the image still has image distortion around the tibial fixation site and inhomogeneous fat suppression. The anatomic identification score of the fat suppression and cartilage evaluation were 3 and 3, respectively.

RESULTS

Out of a total of 66 cases, 41 (62%) cases had meniscal tears: 22 cases had medial meniscal tears, 14 cases had lateral meniscal tears, 6 cases had medial meniscal root tears and 2 cases had bucket handle tears of the lateral meniscus. 25 (38%) patients had cartilage injury: 18 patients had medial femoral cartilage injuries, 4 patients had lateral femoral cartilage injuries, 4 patients had patellar cartilage injuries and 1 case had both lateral femoral and patellar cartilage injuries. 17 (26%) patients had cruciate ligament injury: 10 cases of partial tears of the ACL, 6 cases with complete tears of the ACL, and 1 case each of partial tear of PCL, complete tear of PCL and complete tear of both ACL and PCL.

The mean SNRs and CNRs are described in Table 2. The mean SNRs and CNRs of the patellar cartilage, femoral cartilage and ACL were significantly higher on T2WI and FS T2WI than on mDixon, except for the mean SNR of ACL on in-phase images.

The mean scores for the identification of anatomic structures and FS are summarized in Table 3. The anatomic identification scores did not show significant differences, except for inferiorities of in-phase mDixon in the evaluation of the cruciate ligament ($p = 0.005$ and 0.013 , respectively). The mDixon showed fewer metal artefacts than FSE FS T2WI for certain cases in which it was impossible to evaluate marrow pathology on FSE T2WI owing to image distortion (Figure 3).

Figure 4. A 58-year-old male with knee joint pain without trauma. (a) A sagittal fat-suppressed fast spin-echo T_2 weighted image [repetition time (TR)/echo time (TE) = 3800/70 ms, field of view = 16 cm, slice = 3 mm and matrix = 330×250 pixels] of the knee showing a radial tear of the posterior portion of the medial meniscus (arrow). (b) A corresponding three-point Dixon water-only image (TR/TE = 2900/80 ms, field of view = 16 cm, slice = 3 mm and matrix = 360×280 pixels) showing the radial tear of the posterior portion of the medial meniscus (arrow). The injury of the femoral articular cartilage is also seen. (c). An arthroscopic image revealing the definite radial tear of the meniscus (arrow).

Figure 5. A 58-year-old female with knee joint pain without trauma. (a) A sagittal fast spin-echo T_2 weighted image [repetition time (TR)/echo time (TE) = 3600/70 ms, field of view = 16 cm, slice = 3 mm and matrix = 360×280 pixels] of the knee showing the cartilage injury in the medial femoral condyle (arrow). (b) A corresponding three-point Dixon in-phase image (TR/TE = 2700/80 ms, field of view = 16 cm, slice = 3 mm and matrix = 360×280 pixels) showing a cartilage injury in the medial femoral condyle (arrow). (c) An arthroscopic image revealing the cartilage defect of the femoral condyle (arrow).

ICCs for anatomic identification scores on mDixon and FSE T2WI are described in Table 4. Overall interobserver agreement was excellent (0.754–0.883). ICCs of the scores of the cruciate ligament were higher than those of other evaluations (0.776 and 0.779, respectively).

When we classified the reference diagnoses as normal and abnormal, the sensitivities of both mDixon and T2WI ranged from 82.9% to 100% and the specificities of mDixon ranged from 87.8% to 100% compared with 90.2–100% for T2WI (Table 5). The accuracy of both mDixon and T2WI ranged between 89.4% and 95.5%. There were no significant differences in sensitivity, specificity and accuracy between mDixon and T2WI for diagnostic performance ($p = 0.500$ – 1.000).

DISCUSSION

The mDixon technique rapidly generates multiple image types in a single acquisition.⁶ Among these images, the middle echo with 0 phase offset is a T2WI without FS.⁶ To generate water-only images and fat-only images, three source images are used with a novel phase correction algorithm.^{12–17} The mDixon can produce T2WI with and without FS in a single acquisition, which might result in a 56% reduction in scan time compared with combined FSE T2WI and FS T2WI acquisition.⁶ For imaging of the musculoskeletal system, mDixon provides more homogeneous and robust FS in the extremities and spine, especially in the hands and feet, than chemical shift-selective FS (CHESS).^{16,18} Similar techniques with vendor-specific names are IDEAL (iterative decomposition of water and fat with echo

Table 2. Mean signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR)

Images		Mean SNR	SEM	p -value	Mean CNR	SEM	p -value
Water-only image and FS image	mDixon patellar cartilage	23.00 (± 13.44)	1.96	<0.001	145.97 (± 67.94)	9.91	<0.001
	FS T2WI patellar cartilage	42.50 (± 27.53)	4.01		277.27 (± 109.52)	15.97	
	mDixon femoral cartilage	34.98 (± 19.82)	2.89	<0.001	133.99 (± 61.48)	8.97	<0.001
	FS T2WI femoral cartilage	70.10 (± 34.76)	5.07		199.67 (± 105.31)	15.36	
	mDixon anterior cruciate ligament	11.66 (± 17.15)	2.50	<0.001	157.31 (± 65.50)	9.56	<0.001
	FS T2WI anterior cruciate ligament	18.32 (± 17.53)	2.56		251.45 (± 125.32)	18.28	
In-phase image and T2WI	mDixon patellar cartilage	16.70 (± 11.82)	1.87	<0.001	88.03 (± 79.10)	12.51	<0.001
	T2WI patellar cartilage	20.75 (± 12.77)	2.02		117.13 (± 60.61)	9.58	
	mDixon femoral cartilage	22.86 (± 24.57)	3.88	<0.001	81.88 (± 67.39)	10.65	<0.001
	T2WI femoral cartilage	30.85 (± 25.55)	4.04		107.04 (± 47.34)	7.48	
	mDixon anterior cruciate ligament	11.26 (± 14.22)	2.25	0.523	93.47 (± 76.66)	12.12	<0.001
	T2WI anterior cruciate ligament	11.50 (± 14.29)	2.26		126.38 (± 57.27)	9.06	

FS, fat suppression; mDixon, three-point Dixon; SEM, standard error of the mean; T2WI, T_2 weighted image. Data in parentheses are standard deviations.

Table 3. Mean anatomic identification scores of the images

Images	Sharpness of the image		FS		Cartilage evaluation		Total	
	Reader 1	Reader 2	Reader 1	Reader 2	Reader 1	Reader 2	Reader 1	Reader 2
Water-only image and FS image								
mDixon	2.85 (± 0.40)	2.84 (± 0.48)	2.87 (± 0.38)	2.79 (± 0.41)	2.93 (± 0.31)	2.85 (± 0.47)	8.65 (± 0.77)	8.49 (± 1.19)
FS T2WI	2.90 (± 0.31)	2.85 (± 0.36)	2.81 (± 0.47)	2.79 (± 0.48)	2.09 (± 0.76)	2.94 (± 0.24)	8.684 (± 0.72)	8.59 (± 0.93)
<i>p</i> -value	0.527	0.763	0.102	0.739	0.414	0.234	1.000	0.836
Images	Sharpness of the image		Cruciate ligament evaluation		Cartilage evaluation		Total	
	Reader 1	Reader 2	Reader 1	Reader 2	Reader 1	Reader 2	Reader 1	Reader 2
In-phase image and T2WI								
mDixon	2.85 (± 0.36)	2.85 (± 0.40)	2.56 (± 0.72)	2.68 (± 0.53)	2.90 (± 0.31)	2.82 (± 0.42)	8.31 (± 1.03)	8.35 (± 1.05)
T2WI	2.93 (± 0.26)	2.91 (± 0.29)	2.75 (± 0.53)	2.82 (± 0.42)	2.91 (± 0.29)	2.90 (± 0.31)	8.59 (± 0.76)	8.63 (± 0.75)
<i>p</i> -value	0.046	0.102	0.005	0.013	0.317	0.059	<0.001	0.002

FS, fat suppression; mDixon, three-point Dixon; T2WI, T_2 weighted image. Data in parentheses are standard deviations.

asymmetry and least-squares estimation) of GE healthcare and two Dixon and three Dixon of Siemens Medical Solution.¹⁹ The IDEAL technique is known to be a highly SNR-efficient method that effectively uses the information acquired in source data for the evaluation of calculated water and fat images.²⁰ Nevertheless, in our study, mDixon did not show superiorities in SNR and CNR over T2WI or FS T2WI. Moreover, in most cases, the SNRs and CNRs of the cartilage and ACL with mDixon were lower than those of FSE T2WI, with the exception of SNR of ACL on in-phase imaging. Low et al⁶ reported that the mDixon water-only image is superior to the STIR image with respect to image quality and that the homogeneity of FS is equal to that of the STIR image. Our results for the anatomic identification score of mDixon on FS were also similar to those of FS T2WI ($p > 0.05$, Table 3). The mDixon technique could achieve excellent fat–water separation in cases with metallic foreign bodies (Figure 3). FSE FS T2WI is known to be susceptible to magnetic field inhomogeneity caused by susceptibility differences of off-isocentre imaging, large fields of view and the presence of a metallic material.⁸ We found that mDixon is less sensitive to magnetic field inhomogeneity than FSE FS T2WI and can be useful in the evaluation of cartilage injury

in the post-surgical state for patients with metal devices, although the image still has distortion around the metal fixation site and insufficient homogeneous FS. These results are consistent with reports in previous studies that the IDEAL method reduces metallic artefacts and provides uniform FS.^{8,21}

Low et al⁶ reported that mDixon water-only images show better anatomic sharpness and less motion artefact. We found that the mDixon water-only image was not inferior, but was also not superior, to FS T2WI in the anatomic identification of image sharpness (Table 3). Similarly, on in-phase images, we could not find a significant difference in the anatomic identification score of image sharpness between mDixon and T2WI. The anatomic identification scores of cartilage evaluation were also similar between mDixon and T2WI (and FS T2WI). The mDixon was inferior to T2WI in cruciate ligament evaluation on in-phase images (Table 3). However, the diagnostic ability for cruciate ligament injury of the mDixon was not inferior to that of T2WI (Table 5). Our study results indicate equivalent diagnostic ability for in-phase mDixon and T2WI in the evaluation of the meniscal tear, cartilage injury and ligament injury, which is consistent with the results of a previous study.⁶

Table 4. Intraclass correlation coefficients (ICCs) of anatomic identification scores between radiologists

Images	Sharpness of the image	FS	Cartilage evaluation	Total
Water-only image and FS image				
mDixon	0.667 (0.508–0.782)	0.710 (0.567–0.812)	0.768 (0.644–0.852)	0.815 (0.712–0.883)
FS T2WI	0.581 (0.397–0.720)	0.698 (0.549–0.804)	0.656 (0.495–0.774)	0.820 (0.721–0.886)
Images	Sharpness of the image	Cruciate ligament evaluation	Cartilage evaluation	Total
In-phase image and T2WI				
mDixon	0.621 (0.446–0.749)	0.779 (0.655–0.860)	0.709 (0.560–0.813)	0.754 (0.628–0.841)
T2WI	0.508 (0.304–0.668)	0.776 (0.656–0.857)	0.706 (0.561–0.809)	0.830 (0.736–0.892)

FS, fat suppression; mDixon, three-point Dixon; T2WI, T_2 weighted image. Data in parentheses are 95% confidence interval.

ICC values are characterized as follows: poor agreement (≤ 0.4), fair-to-good agreement ($0.4 < \text{ICC} \leq 0.75$) and excellent agreement (> 0.75).

Table 5. Sensitivity, specificity and accuracy of three-point Dixon (mDixon) and T_2 weighted images (T2WIs) in diagnosing meniscal, cartilage and ligament injuries (%)

Images		Sensitivity (%)		Specificity (%)		Accuracy (%)	
		Reader 1	Reader 2	Reader 1	Reader 2	Reader 1	Reader 2
Meniscal injury	mDixon	90.2 (37/41)	92.7 (38/41)	100 (25/25)	100 (25/25)	93.9 (62/66)	95.5 (63/66)
	95% confidence interval	79.0–96.6	82.8–98.0	88.7–100	88.7–100	86.7–97.9	88.7–98.7
	FS T2WI	87.8 (36/41)	90.2 (37/41)	100 (25/25)	100 (25/25)	92.4 (61/66)	93.9 (62/66)
	95% confidence interval	76.1–95.1	79.0–96.6	88.7–100	88.7–100	84.7–97.0	86.7–97.9
	<i>p</i> -value	1.000	1.000	1.000	1.000	1.000	1.000
Cartilage injury	mDixon	92.0 (23/25)	100 (25/25)	97.6 (40/41)	87.8 (36/41)	95.5 (63/66)	92.4 (61/66)
	95% confidence interval	76.9–98.6	88.7–100	88.9–99.9	76.1–95.1	88.7–98.7	84.7–97.0
	FS T2WI	92.0 (23/25)	100 (25/25)	95.1 (39/41)	90.2 (37/41)	93.9 (62/66)	93.9 (62/66)
	95% confidence interval	76.9–98.6	88.7–100	85.4–99.1	79.0–96.6	86.7–97.9	86.7–97.9
	<i>p</i> -value	1.000	1.000	1.000	1.000	1.000	1.000
Ligament injury	mDixon	85.0 (17/20)	90.0 (18/20)	95.7 (44/46)	95.7 (44/46)	92.4 (61/66)	93.9 (62/66)
	95% confidence interval	65.6–95.8	71.7–98.2	86.9–99.2	86.9–99.2	84.7–97.0	86.7–97.9
	FS T2WI	85.0 (17/20)	90.0 (18/20)	95.7 (44/46)	95.7 (44/46)	92.4 (61/66)	93.9 (62/66)
	95% confidence interval	65.6–95.8	71.7–98.2	86.9–99.2	86.9–99.2	84.7–97.0	86.7–97.9
	<i>p</i> -value	1.000	1.000	1.000	1.000	1.000	1.000
Meniscal injury	mDixon	85.0 (34/40)	92.5 (37/40)	100 (26/26)	96.2 (25/26)	90.9 (60/66)	93.9 (62/66)
	95% confidence interval	72.5–93.3	81.7–97.9	89.1–100	83.0–99.8	82.8–96.0	86.7–97.7
	T2WI	85.0 (34/40)	92.5 (37/40)	100 (26/26)	96.2 (25/26)	90.9 (60/66)	93.9 (62/66)
	95% confidence interval	72.5–93.3	81.7–97.9	89.1–100	83.0–99.8	82.8–96.0	86.7–97.9
	<i>p</i> -value	1.000	1.000	1.000	1.000	1.000	1.000
Cartilage injury	mDixon	84.0 (21/25)	92.0 (23/25)	100.0 (41/41)	92.7 (38/41)	93.9 (62/66)	92.4 (61/66)
	95% confidence interval	67.0–94.3	76.9–98.6	93.0–100	82.2–98.0	86.7–97.9	84.7–97.0
	T2WI	84.0 (21/25)	96.0 (24/25)	100.0 (41/41)	92.7 (38/41)	93.9 (62/66)	93.9 (62/66)
	95% confidence interval	67.0–94.3	82.4–99.8	93.0–100	82.2–98.0	86.7–97.9	86.7–97.9
	<i>p</i> -value	1.000	1.000	1.000	1.000	1.000	1.000
Ligament injury	mDixon	89.5 (17/19)	89.5 (17/19)	93.6 (44/47)	91.5 (43/47)	92.4 (61/66)	90.9 (60/66)
	95% confidence interval	70.4–98.1	70.4–98.1	84.3–98.2	81.6–97.0	84.7–97.0	82.8–96.0
	T2WI	89.5 (17/19)	89.5 (17/19)	97.9 (46/47)	93.6 (44/47)	95.5 (63/66)	92.4 (61/66)
	95% confidence interval	70.4–98.1	70.4–98.1	90.3–99.9	84.3–98.2	88.7–98.7	84.7–97.0
	<i>p</i> -value	1.000	1.000	0.500	1.000	0.500	1.000

FS, fat suppression.

Numbers in parentheses represent the number of patients used to calculate percentages.

The scan time for mDixon is another important issue. Our scan time for the mDixon was 3 min and 40 s. Unlike three-dimensional isotropic FSE T_2 weighted MR sequences such as VISTA, mDixon does not require extra reformation time. The total scan time for sagittal FSE FS T2WI and FSE T2WI was 5 m. Thus, the substitution of both sagittal FSE T2WIs and FS T2WIs with mDixon can save 27% of the scan time.

Our study has several limitations. First, we used subjective evaluation criteria to produce an anatomic identification score for image sharpness, FS and cartilage shape. Nevertheless, we confirmed that the scores were fairly reproducible because the ICCs of the scores were very high. Second, it is difficult to provide a true quantitative comparison of SNR and CNR between the two different MR sequences obtained with different

MR parameters. Third, there was essentially no way to blind the two observers as far as what sequences they were evaluating, and the surgeon was not completely blind to the MR findings.

In conclusion, mDixon provides simultaneous acquisition of T2WI with and without FS and can reduce the scan time for knee joint MRI by approximately 27%. Therefore, there would be a net saving in time, if mDixon was the only sequence used. The mDixon images have equivalent anatomic identification abilities, with the exception of cruciate ligament delineation on in-phase images, and have diagnostic performance comparable with that of FSE T2WI for meniscal, cartilage and ligament injuries of the knee joint.

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