

가
 : 15 T2- (PDWSE and
 T2WSE), (TSE), (MPGR), 3 (3D
 steady-state gradient-echo, 3DGRE) 5가
 , T1- (T1WSE) 3 (3D spoiled
 gradient-echo, 3DSPGR)
 5 , 4
 (SNR) - (CNR)
 : 3DSPGR T1WSE 가
 가 (negative contrast)가
 (positive contrast)가 가
 - - CNR 가 TSE(-351.1 ± 15.3)
 , - - CNR -14.7 ± 10.8
 (negative contrast)가 가 MPGR(CNR = -74.7)
 3DGRE(CNR = -34.3) . - - CNR MPGR(161.9 ± 17.7)
 가 (CNR = -81.8)가 가
 T1WSE(CNR 가= 156.9)가
 CNR
 MPGR 가
 , 3DSPGR T1WSE
 : MPGR , T1WSE
 가
 3DGRE 3DSPGR
 (magneti-
 zation transfer contrast, MTC)(2-5), spoiled GRASS (SP-
 GR) (6), fat-suppressed 3-dimensional SPGR (7-11)
 (MR) 가
 가

(1).

가가

가

210 MR

(subchondral bone) (signal-to-noise ratios, S-NR)

MR (contrast-to-noise ratios, CNR) (12,13).

1.5T Gyroscan ACS-NT (Philips, Netherlands) local coil

MR MR

T1- (T1WSE), (PDWSE), T2- (T2WSE), (TSE) (multiplanar gradient-echo, MPGR), 3 (3D steady-state gradient-echo, 3D-GRE) 3 (3D spoiled gradient-echo, 3DSPGR) PDWSE, T2WSE, TSE, MPGR, 3DGRE (magnetization transfer contrast, MTC), T1WSE 3DSPGR (fat suppression)

(FOV) 150 cm, (matrix) 256 × 205, / (slice thickness/gap) 5mm/0.5mm

T1WSE 450/15/90 ° (TR/TE/flip angle), 2excitations, PDWSE T2WSE 2500/ 20,100/ 90 °, 1excitation, TSE 3000/100/90 °, 4excitations, MPGR 600/14/35 °, 2 excitations, 3DGRE 45/14/35 °, 2 excitations, 3DSPGR 45/14/60 °, 2 excitations (Table 1).

off-resonance, 700 pulse angle, 1500 Hz offset, 250 Hz bandwidth, 10 msec length

(frequency selective fat suppression)

1 MR 147†, 15

(0, no identifiable;1, poor;2, average;3, good;4, excellent)

4 (0, no effect;1, mild;2, moderate;3, marked)

Table 2. Mean Scores of Articular Cartilage by Qualitative Evaluation

Sequences	without MTC (scores, 0-4)	with MTC (scores, 0-4)	Effects (scores, 0-3)
PDWSE	1.2	1.6	0.8
T2WSE	1.6	1.6	0
TSE	1.4	1.4	0
MPGR	0.8	3.0	2.2
3DGRE	1.2	2.2	1.2

	withoutFS (scores, 0-4)	withFS (scores, 0-4)	Effects (scores, 0-3)
T1WSE	2.6	4.0	3.0
3DSPGR	3.2	4.0	3.0

Abbreviations : PDWSE= proton density-weighted spin-echo, T2WSE= T2-weighted spin-echo, TSE= turbo spin-echo, MPGR= multiplanar gradient-echo, 3DGRE= 3 dimensional steady-state gradient-echo, T1WSE= T1-weighted spin-echo, 3DSPGR= 3 dimensional spoiled gradient-echo, MTC= magnetization transfer contrast, FS= fat suppression.

Table 1. Scan Parameters for Variable Pulse Sequences

Sequences	TR(msec)	TE(msec)	Flip angle(degree)	Number of Excitation	Scan Time
PDWSE	2500	20	90	1	4 min 18 sec
T2WSE	2500	100	90	1	4 min 18 sec
TSE	3000	100	90	4	2 min 51 sec
MPGR	600	14	35	2	3 min 18 sec
3DGRE	45	14	35	2	2 min 50 sec
T1WSE	450	15	90	2	2 min 29 sec
3DSPGR	45	14	60	2	2 min 50 sec

Note : All scans were performed with parameters of a FOV of 150 cm, a matrix of 256 × 205, a slice thickness of 5 mm, interslice gap of 0.5 mm. The echo train length in TSE was 11.

Abbreviations : PDWSE= proton density-weighted spin-echo, T2WSE= T2-weighted spin-echo, TSE= turbo spin-echo, MPGR= multiplanar gradient-echo, 3DGRE= 3 dimensional steady-state gradient-echo, T1WSE= T1-weighted spin-echo, 3DSPGR= 3 dimensional spoiled gradient-echo.

MPGR, (negative contrast) PDWSE, T2WSE, TSE, 3DGRE 가 가
 3DSPGR (positive contrast) T1WSE 3.0 가 3DGRE(score 3.0) T1WSE (score
 MPGR (score 2.2), 3DGRE(score 1.2), PDWSE(score 0.8) MPGR (s-
 3DSPGR 가 가 T2WSE TSE
 MPGR(score 0.8) 가 가 가 (Table 2) (Fig. 1 and

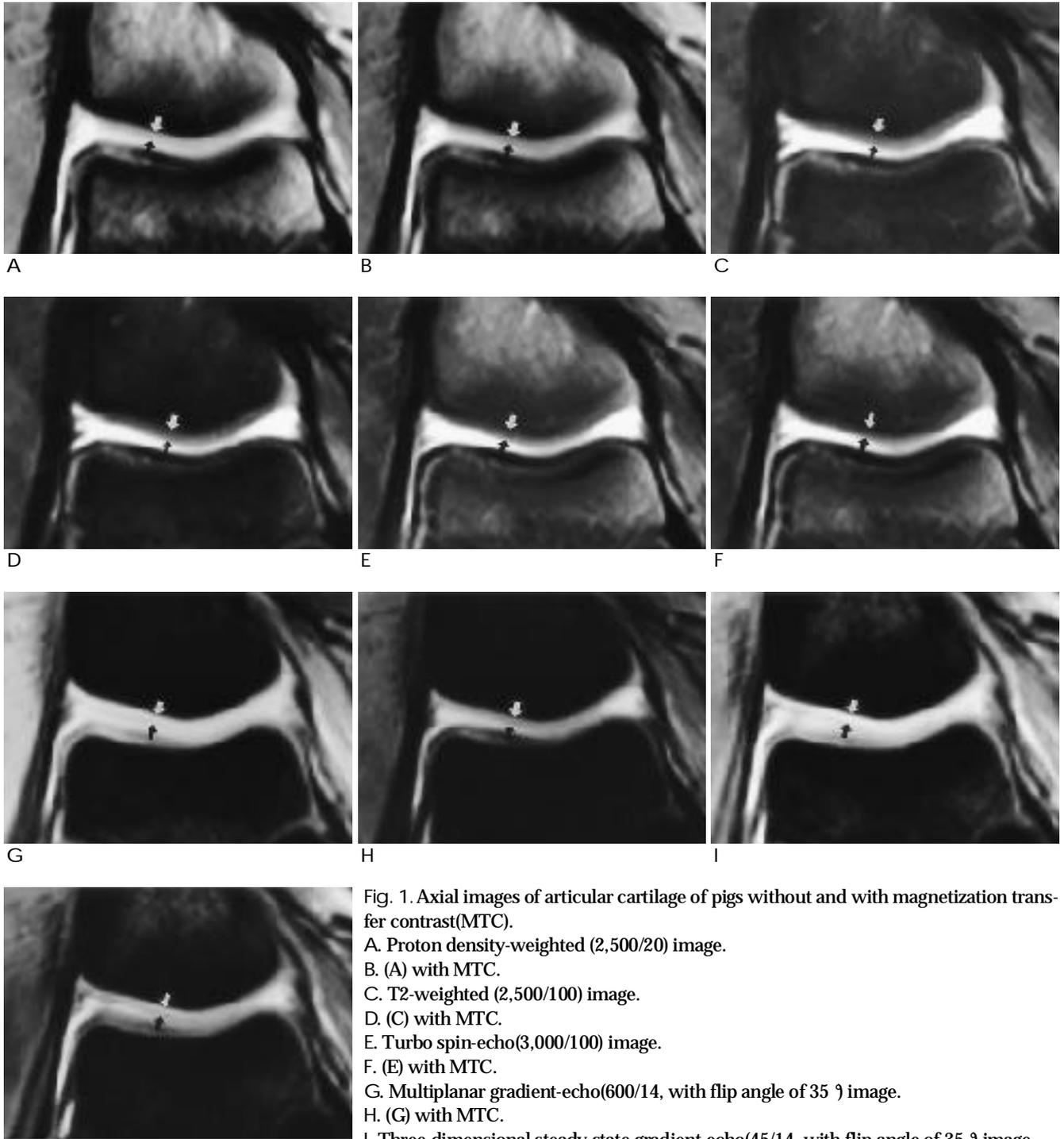


Fig. 1. Axial images of articular cartilage of pigs without and with magnetization transfer contrast(MTC).
 A. Proton density-weighted (2,500/20) image.
 B. (A) with MTC.
 C. T2-weighted (2,500/100) image.
 D. (C) with MTC.
 E. Turbo spin-echo(3,000/100) image.
 F. (E) with MTC.
 G. Multiplanar gradient-echo(600/14, with flip angle of 35 °) image.
 H. (G) with MTC.
 I. Three-dimensional steady-state gradient-echo(45/14, with flip angle of 35 °) image.
 J. (I) with MTC. Note evident visualization of cartilage in (H) and (J) in contrast to other sequences. These findings indicate that MTC increase the negative contrast of cartilage and, therefore, to be helpful in depiction of cartilage. (black and white arrows indicate superficial and basal margins of cartilage, respectively)

2). MPGR 3DGRE
 SNR MPGR (198.1 ± 22.3) 가 SNR 3DGRE (202.2 ± 30.0) MPGR (198.1 ± 22.3) 가 T2WSE (54.3 ± 14.5) 가 (Table 3). SNR TSE (427.8 ± 8.4), 3DGRE (307.0 ± 6.7), T2WSE (228.2 ± 2.8), MPGR (216 ± 2.5), PDWSE (173.2 ± 2.8) T1WSE (58.1 ± 1.5), 3DGRE (42.5 ± 1.9) SNR (Table 4).
 4). SNR T1WSE (202.0 ± 16.3), PDWSE (136.4 ± 8.9), TSE (119.8 ± 9.2) MPGR (36.6 ± 4.4) T2WSE (32.4 ± 3.4) 가 (Table 5).

Table 3. Signal-to-Noise Ratios of Articular Cartilage

Sequences	without MTC	with MTC	Difference
PDWSE	138.7 ± 13.4	130.7 ± 15.7	-8.0
T2WSE	54.3 ± 14.5	48.2 ± 13.3	-6.1
TSE	102.3 ± 16.9	103.3 ± 18.4	1.0
MPGR	198.1 ± 22.3	113.4 ± 18.4	-84.7
3DGRE	202.2 ± 30.0	184.4 ± 27.5	-17.8
	without FS	with FS	Difference
T1WSE	111.5 ± 10.3	116.4 ± 9.8	4.9
3DSPGR	119.4 ± 14.1	136.1 ± 16.1	16.7

Abbreviations : PDWSE= proton density-weighted spin-echo, T2WSE= T2-weighted spin-echo, TSE= turbo spin-echo, MPGR= multiplanar gradient-echo, 3DGRE= 3 dimensional steady-state gradient-echo, T1WSE= T1-weighted spin-echo, 3DSPGR= 3 dimensional spoiled gradient-echo, MTC= magnetization transfer contrast, FS= fat suppression.

가 , MP-
 가 , 3DGRE, PDWSE,
 GR 가 3DGRE, PDWSE,
 T2WSE, TSE (magnetization transfer ratio)
 MPGR 가 3DGRE,
 T2WSE, PDWSE, TSE (Table 7).
 SPGR T1WSE 가 3D-
 (Table 3-6).
 - - CNR 가 - -

Table 4. Signal-to-Noise Ratios of Normal Saline

Sequences	without MTC	with MTC	Difference
PDWSE	173.2 ± 1.8	180.9 ± 1.8	7.7
T2WSE	228.2 ± 2.8	232.3 ± 2.7	4.1
TSE	427.8 ± 8.4	457.1 ± 6.8	29.3
MPGR	216.1 ± 2.5	208.9 ± 2.6	-7.2
3DGRE	307.0 ± 6.7	328.9 ± 9.9	21.9
	without FS	with FS	Difference
T1WSE	58.1 ± 1.5	52.0 ± 3.6	-6.1
3DSPGR	42.5 ± 1.9	46.5 ± 3.7	4.0

Abbreviations : PDWSE= proton density-weighted spin-echo, T2WSE= T2-weighted spin-echo, TSE= turbo spin-echo, MPGR= multiplanar gradient-echo, 3DGRE= 3 dimensional steady-state gradient-echo, T1WSE= T1-weighted spin-echo, 3DSPGR= 3 dimensional spoiled gradient-echo, MTC= magnetization transfer contrast, FS= fat suppression.

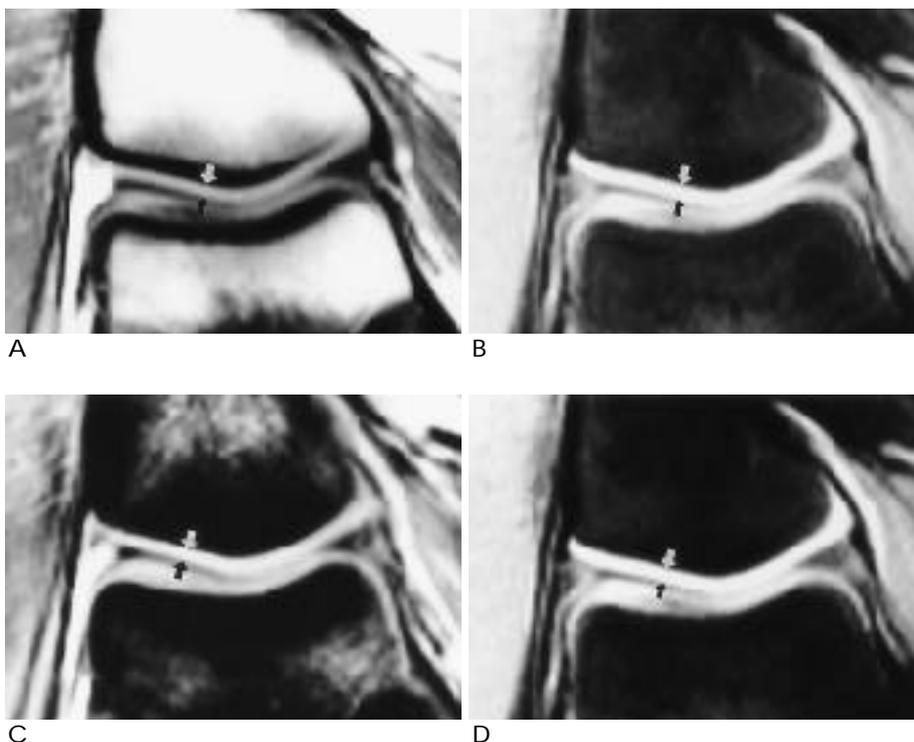


Fig. 2. Axial images of articular cartilage of pigs without and with fat-suppression(FS) technique.
 A. T1-weighted (450/15) image.
 B. (A) with FS.
 C. Three-dimensional spoiled gradient-echo(45/14, with flip angle of 60 °) image.
 D. (C) with FS. The positive contrast of cartilage was more increased in FS imaging, as compared with (A) and (C). More clear visualization of cartilage in FS imaging which provide the cartilage-only image. (black and white arrows indicate superficial and basal margins of cartilage, respectively)

CNR TSE (-351.1 ± 15.3), T2WSE (-186.3 ± 10.7), 3DGRE (-145.5 ± 18.3), MPGR (-96.2 ± 15.9) PDWSE (-50.6 ± 14.2) TSE (-351.1 ± 15.3) 3DSPGR (92.5 ± 12.7) MPGR(CNR = -74.7)

3DGRE(CNR = -34.3) T1WSE 3DSPGR 가 가 가 가 가 (Table 8). CNR PDWSE, TSE, T1WSE MPGR(161.9 ± 17.7) 가 CNR (CNR = -81.8) (Table 9). 3DSPGR(122.9 ± 12.3) 가 CNR (Table 9). CNR 가 CNR 가 MPGR(CNR = -81.8) T1WSE(CNR = 156.9) 가 가 (Table 9).

Table 5. Signal-to-Noise Ratios of Subchondral Bone

Sequences	without MTC	with MTC	Difference
PDWSE	136.4 ± 8.9	134.6 ± 9.5	-1.8
T2WSE	32.4 ± 3.4	31.4 ± 3.1	-1.0
TSE	119.8 ± 9.2	117.1 ± 7.7	-2.7
MPGR	36.6 ± 4.4	34.1 ± 4.6	-2.5
3DGRE	72.6 ± 11.6	85.2 ± 13.0	12.6
	without FS	with FS	Difference
T1WSE	202.0 ± 16.3	50.1 ± 3.1	-151.9
3DSPGR	66.5 ± 12.8	13.9 ± 3.9	-52.6

Abbreviations : PDWSE= proton density-weighted spin-echo, T2WSE= T2-weighted spin-echo, TSE= turbo spin-echo, MPGR= multiplanar gradient-echo, 3DGRE= 3 dimensional steady-state gradient-echo, T1WSE= T1-weighted spin-echo, 3DSPGR= 3 dimensional spoiled gradient-echo, MTC= magnetization transfer contrast, FS= fat suppression.

Table 6. Signal-to-Noise Ratios of Muscles

Sequences	without MTC	with MTC	Difference
PDWSE	123.1 ± 2.6	111.7 ± 2.5	-11.4
T2WSE	34.3 ± 2.3	30.3 ± 2.2	-4.0
TSE	60.4 ± 3.6	61.4 ± 2.8	1.0
MPGR	176.5 ± 3.4	89.6 ± 2.7	-86.9
3DGRE	165.8 ± 7.9	139.2 ± 5.3	-26.6
	without FS	with FS	Difference
T1WSE	93.4 ± 2.3	96.2 ± 1.9	2.8
3DSPGR	101.7 ± 4.7	103.9 ± 5.5	2.2

Abbreviations : PDWSE= proton density-weighted spin-echo, T2WSE= T2-weighted spin-echo, TSE= turbo spin-echo, MPGR= multiplanar gradient-echo, 3DGRE= 3 dimensional steady-state gradient-echo, T1WSE= T1-weighted spin-echo, 3DSPGR= 3 dimensional spoiled gradient-echo, MTC= magnetization transfer contrast, FS= fat suppression.

Table 7. Magnetization Transfer Ratios(MTR, %)

Sequences	Muscle(%)	Cartilage(%)	Saline(%)
MPGR	46.9	40.1	-1.2
3DGRE	21.7	14.9	0.1
PDWSE	9.3	5.8	-4.5
T2WSE	10.1	8.7	-4.7
TSE	5.2	5.3	0.3

Abbreviations : MPGR= multiplanar gradient-echo, 3DGRE= 3 dimensional steady-state gradient-echo, PDWSE= proton density-weighted spin-echo, T2WSE= T2-weighted spin-echo, TSE= turbo spin-echo.

Table 8. Cartilage-Saline Contrast-to-Noise Ratios

Sequences	without MTC	with MTC	Difference
PDWSE	- 35.4 ± 11.9	- 50.6 ± 14.2	-15.2
T2WSE	-176.3 ± 20.2	-186.3 ± 10.7	-10.0
TSE	-329.1 ± 16.7	-351.1 ± 15.3	-22.0
MPGR	- 21.5 ± 19.7	- 96.2 ± 15.9	-74.7
3DGRE	-111.2 ± 25.9	-145.5 ± 18.3	-34.3
	without FS	with FS	Difference
T1WSE	54.7 ± 9	65.5 ± 6.5	10.8
3DSPGR	76.4 ± 13	92.5 ± 12.7	16.1

Abbreviations : PDWSE= proton density-weighted spin-echo, T2WSE= T2-weighted spin-echo, TSE= turbo spin-echo, MPGR= multiplanar gradient-echo, 3DGRE= 3 dimensional steady-state gradient-echo, T1WSE= T1-weighted spin-echo, 3DSPGR= 3 dimensional spoiled gradient-echo, MTC= magnetization transfer contrast, FS= fat suppression.

Table 9. Cartilage-Bone Contrast-to-Noise Ratios

Sequences	without MTC	with MTC	Difference
PDWSE	2.3 ± 4.5	-3.9 ± 6.2	-6.2
T2WSE	22.7 ± 19.6	17.4 ± 10.3	-5.3
TSE	-19.8 ± 8.6	-14.7 ± 10.8	5.1
MPGR	161.9 ± 17.7	80.1 ± 14	-81.8
3DGRE	137.0 ± 20.6	101.2 ± 15.0	-35.8
	without FS	with FS	Difference
T1WSE	-90.3 ± 6.2	66.6 ± 6.7	156.9
3DSPGR	54.4 ± 12.3	122.9 ± 12.3	68.4

Abbreviations : PDWSE= proton density-weighted spin-echo, T2WSE= T2-weighted spin-echo, TSE= turbo spin-echo, MPGR= multiplanar gradient-echo, 3DGRE= 3 dimensional steady-state gradient-echo, T1WSE= T1-weighted spin-echo, 3DSPGR= 3 dimensional spoiled gradient-echo, MTC= magnetization transfer contrast, FS= fat suppression.

:
 T1WSE MPGR 가 가 T2WSE 가 (23).
 TSE 가 가
 4가 가 (Table 8)(Fig. 1). TSE 가 (24,25)
 MR 가 가 SNR TSE
 (1). TSE
 (14), T2 (15-17), T1 가
 (6,18,19), (1,7,9-11), 3 3 가
 5,20), MR (21), (2- (partial volume effect)
 MR (TE), (flip angle) (TR),
 (optimization) (6).
 Table 1 SNR CNR
 (FOV), 15°, 25°, 35°, 45°, 60°
 가 5mm 3 3 3 35°
 mm 가 2-3 가
 SNR 가 가
 가 가 T1
 가 가 T2 T1
 , T2 가 T1, T2 T1
 가 가 (14-17). (Table 8 and 9)(Fig. 1 and 2).
 T1WSE T1
 SNR CNR 3DSPGR
 (Table 8 and 9)(Fig. 2). PDWSE Totterman (11)
 가 , T2WSE - - Peterfy (10), Disler (26) 3 , Reicht (7,9),
 가 spoiled
 가 가 (Table 2)(Fig. 1). artifact) (chemical shift ar-
 TSE가 180 refocusing RF pulse (7,8,26).
 가 (22,23). TSE (free water) (bound water)
 (magnetization)가 (transfer) (cross relaxation)
 가 가

(2,4,5). 가 , 가 , 가 (3,10,20). (2). (subtraction) 3DSPGR (10,27). (Table 8)(Fig. 1 and 2). 가 MR (1,28) Lehner (29) 2 (bilaminar) , Modle (28) 3 (trilaminar) , Recht (7) Rubenstein (30) 2-3 가 , , 3 가 가 MPGR T1WSE 가 3DGRE 3DSPGR

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MR Imaging of Articular Cartilage : Comparison of Magnetization Transfer Contrast and Fat-Suppression in Multiplanar and 3D Gradient-Echo, Spin-Echo, Turbo Spin-Echo Techniques¹

Young Joon Lee, M.D., Eun Young Joo, M.D., Choong Ki Eun, M.D.

¹*Department of Diagnostic Radiology, Pusan Paik Hospital, College of Medicine, Inje University*

Purpose : The purpose of this study was to evaluate the effects of magnetization transfer contrast(MTC) and fat-suppression(FS) in variable spin-echo and gradient-echo sequences for articular cartilage imaging and to determine the optimal pulse sequences.

Materials and Methods : Using variable 7-pulse sequences, the knees of 15 pigs were imaged. Axial images were obtained using proton density and T2-weighted spin-echo (PDWSE and T2WSE), turbo spin-echo (TSE), multiplanar gradient-echo (MPGR), and 3D steady-state gradient-echo (3DGRE) sequences, and the same pulse sequences were then repeated using MTC. Also T1-weighted spin-echo(T1WSE) and 3D spoiled gradient-echo(3DSPGR) images of knees were also acquired, and the procedure was repeated using FS. For each knee, a total of 14 axial images were acquired, and using a 6-band scoring system, the visibility of and the visibilities of the the articular cartilage was analyzed. The visual effect of MTC and FS was scored using a 4-band scale. For each image, the signal intensities of articular cartilage, subchondral bone, muscles, and saline were measured, and signal-to-noise ratios(SNR) and contrast-to-noise ratios(CNR) were also calculated.

Results : Visibility of the cartilage was best when 3DSPGR and T1WSE sequences were used. MTC imaging increased the negative contrast between cartilage and saline, but FS imaging provided more positive contrast. CNR between cartilage and saline was highest when using TSE with FS(-351.1 ± 15.3), though CNR between cartilage and bone then fell to -14.7 ± 10.8. In MTC imaging using MPGR showed the greatest increase of negative contrast between cartilage and saline(CNR change= -74.7); the next highest was when 3DGRE was used(CNR change= -34.3). CNR between cartilage and bone was highest with MPGR(161.9 ± 17.7), but with MTC, the greatest CNR decrease(-81.8) was observed. The greatest CNR increase between cartilage and bone was noted in T1WSE with FS. In all scans, FS provided a cartilage-only positive contrast image, though the absolute value of CNR was lower than that of MTC imaging.

Conclusion : The most prominent effects of MTC and FS were seen in MPGR and T1WSE, respectively, though for cartilage, optimal high signal intensity and contrast can be achieved using 3DGRE with MTC, and 3DSPGR with FS.

Index words : Knee, MR

Knee, ligaments, menisci, and cartilage

Magnetic resonance(MR), fat suppression

Magnetic resonance(MR), magnetization transfer contrast

Address reprint requests to : Young Joon Lee, M.D., Department of Diagonostic Radiology, College of Medicine, Inje University, Pusan Paik Hospital, # 633-165 Gaekum-Dong, Pusanjin-Gu, Pusan, 614-735 Korea.
Tel. 82-51-890-6579 Fax. 82-896-1085