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A Comparative Quantitative Analysis of IDEAL (Iterative Decomposition of Water and Fat with Echo Asymmetry and Least Squares Estimation) and CHESS (Chemical Shift Selection Suppression) Technique in 3.0T Musculoskeletal MRI

Myoung-Hoon Kim[1], Jae-Hwan Cho[2,3], Seong-Gyu Shin[4], Kyung-Rae Dong[5,6], Woon-Kwan Chung[6], Tae-Hyun Park[7], Jae-Ouk Ahn[8]*, Cheol-Soo Park[9], Hyon-Chol Jang[10,11], and Yoon-Shin Kim[11]

[1]*Department of Neuro-Surgery, Yesan Myoungji Hospital, Yesan 340-802, Korea*
[2]*Department of Radiological Science, Gyeongsan University College, Gyeongsan 712-718, Korea*
[3]*Department of Computer Science and Engineering, Soonchunhyang University, Asan 336-745, Korea*
[4]*Department of Radiological Technology, Busan dong-a University Medical Center, Busan 602-715, Korea*
[5]*Department of Radiological Technology, Gwangju Health College University, Gwangju 506-701, Korea*
[6]*Department of Nuclear Engineering, Chosun University, Gwangju 501-759, Korea*
[7]*Department of Radiological Technology, Soonchunhyang university Bucheon Hospital, Bucheon 420-767, Korea*
[8]*Department of Medical IT Engineering, Soonchunhyang University, Asan 336-745, Korea*
[9]*Department of Radiological Science, Hanlym Polytechnic University, Chuncheon 200-711, Korea*
[10]*Department of Radiological Science, Daegu Polytechnic University, Daegu 706-711, Korea*
[11]*Department of Public Health, Hanyang University, Seoul 133-791, Korea*

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Patients who underwent hip arthroplasty using the conventional fat suppression technique (CHESS) and a new technique (IDEAL) were compared quantitatively to assess the effectiveness and usefulness of the IDEAL technique. In 20 patients who underwent hip arthroplasty from March 2009 to December 2010, fat suppression T2 and T1 weighted images were obtained on a 3.0T MR scanner using the CHESS and IDEAL techniques. The level of distortion in the area of interest, the level of the development of susceptibility artifacts, and homogeneous fat suppression were analyzed from the acquired images. Quantitative analysis revealed the IDEAL technique to produce a lower level of image distortion caused by the development of susceptibility artifacts due to metal on the acquired images compared to the CHESS technique. Qualitative analysis of the anterior area revealed the IDEAL technique to generate fewer susceptibility artifacts than the CHESS technique but with homogeneous fat suppression. In the middle area, the IDEAL technique generated fewer susceptibility artifacts than the CHESS technique but with homogeneous fat suppression. In the posterior area, the IDEAL technique generated fewer susceptibility artifacts than the CHESS technique. Fat suppression was not statistically different, and the two techniques achieved homogeneous fat suppression. In conclusion, the IDEAL technique generated fewer susceptibility artifacts caused by metals and less image distortion than the CHESS technique. In addition, homogeneous fat suppression was feasible. In conclusion, the IDEAL technique generates high quality images, and can provide good information for diagnosis.

Keywords : CHESS, IDEAL, susceptibility artifacts, homogeneous fat suppression

1. Introduction

With the aging society, the average life span is prolonged and the social activities of the elderly are on the rise. Consequently, there has been an increase in the incidence of hip fractures (fractures in the femoral neck and intertronchanteric fracture). In particular, despite the development of treatments and rehabilitation techniques, these fractures have a high complication rate and death rate [1]. The incidence of femoral fractures increases noticeably in the sixth decade. Melton *et al.* [2] reported that in the mid-80s, one in three females and one in six males developed hip fractures. According to American statistics, more than 250,000 patients develop hip fractures annually, and the number is estimated to increase 2 fold in 2050, making it an important social issue.

Hip fractures occur primarily in elderly patients with

*Corresponding author: Tel: +82-41-530-1365
Fax: +82-41-530-1548, e-mail: jahn1365@gmail.com

severe osteoporosis due to small trauma. As surgical treatment methods, reduction and internal fixation have been performed in the past but the rate of nonunion, bone necrosis and fixation failure is high. Therefore, bipolar hip arthroplasty and total hip arthroplasty are performed for early walking. Hip arthroplasty that employs the metal on metal articulation was first applied approximately 40 years ago [3, 4]. The durability of the metal used in early products was not good. Recently, arthroplasty using second generation metal on metal articulation was developed [5, 6]. Nevertheless, a range of complications, such as fractures, dislocations, etc., have been encountered after hip arthroplasty. Therefore, radiological tests have been performed to assess the presence or absence of complications after total hip arthroplasty as well as to assess the condition of the hip prosthesis. Regarding radiological tests, plain X-ray radiography was performed as the first test because it is a simple, fast and economical. Subsequently, CT or MRI was also performed. MRI is best for diagnosis but in patients who underwent hip arthroplasty, the devices cause image distortion or susceptibility artifacts, meaning that MRI cannot provide sufficient radiological information in these cases. Of the MRI techniques, fat suppression suppresses the normal fat signals, which can improve the efficacy of diagnosing the infiltration of fats into lesions or invasion into the bone marrow. Therefore, it has been applied as an essential technique for an examination of the musculoskeletal system. In the currently used fat suppression technique, chemical shift selection suppression (CHESS), the level of fat suppression differs according to the inhomogeneity of the main magnetic field in an area (B0). Therefore, inhomogeneous fat suppression can occur in an examination of the area beyond the main magnetic field [7]. In Dixon's method, similarly, depending on the inhomogeneity of the main magnetic field, the level of fat suppression level was shown to be different [8]. Therefore, conventional fat suppression techniques have significant limitations in obtaining homogeneous images. In particular, metal materials can induce more severe inhomogeneous fat suppression because of the difference in the magnetic susceptibility of metal materials from the adjacent tissues. Recently, the iterative decomposition of water and fat with echo asymmetry and least squares estimation (IDEAL) technique was introduced. This technique has been reported to suppress fat homogeneously without affecting the major magnetic field [9].

Therefore, the present study evaluated the effectiveness and utility of the IDEAL technique in patients who underwent hip arthroplasty by a quantitative comparison with the conventional fat suppression technique CHESS.

2. Patients and Methods

2.1 Patients

The subjects were 20 patients who underwent hip arthroplasty from March 2009 to December 2010. Their age ranged from 58 to 72 years with a mean of 68.8 years. Artificial prostheses were made from titanium alloy materials. The length ranged from 190 mm to 385 mm depending on the femoral injury area. The diameter ranged from 14 to 25 mm. The neck shaft angle of the artificial prosthesis was 145° (Fig. 1).

2.2 Data acquisition

The MR images were obtained using a 3.0T MR scanner (Signa 3.0T HDx. GE Healthcare. Milwaukee. WI) and a HD T/R 8ch Torso phased array coil (In vivo Corp. Gainesville. FL). First, T2 weighted sagittal plane images (TR = 3500 sec, TE = 100 msec, NEX = 2) were obtained to assess the level of insertion of artificial materials. Subsequently, prior to contrast enhancement, the fat suppression T2 weighted coronal images were obtained by the CHESS technique using the fast spin-echo (FSE) imaging method. From the same area, the fat suppression T2 weighted coronal plane images were obtained using the IDEAL technique. The imaging parameters were as follows:

Repetition time (TR): 3500 ms, echo time (TE): 90 ms, Matrix: 256 × 256, number of excitation (NEX): 1, Slice thickness: 5.0 mm, field of view (FOV): 380 mm.

In the fast spin-echo (FSE) imaging method employing

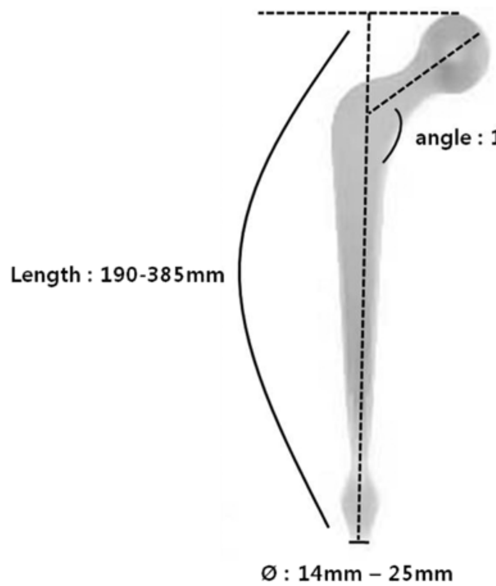

Fig. 1. In regard to the length of a prosthesis, a length ranging from 190 mm to 385 mm could be used depending on the femoral injury area. The diameter ranged from 14 mm to 25 mm, and the neck shaft angle was 145°.

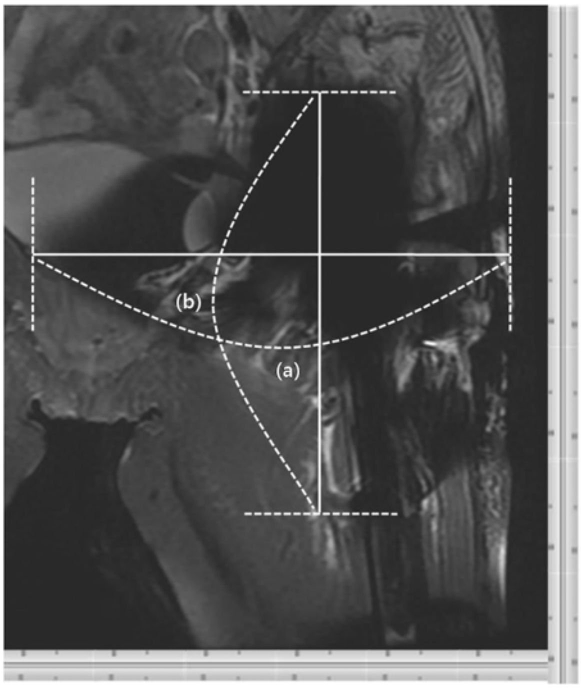

Fig. 2. To measure the length of the area where susceptibility artifacts developed due to metals, the length (a) and the width (b) including maximally the area of the development of artifacts were measured.

the post-contrast CHESS technique, the fat suppression, T1 weighted, coronal plane images were obtained from the same area where the fat suppression T1 weighted images coronal plane images had been obtained by using the IDEAL technique. The imaging parameters were as follows:

Repetition time (TR): 700 ms, echo time (TE): 15 ms, Matrix: 256 × 256, number of excitation (NEX): 1, Slice thickness: 5.0 mm, and field of view (FOV): 380 mm.

Pre-contrast T2 weighted images and post-contrast T1 weighted images obtained using the CHESS and IDEAL techniques were sent to the Advantage Workstation (Ver 4.3, Revision 4. GE healthcare. Milwaukee. WI, USA). First, the length of the area where susceptibility artifacts had developed due to metals was measured to assess the level of distortion of the area of interest. Regarding the measurement points, an image of the midline area including the area where artifacts had developed was acquired, and the width and length were measured (Fig. 2). In addition, a total 5 examiners (one specialist in reading the musculoskeletal system, a resident, and 3 radiology technicians) evaluated the images with regard to the level of susceptibility artifacts and the homogeneity of fat suppression in the three areasanterior area, middle area and posterior area). The window width and window level were preset at 450/40, and were evaluated using a 5 points score; Unacceptable (1 point), Suboptimal (2 points), Adequate (3 points), Good (4 points) and Excellent diagnostic quality (5 points). On the images acquired from the two groups, the difference in the average length of the area where the artifacts had developed was analyzed using a paired student t-test (SPSS win 17.0, Chicago, USA). Based on the images acquired using the IDEAL technique, the ratio statistic of the length on the images acquired by the CHESS and IDEAL techniques was obtained. The results were validated using a paired student t-test. P values < 0.05 were considered significant.

3. Results

On the pre-contrast T2 weighted images, the length of the area where susceptibility artifacts had developed due to metals was measured. On the images acquired using the CHESS technique, the length and width was 24.31 ± 5.43 cm and 28.12 ± 6.25 cm, respectively. On the images acquired using IDEAL technique, the length and width was 13.27 ± 3.77 cm and 25.34 ± 5.44 cm, respectively. In addition, on the post-contrast images, the length of the area where susceptibility artifacts had developed due to metals was measured. On the images acquired using the CHESS technique, the length and width was 25.48 ± 6.02 cm and 30.26 ± 7.04 cm, respectively. On the images acquired using the IDEAL technique, the length and width was 15.21 ± 4.01 cm and 26.22 ± 6.11 cm, respectively (Table 1). On the two images, the length ($p < 0.001$) and width ($p < 0.05$) on the image acquired using the IDEAL technique were shorter than those acquired using the CHESS technique. On the two images, the ratio statistics of the CHESS and IDEAL techniques was calculated based on the images acquired using the

Table 1. Measurement of the length of the area where susceptibility artifacts had developed due to metal (N=20)

Unit: cm

Image	Group	Width	Vertical length
Coronal T2	CHESS	24.31 ± 5.43	28.12 ± 6.25
Weighted image	IDEAL	13.27 ± 3.77	25.34 ± 5.44
(pre)	P-value	0.0002*	0.023**
Coronal T1	CHESS	25.48 ± 6.02	30.26 ± 7.04
Weighted image	IDEAL	15.21 ± 4.01	26.22 ± 6.11
(post)	P-value	0.0002*	0.030**

CHESS: Chemical Shift Selection Suppression, IDEAL: Iterative decomposition of water and fat with echo asymmetry and least squares estimation, Pre: Before contrast injection, post: After contrast injection. The interaction effect was determined using the paired t test model.

*$p < 0.001$, **$p < 0.05$

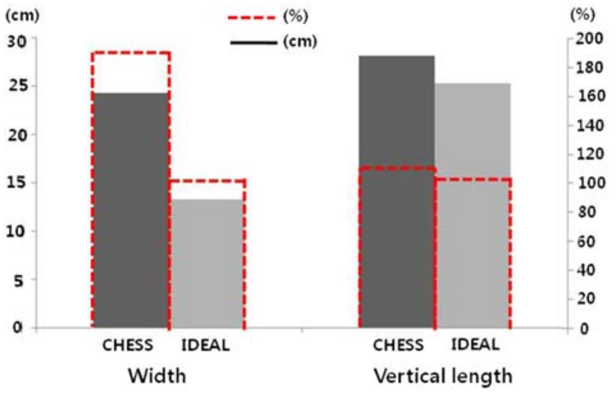

Fig. 3. (Color online) Ratio statistics of the length on the images obtained using the CHESS and IDEAL techniques based on the images obtained using the IDEAL technique.

IDEAL technique. The CHESS technique was approximately 83.2% longer and 10.1% wider than the IDEAL technique (Fig. 3). In other words, the image distortion caused by susceptibility artifacts due to metals was smaller using the IDEAL technique than using the CHESS technique.

The pre-contrast T2 weighted images and post-contrast T1 weighted images acquired using the CHESS and IDEAL techniques were evaluated. In the anterior area, the IDEAL technique developed fewer susceptibility artifacts than the CHESS technique and homogeneous fat suppression ($p < 0.05$) (Table 2) (Fig. 4). In the middle area, the IDEAL technique developed fewer susceptibility artifacts than the CHESS technique, as well as homogeneous fat suppression ($p < 0.05$) (Table 3) (Fig. 5). In the posterior area, the IDEAL technique developed fewer susceptibility artifacts than the CHESS technique ($p < 0.05$). Fat suppression

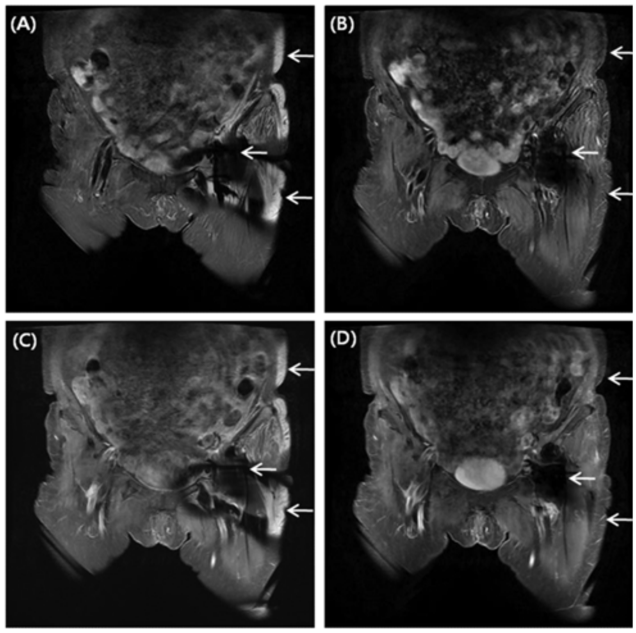

Fig. 4. In the anterior area, pre-contrast T2 weighted images obtained using the CHESS technique (A) and IDEAL technique (B). Post-contrast T1 weighted image obtained using the CHESS technique (C) and IDEAL technique (D).

was not statistically different. Fat suppression by the two techniques was homogeneous ($p < 0.05$) (Table 4) (Fig. 6). Overall, the IDEAL technique developed fewer susceptibility artifacts due to metals and less image distortion than the CHESS technique. Furthermore, homogeneous fat suppression could be achieved. In the anterior (Table 2 and Fig. 4), middle (Table 3 and Fig. 5) and posterior area (Table 4 and Fig. 6), the IDEAL technique developed fewer susceptibility artifacts than the CHESS technique as

Table 2. In the anterior area, evaluation of the images obtained using the CHESS and IDEAL techniques

Image	Group	Susceptibility artifact development level	Homogeneous fat suppression
Coronal T2 Weighted image (pre)	CHESS	1.60 ± 0.54	2.40 ± 0.54
	IDEAL	3.00 ± 0.70	4.00 ± 0.70
	P-value	0.045*	0.035*
Coronal T1 Weighted image (post)	CHESS	2.40 ± 0.54	1.60 ± 0.54
	IDEAL	3.00 ± 0.70	3.20 ± 0.83
	P-value	0.020*	0.045*

CHESS: Chemical Shift Selection Suppression, IDEAL: Iterative decomposition of water and fat with echo asymmetry and least squares estimation, Pre: Before contrast injection, post: After contrast injection. The interaction effect was determined using the paired t test model.
*$p < 0.05$

Table 3. In the middle area, evaluation of the images obtained using the CHESS and IDEAL technique

Image	Group	Susceptibility artifact development level	Homogeneous fat suppression
Coronal T2 Weighted image (pre)	CHESS	2.40 ± 0.54	2.00 ± 0.70
	IDEAL	4.00 ± 1.00	4.00 ± 1.00
	P-value	0.044*	0.011*
Coronal T1 Weighted image (post)	CHESS	3.00 ± 0.70	1.60 ± 0.54
	IDEAL	4.00 ± 1.00	4.00 ± 1.00
	P-value	0.0264*	0.044*

CHESS: Chemical Shift Selection Suppression, IDEAL: Iterative decomposition of water and fat with echo asymmetry and least squares estimation, Pre: Before contrast injection, post: After contrast injection. The interaction effect was determined using the paired t test model.
*$p < 0.05$

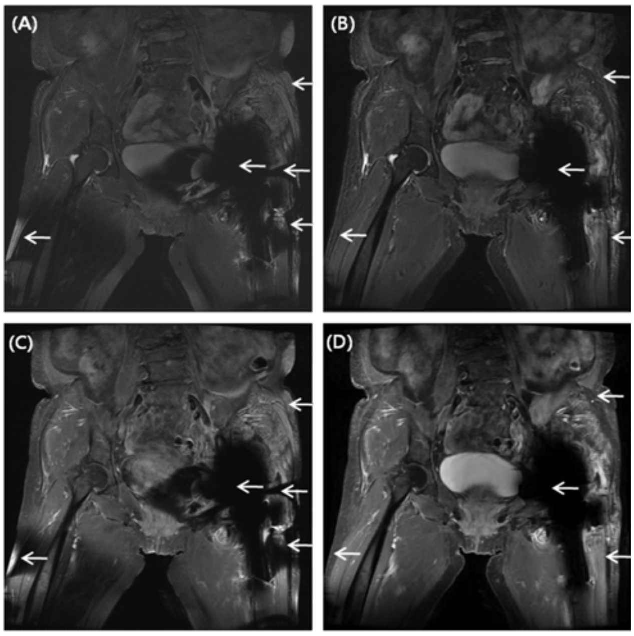

Fig. 5. In the middle area, pre-contrast T2 weighted images obtained using the CHESS technique (A) and IDEAL technique (B). Post-contrast T1 weighted image obtained using the CHESS technique (C) and IDEAL technique (D).

Table 4. In the posterior area, evaluation of the images obtained using the CHESS and IDEAL technique

Image	Group	Susceptibility artifact development level	Homogeneous fat suppression
Coronal T2 Weighted image (pre)	CHESS	2.40 ± 0.89	2.40 ± 0.54
	IDEAL	3.00 ± 0.70	3.20 ± 0.83
	P-value	0.026*	0.178**
Coronal T1 Weighted image (post)	CHESS	1.60 ± 0.54	2.40 ± 0.54
	IDEAL	3.00 ± 0.70	3.20 ± 0.83
	P-value	0.030*	0.274**

CHESS: Chemical Shift Selection Suppression, IDEAL: Iterative decomposition of water and fat with echo asymmetry and least squares estimation, Pre: Before contrast injection, post: After contrast injection. The interaction effect was determined using the paired t test model.
*$p < 0.05$, **$p > 0.05$

well as homogeneous fat suppression ($p < 0.05$). Both techniques produced similar fat suppression.

4. Discussion

Among the MRI techniques available, fat suppression has been used as an essential technique for examining the musculoskeletal system because it suppresses the normal fat signals and increases the efficacy of a diagnosis of fat infiltration into lesions or invasion into the bone marrow.

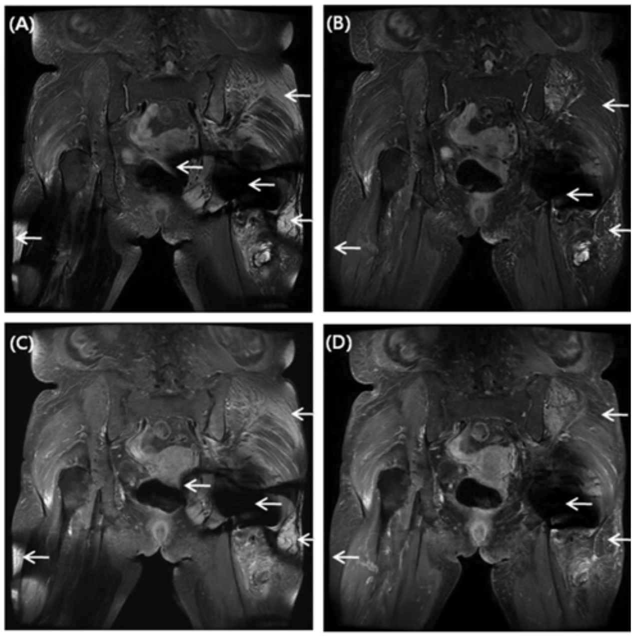

Fig. 6. In the posterior area, pre-contrast T2 weighted image obtained using the CHESS technique (A) and IDEAL technique (B), and post-contrast T1 weighted image obtained using the CHESS technique (C) and IDEAL technique (D).

The CHEES technique, which is used most commonly, is a method that suppresses fat signals by applying the difference in the resonance frequency between water molecules and fat. The chemical environment of hydrogen contained in water molecules and fat is different, and their chemical movement differs by 3.5 ppm. By the application of such a frequency difference, the technique obtains the signal of only one component, either water or fat molecules, but the level of fat suppression can be different if the main magnetic field is heterogeneous. Accordingly, fat suppression may be inhomogeneous in these tests [10] (Fig. 7).

Dixon is a method that suppresses fat by obtaining two different images applying the difference in the processional frequency between water and fat molecules , and adding and subtracting them (Fig. 8). The post-treatment process time for a reconstruction of the two images is long, making the entire process time quite long. The method is also affected greatly by the inhomogeneity of the main magnetic field [11]. On the other hand, the basic principle of the newly developed IDEAL technique is the separation of signals primarily by the phase difference between fat and water molecules. This is a method that modifies the previously applied 2 point Dixon method to a 3 point technique, and the echo of three different phases (water-fat phase shifts $-\pi/6$, $\pi/2$, $7\pi/6$) is obtained by the phase difference according to the difference in resonance fre-

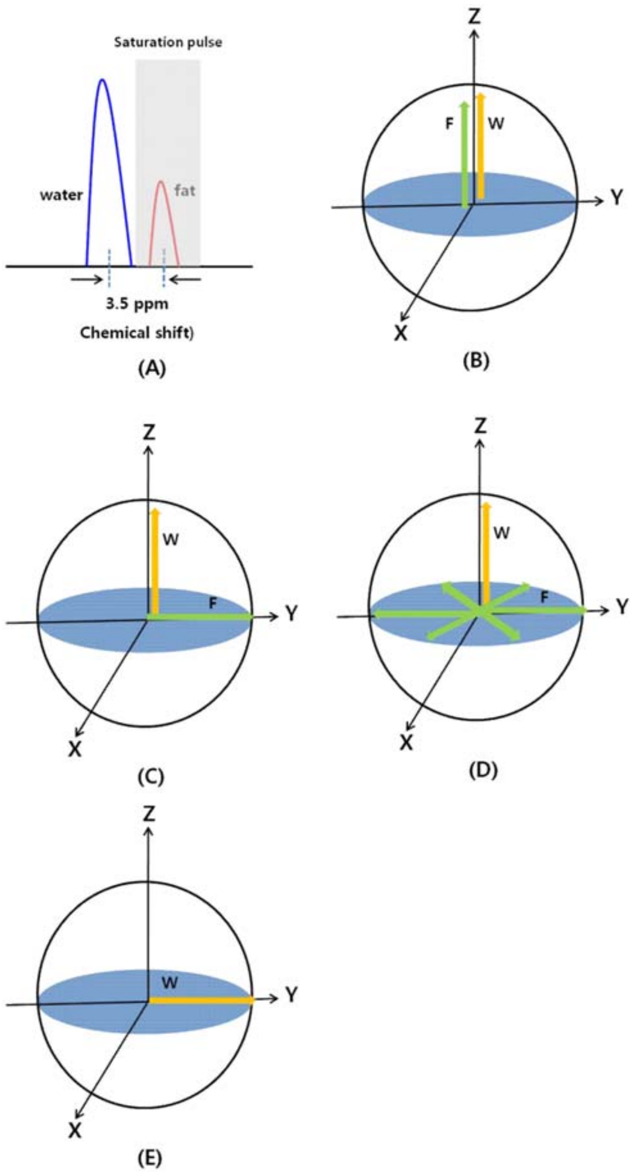

Fig. 7. (Color online) To observe water signals only, saturation pulses that match the resonance frequency of fat molecules were accepted (A, B). Only fat was excited and transversed, and water remained as the Z-axis direction (C). The transverses were decayed artificially by the application of spoiler gradients (D). Only water signals were shown when a routine pulse sequence was added (E).

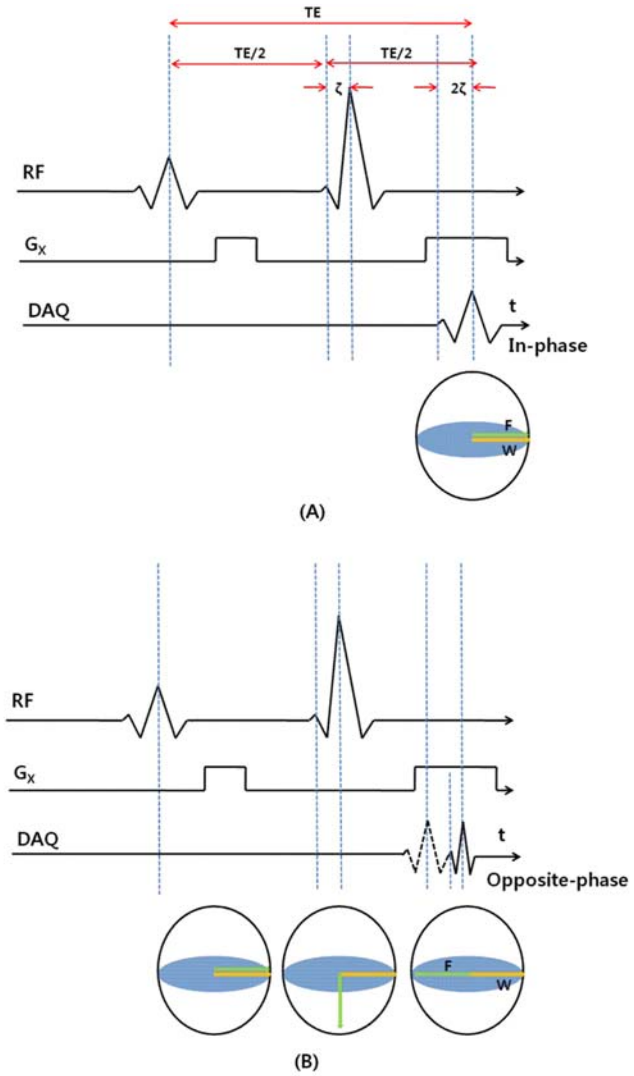

Fig. 8. (Color online) Pulse sequence according to the Dixon method. An inphase (A) and opposite phase (B) were obtained. The in-phase images were routine SE, and the magnetization vector of water and fat were identical. The signals of the opposite phase image were obtained by regulating the time that accepts a 180^0 refocusing pulse (ζ of A) and allowing the proton of fats and water on TE to become opposite phases.) Subsequently, the signals for water only or fat only were obtained by adding and subtracting the image (A) and image (B).

quency between fat and water. Based on this, fat signals and water signals are separated by applying a reconstruction algorithm, and independent water suppression and fat suppression images can be generated [12] (Fig. 9). In other words, for each time echo (TE), the echoes were acquired from 3 different phases, and based on them, 4 types of images (water-only, fat-only, inphase, and out of phase) were reconstructed by the application of a reconstruction algorithm [13]. Studies that applied the IDEAL technique were conducted primarily in the head and deck area. Ma *et al*. [14] compared the 2 point Dixon method and 3 point IDEAL technique in the head and neck area. The Dixon method generated artifacts due to the movement of blood vessels and the difference in susceptibility, and fat suppression was inhomogeneous. With the IDEAL technique, homogeneous fat suppression was achieved, and artifacts due to the difference in susceptibility were reduced. Costa *et al.* [15] reported that the detection rate of lipoma

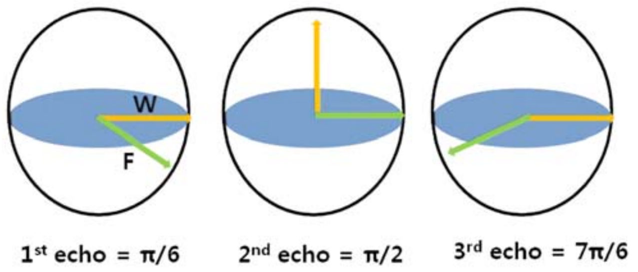

Fig. 9. (Color online) The previously used 2-point Dixon method was modified to a 3-point technique. By the application of the phase difference generated by the difference in the resonance frequency of fats and water, the echoes on three different phases (water-fat phase shifts $-\pi/6$, $\pi/2$, $7\pi/6$) were obtained. Based on them, the fat and water signals were separated using a reconstruction algorithm, and independent fat suppression images and water suppression images were generated.

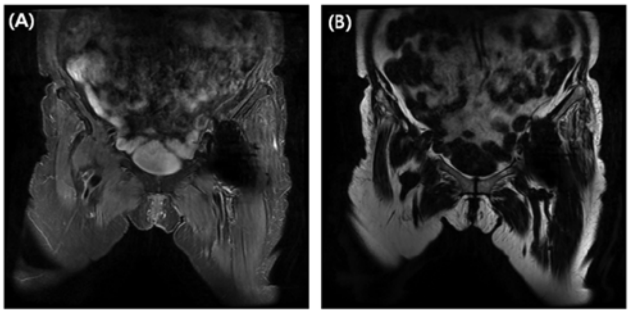

Fig. 10. By applying the IDEAL technique, a fat suppression image (A) and a water suppression image (B) were obtained using a single scan.

in the area above the chest using the IDEAL technique was higher than the CHEES technique. In the present study, the study subjects were patients who had received hip arthroplasty. The results show that the IDEAL technique developed fewer susceptibility artifacts caused by metals than the CHESS technique, and there was less image distortion. In addition, homogeneous fat suppression could be achieved. Furthermore, water or fat suppression could be achieved in the two types of images by a single scan due to the principle of IDEAL technique (Fig. 10). The IDEAL technique reconstructs images based on the signals obtained by excitation 3 times, and homogeneous fat suppression could be achieved. Nevertheless, the time for an examination of the images and the reconstruction time were relatively longer compared to conventional fat suppression techniques. In the present study, the time required to obtain data by the application of the CHESS and IDEAL technique was 248 sec and 368 sec, respectively, showing a 120 sec difference. This might a factor that should be considered for the application of IDEAL technique. On the other hand, the test time could be reduced sufficiently if it is applied in combination with parallel imaging. In the posterior area, the images obtained by the CHESS and IDEAL techniques achieved homogeneous fat suppression. This did not deviate greatly from the isocenter of the magnetic field. Hence, homogeneous fat suppression could be achieved. This study had several limitations. First, the size of the prosthesis of the subjects was different, making it difficult to analyze the level of susceptibility artifacts objectively. Second, the fat content was different depending on the constitution of the subjects. Hence, the homogeneity of fat suppression was different. In the present study, in the group in whom the CHESS technique had been applied, fat suppression was homogeneous if the patient's weight and fat content was low. In overweight patients, the homogeneity of fat suppression deteriorated. In the present study, by applying the IDEAL technique, the development of susceptibility artifacts caused by metals could be reduced, and homogeneous fat suppression could be achieved.

5. Conclusion

In an examination of the musculoskeletal system by MRI, the IDEAL technique can achieve homogeneous fat suppression. The development of susceptibility artifacts could be reduced even in patients with a metal prosthesis. In conclusion, the IDEAL technique generates high quality images, and can provide good information for diagnosis.

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