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WATER FAT SEPARATION USING THE SINGLE ACQUISITION "SANDWICH" TYPE 3-POINT DIXON METHOD TO OPTIMIZE KNEE JOINT SCANS

ERIKO SHIBAHARA[1], HIROSHI FUKATSU[1], SHINJI NAGANAWA[1], TOKIKO ITO[1], ERIKO IWAYAMA[1], TAKEO ISHIGAKI[1], TORU SEGAWA[2] and WAGUO ZHANG[3]

[1] *Department of Radiology, Nagoya University School of Medicine*
[2] *Toshiba Inc.*
[3] *Toshiba America MRI Inc.*

ABSTRACT

In this paper, we tried to evaluate the effect of water-fat separation on and to optimize the scan condition of the newly developed "Sandwiched" 3-point Dixon method at 0.35 Tesla (T), for knee joint imaging. Using a 0.35T superconductive open magnet system with a solenoid type knee coil, one male and two female normal volunteers (27–37y.o.) underwent knee joint imaging.

Each sequence provided good water-fat separated images. At 0.35T, the gradient echo provided a better contrast than the spin echo. Optimal cartilage-marrow and cartilage-fluid contrast could be obtained at a frip angle (FA) of 90 degrees. There was no significant correlation between cartilage-marrow, cartilage-fluid contrast and repetition time (TR) values within the tested range.

Cartilage-fluid and cartilage-marrow contrast were both best at an FA of 90 degrees with the gradient echo sequence. TR from 350 ms to 650 ms did not cause any significant contrast difference in the fat suppressed images. This method is useful and could be the only practical choice for obtaining fat suppressed T1 weighted images for joint magnetic resonance (MR) imaging at 0.35T.

Key Words: Magnetic resonance imaging, Water-fat separation, Knee joint

INTRODUCTION

Recently, the chemical selective saturation (CHESS) method for fat suppression mainly developed for high magnetic fields has become a standard tool for clinical magnetic resonance (MR) imaging. The method is used for fatty tissue discrimination to improve non-fatty tissue delineation such as joint cartilage using pre- and post-contrast enhanced T1 weighted images. Thus CHESS has already established its role in abdominal, musculoskeletal, orbital and breast imaging at 1.5T.[1-9] However at low or medium magnetic field settings, CHESS usually does not work well because the water-fat chemical shift is too small. Other choices at low fields include the Dixon method,[10,11] and its modifications,[12-14] along with the short TI inversion recovery (STIR),[15-18] although both techniques have problems. The Dixon method and its modifications need at least two scans to create water-fat separation images, which are not suited for movable objects or dynamic MRI with Gadolinium agents. STIR cannot be used for post-contrast imaging because the signal from T1-shortened tissue by gadolinium agents should be decreased.

Correspondence Address: Eriko Shibahara M.D., 65 Tsurumai-cho, Showa-ku, Nagoya 466-8550, Japan
Tel: 81-52-744-2328 Fax: 81-52-744-2335

To solve these problems we applied the 3-point Dixon method[19-21] at 0.35T. This enabled us to obtain water-fat separation with a single scan and in addition, to perform the correction of static field inhomogeneity. The imaging sequence is composed of a single radiofrequency (RF) echo or a gradient echo, which is "sandwiched" between two other gradient echoes. In this paper, we discuss the reliability of our method using volunteers, and also assess the potential clinical usefulness of this new fat suppression method for joint imaging.

MATERIALS AND METHODS

The MR equipment used here was a 0.35T superconductive open magnet system (OPART: Toshiba America Inc., San Francisco, USA). A solenoid type knee coil was prepared for examination of knee joints. The 3-Point Dixon method utilizes a single RF echo or an in-phase gradient echo "sandwiched" between two out-of-phase gradient echoes.[19]

This method enables a low magnetic field machine to acquire a complete k-space data set needed for water-fat separation with a single acquisition. Fig. 1 shows a diagram of the spin echo version of the "sandwich" sequence implemented for this study.

Volunteer study

One male and two female joint disease-free volunteers (27–37y.o.) underwent knee joint imaging using the 3-point Dixon method. Eight contiguous sagittal planes 4 mm thick with a 0.8 mm gap were imaged. For T2 weighted images, fast spin echo (FSE) was applied with a TR of 3000 ms, an echo time (TE) of 100 ms, and an echo train length (ETL) of 11. For T1 weighted images, spin echo (SE) was used with a TR of 450 ms and a TE of 15 ms. For the 3-point Dixon methods, both SE and gradient echo (GE) types (Fig. 1) were imaged. The SE type used a TR of 500 ms and a TE of 36 ms, while the GE type used a TE of 20 ms. For

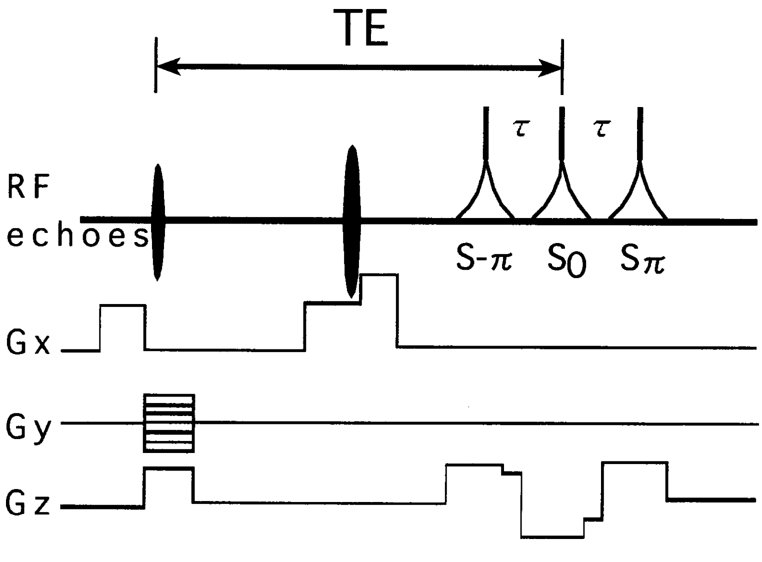

Figure 1 Schematic diagram of spin echo type 3-point Dixon with "Sandwich echoes".
Two out-of-phase gradient echoes are obtained before and after the in-phase spin echo so that three points are available within a single acquisition. The same data set is used for the calculation of the Bo distribution to assure the homogeneous effect within the FOV.

the GE type, flip angles (FA) of 15 to 120 with an increment of 15 degrees were tested for optimization with a TR of 350 ms. Using the optimized FA value, TR values of 350 ms, 500 ms and 650 ms were tested for optimization. For all of the above-described sequences, a 192 × 256 matrix and 3 signal averaging were employed.

The signal to noise ratio (SNR) of the bone marrow, subcutaneous fat, biceps femoris muscle, joint fluid and joint cartilage of the anterior portion of the medial femoral condyle were measured for each of the pulse sequences and every volunteer. The measurement was performed by region of interest (ROI) signal measurement using standard devices on the MR console. The ROIs were approximately 10 mm^2 large and were carefully positioned on similar anatomical locations among the three volunteers. In addition, the contrast to noise ratios (CNR) between the bone marrow and joint cartilage, as well as that between the joint cartilage and joint fluid, were calculated.

RESULTS

Each sequence provided good quality water-fat separated images. Fig. 2 shows five different contrast images obtained by the single acquisition 3-point Dixon method: water image, fat image, two out-of-phase images and one in-phase image, from which water and fat images were reconstructed. As a result, it is possible to obtain fat suppressed images as well as non-fat suppressed images simultaneously with a single acquisition.

Figure 2a–e 3-point Dixon method creates 2 out-of phase and 1 in-phase with which water and fat images are reconstructed. a Calculated water image. b Calculated fat image. c Out-of-phase image with TE=9ms. d In-phase image with TE=20ms. e Out-of-phase image with TE=30ms. Note that all five different contrast images can be obtained with only single acquisition.

Figure 3a–b 3-point Dixon method is applicable both for SE and GE however; cartilage marrow contrast is better with GE than SE, which is more suited for clinical purpose. a SE type image. b GE type image.

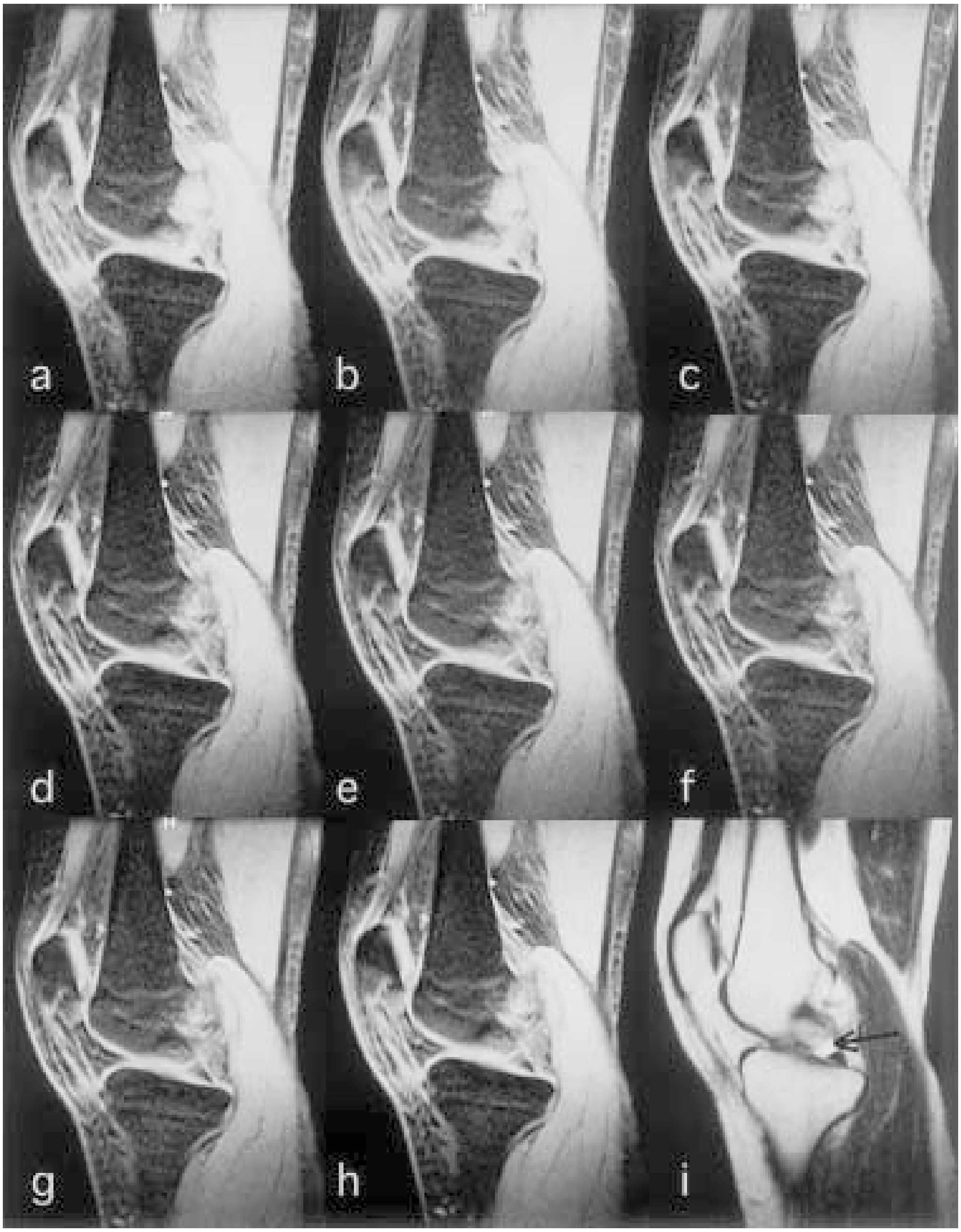

Figure 4a–i Contrast difference according to the FA change with 3-point Dixon type fat suppression at 0.35 T. Note the sequential change of fluid signal. Note also that joint fluid collection shows high signal at lower FA while it turns out to be darker than joint cartilage at higher FA.

Higher FA (90 or larger) should be suited for tissue characterization within around the joints. a FA=15. b FA=30. c FA=45. d FA=60. e FA=75. f FA=90. g FA=105. h FA=120. i T2 weighted image with FSE to show the bright signal of the joint fluid (arrow).

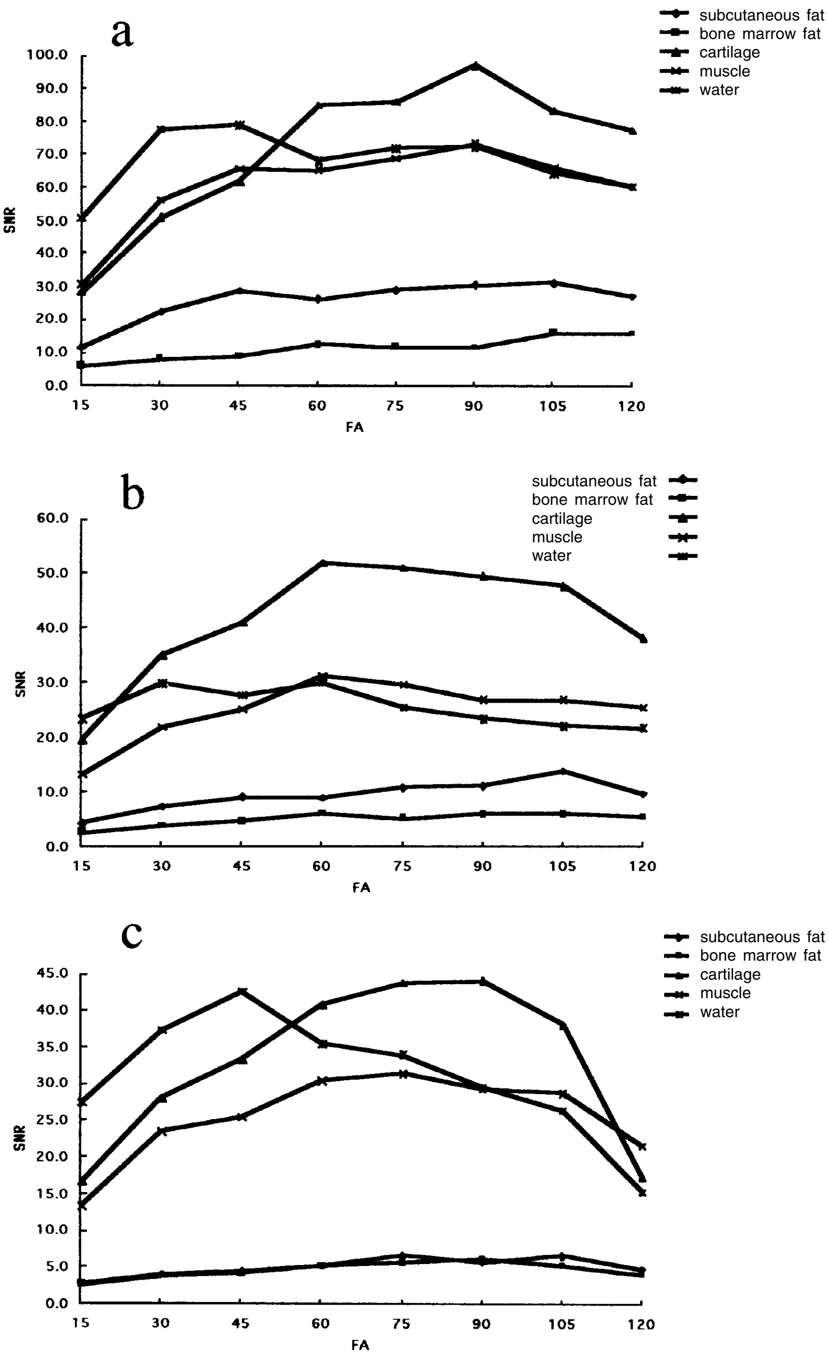

Figure 5a–c SNR of each component according to the FA change at 0.35 T; there are some variation among volunteers however, FA=90 appears to be optimal both for cartilage and water identification. a SNR graph for volunteer 1. b SNR graph for volunteer 2. c SNR graph for volunteer 3.

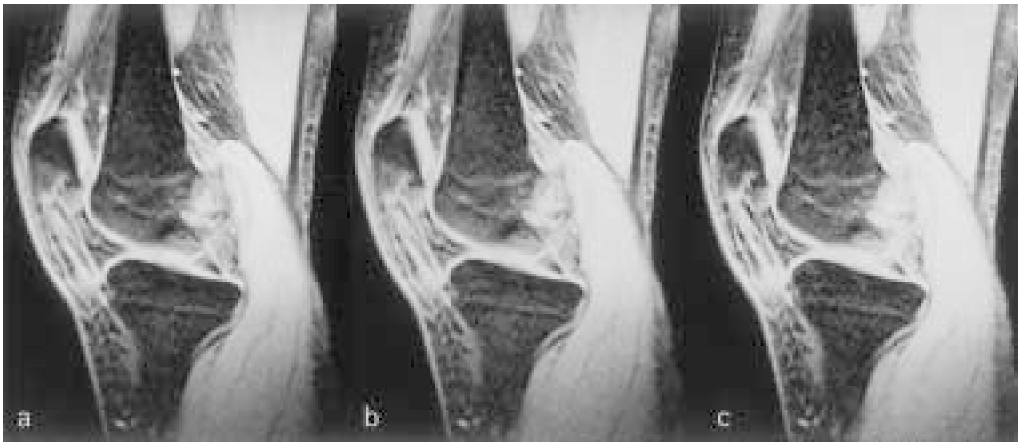

Figure 6a–c Contrast change according to the TR change. There were no significant contrast differences among these three conditions.
a TR=350ms. b TR=500ms. c TR=650ms.

At 0.35T, the GE type sequence provided better cartilage-fluid and cartilage-bone marrow contrast than that of the SE sequence (Fig. 3).

As the FA of the GE type sequence changed, the cartilage-fluid contrast and cartilage-marrow contrast altered (Fig. 4), with the FA of 90 degrees giving the best cartilage-fluid contrast. The cartilage-marrow contrast was rather subtle and not clearly recognized by picture observation only; however as a result, optimal cartilage-marrow and cartilage-fluid contrast were obtained at an FA of 90 degrees (Fig. 5). On the other hand, there was no apparent correlation between cartilage-marrow and cartilage-fluid contrast and TR values when the TR was between 350 and 650 ms. (Figs. 6, 7)

DISCUSSION

Fat suppression has become one of the essential techniques of clinical MR imaging because it is useful in fat tissue discrimination, contrast improvement among non-fatty tissue, contrast improvement of the gadolinium enhanced T1WI and for elimination of artifacts from fat tissue. At high magnetic field settings, the CHESS method is widely accepted as the standard fat suppression method because the chemical shift value is large enough to permit spectral frequency selection. However at low magnetic fields, the CHESS method cannot work well because the chemical shift value is too small. Although the STIR, and Dixon methods (along with its modified sequences) have been introduced as CHESS substitutes in low magnetic fields, these imaging techniques cannot completely meet clinical demands; STIR is not suited for post-enhanced T1 weighted images, while Dixon and its modifications essentially require at least two or three acquisitions, which may cause difficulties in regions such as the abdomen and chest with movable organs.

"Sandwich" type 3-point Dixon method achieves water-fat separation in a single scan by acquiring three "sandwiched" echoes after a single RF excitation and refocusing. As the time needed for water-fat spins to evolve from in-phase to out-of-phase at 0.35T is as long as 10.2 ms for a 3.3-ppm chemical shift, there is sufficient time to acquire complete k-space data lines.

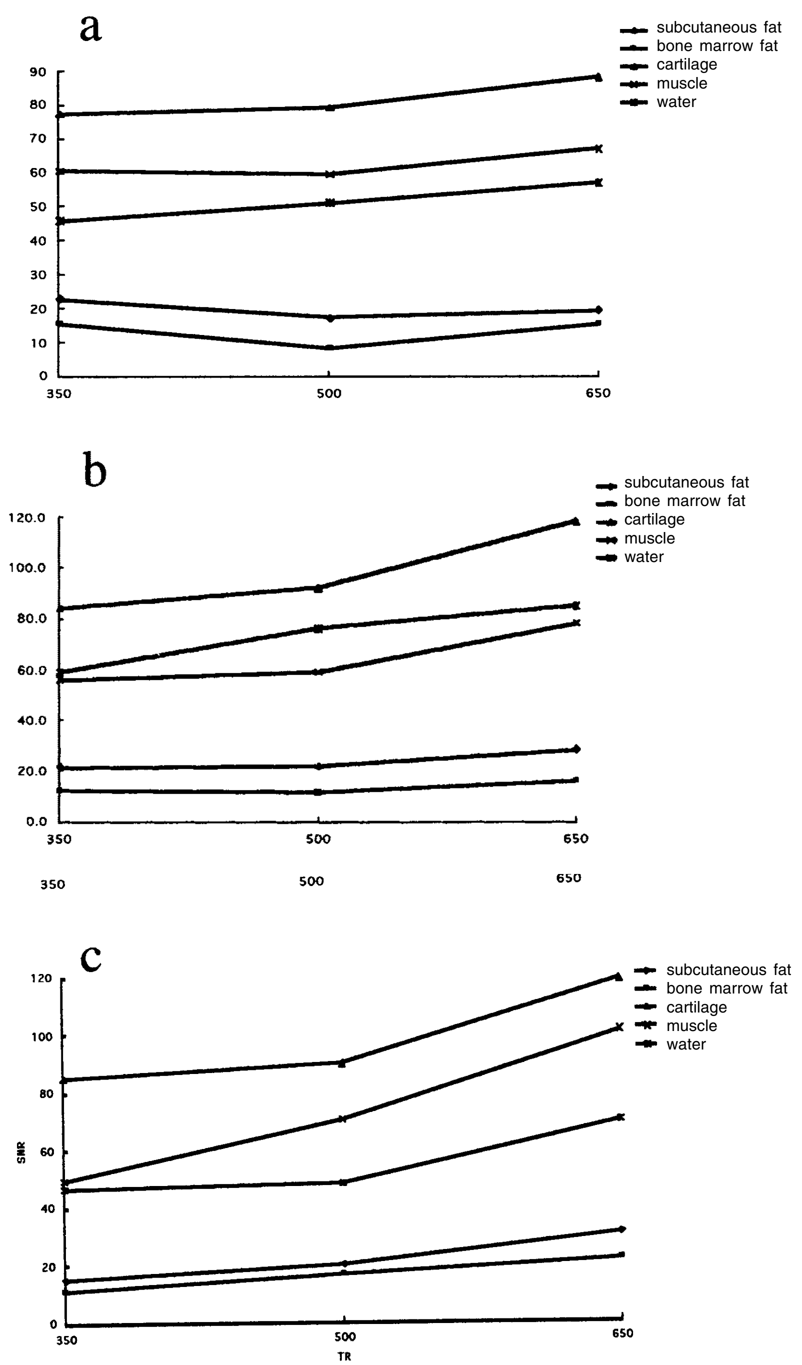

Figure 7a–c SNR of each component according to the TR change at 0.35 T while FA was constant; there was no significant correlation available concerning the cartilage and fluid contrast. a SNR graph for volunteer 1. b SNR graph for volunteer 2. c SNR graph for volunteer 3.

Although the procedure for calculating the water/fat images involves additional data processing, the reacquired data set can be acquired by a single short scan. This ability provides a considerable clinical advantage when we need both pre- and post-contrast, and fat and non-fat suppressed images. Four different contrast images (a pre-contrast, non-fat suppressed image; a pre-contrast, fat suppressed image; a post-contrast, non-fat suppressed image; and a post-contrast, fat suppressed image) can be obtained with only 2 scans instead of the 4 scans needed by the CHESS method.

GE provided a better signal-to-noise ratio and contrast, possibly because with the 3-point Dixon method implementation, SE has a considerably longer TE, 36 ms, while GE requires a shorter TE value of 20 ms. Using GE, T1-weighting can be altered by changing the FA value. The optimal FA of 90 degrees for cartilage-fluid and cartilage-marrow contrast is also good for contrast enhanced images.

According to our results regarding the influence of TR, no significant contrast difference between TR values of 350 ms and 650 ms was noted. This result occurs because the extreme contrast change caused by fat signal suppression dominates the whole image contrast, at least when TR is in the value range discussed above. This indicates that TR can be lengthened without changing the intrinsic contrast if more slices are needed. There might be a significant contrast change with longer TR values; however, so far as the T1 weighted contrast is concerned, a TR longer than 700 ms should be ruled out because the intrinsic T1 value of the soft tissue at 0.35T is rather short.

This promising 3-point Dixon method has some problems; it is susceptible to large static field homogeneity. For example, if the object is out of the magnet center or if the reacquired field of view (FOV) is larger than 35 cm^2, the quality of water fat separation is often compromised. If imaging of a unilateral shoulder, elbow or wrist scan is scheduled, with an open type MR system, it is beneficial to set the target organ in the magnetic center. In the abdominal region, phase changing due to respiratory motion is a serious problem. To solve this problem, it is necessary to acquire k-space data during a breath hold. However, breath-hold scans with a short scan time at low magnetic fields cannot provide adequate SNR using a conventional RF coil system. The development of a phased array coil system is needed.

The 3-point Dixon method might be employed as a standard fat suppression imaging method at low and medium magnetic field settings because it meets most clinical demands, at least in the musculoskeletal region.

CONCLUSION

We applied the 3-point Dixon method with a "sandwiched echo," which provides water-fat separated images with a single excitation at 0.35T. For joint examination, GE was better than SE. Cartilage-fluid and cartilage-marrow contrast was best at an FA of 90 degrees with GE. The same scan condition was also suited for post-contrast enhanced scans. TR in the range of 350 ms to 650 ms did not make a significant contrast difference in fat suppressed images.

These results led us to conclude that the 3-point Dixon method with a "sandwiched echo" is useful in joint MR imaging at low magnetic field (0.35T) settings.

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