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Fat suppression at 2D MR imaging of the hands: Dixon method versus CHESS technique and STIR sequence

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ABSTRACT

Objective: To compare the effectiveness of fat suppression and the signal-to-noise ratio (SNR) of the Dixon method with those of the CHESS (Chemical Shift-Selective) technique and STIR (Short Tau Inversion Recovery) sequence in hands of normal subjects at 2D MR imaging.

Material and methods: 14 healthy volunteers (mean age of 29.4 years) consented to have both hands prospectively imaged with SE T1 Dixon, T1 CHESS, T2 Dixon, T2 CHESS and STIR sequences in a 1.5T MR scanner. Three radiologists scored the effectiveness of fat suppression in bone marrow (EFS^{BM}) and soft tissues (EFS^{ST}) in 20 joints per subject. One radiologist measured the SNR in 10 bones per subject. Statistical analysis used two-way ANOVA with random effects, paired *t*-test and observed agreement to assess differences in effectiveness of fat suppression, differences in SNR and inter-observer agreement.

Results: EFS^{BM} was statistically significantly higher for T1 Dixon than for T1 CHESS and for T2 Dixon than for T2 CHESS ($p < 0.0001$). EFS^{BM} was significantly higher for T2 Dixon than for STIR in the coronal plane ($p = 0.0020$). The SNR was significantly higher for T1 Dixon than for T1 CHESS and for T2 Dixon than for STIR ($p < 0.0001$). The SNR was significantly lower for T2 Dixon than for T2 CHESS ($p < 0.0001$).

Conclusion: The Dixon method yields more effective fat suppression and higher SNR than the CHESS technique at 2D T1-weighted MR imaging of the hands. At T2-weighted MR imaging, fat suppression is more effective with the Dixon method while SNR is higher with the CHESS technique.

1. Introduction

Fat signal suppression is widely used in musculoskeletal MR imaging because of its high sensitivity for lesion detection. In the assessment of inflammatory hand diseases, OMERACT (Outcome Measures in Rheumatology Clinical Trials) recommendations to assess rheumatoid arthritis consist of fat-saturated T2-weighted or Short Tau Inversion Recovery (STIR) images along with T1-weighted images before and after contrast material injection which may also be performed with fat-saturation [1–5].

Several techniques enable fat signal suppression [6]. Chemical Shift-Selective (CHESS) technique is a fat suppression technique based on the frequency-selective presaturation of fat protons. It is commonly used because of its selectivity for fat, high signal-to-noise ratio (SNR) and relatively fast examination time. However inhomogeneous fat suppression frequently occurs due to its B_0- and B_1-sensitivity, mostly in anatomical areas with challenging geometric features such as hands. STIR sequence is a fat-suppressed sequence insensitive to B_0- and B_1-heterogeneity which therefore brings homogenous fat suppression. However its low SNR may be challenging in the evaluation of complex anatomical areas such as hands. Dixon method first described by Dixon in 1984 (2-point method) allows "water only" (i.e. fat-suppressed) and "fat only" (i.e. water-suppressed) images to be obtained [7]. The low sensitivity to field heterogeneity of later improved 3- and 4-point Dixon methods brings homogeneous and robust fat suppression without loss of signal and diminished SNR [8].

Few studies compared fat suppression methods including Dixon in musculoskeletal imaging [9–14]. To the best of our knowledge, one study only focused on hands MR imaging and compared coronal 2D T1-weighted Dixon with coronal 2D T1-weighted CHESS sequences in 8 volunteers [9].

Abbreviations: CHESS, Chemical Shift-Selective; EFS^{BM}, global score for the effectiveness of fat suppression in bone marrow; EFS^{ST}, global score for the effectiveness of fat suppression in soft tissues; SE, spin echo; ROI, region of interest; SNR, signal-to-noise ratio; STIR, Short Tau Inversion Recovery.

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We hypothesized that the Dixon method yields more effective fat suppression than CHESS and STIR techniques with higher SNR in both axial and coronal imaging of the hands. The aim of our study was to compare the effectiveness of fat suppression and the SNR of the Dixon method with those of the CHESS technique and STIR sequence in hands of normal subjects at 2D MR imaging.

2. Material and methods

2.1. Subjects

From November 2014 until January 2015, 14 residents from our department volunteered to participate in the current study (8 men, mean age of 29.5 years; 6 women, mean age of 29.3 years). Subjects had no symptom at the hands and none had history nor treatment for inflammatory arthritis. This prospective study was approved by our institutional ethics committee and conducted according to the principles of the Declaration of Helsinki. All subjects provided written informed consent before participating in the study.

2.2. MR imaging

MR examinations were performed on a 1.5 T MR scanner (Optima MR450w; General Electric, Milwaukee, USA) by using a flexible 16-channel medium-sized extremity coil (Flex coil; General Electric, Milwaukee, USA). Subjects were positioned in prone procubitus with arms extended above head and hands joined palm-to-palm. Hands were separated by a 4-millimeter-thick plastic plate and maintained with straps. The flexible coil was placed around the hands and also maintained with straps. Subjects were asked to stay immobile and breath normally during acquisition.

Five 2D sequences were systematically obtained: fast spin echo (SE) T1 Dixon "IDEAL", fast SE T1 CHESS, fast SE T2 Dixon "IDEAL", fast SE T2 CHESS and STIR sequences. MRI sequences parameters are summarized in Table 1. Images were acquired in the axial plane for 7 subjects (4 men – 3 women) and in the coronal plane for 7 others (4 men – 3 women). Both hands were simultaneously imaged during the same sequence and the number of slices was adapted to the anatomy of the subjects. Investigated area extended from distal radioulnar joints to metacarpophalangeal joints. The fat-suppressed sequences were anonymized, randomly ordered and archived by an independent operator in the institutional picture archiving communication system (PACS) (Carestream Vue 11.4.0.1253; Carestream Health, Inc., Toronto, Canada). Dixon in-phase, opposed-phase and water-suppressed images were not used in the study.

2.3. MR image evaluation

In February 2015, three radiologists (one last year radiology resident (T.K.), two musculoskeletal radiologists with 2 years (V.P.) and 20 years (B.V.) of experience) separately analyzed the MR images with the aim to score the effectiveness of fat suppression. Readers were blinded to the fat suppression method. Prior to the analysis readers shared a one-hour training session using images not part of the study to review the scoring system of MR images (described below).

Twenty joints per subject were individually assessed (Fig. 1). Readers were asked to score all joints. If scoring was not possible, the joint was declared not assessable. Effectiveness of fat suppression was scored separately for epiphyseal bone marrow and periarticular soft tissues as follow: 0, complete failure of fat suppression; 1, partial failure of fat suppression; 2, effective fat suppression (Fig. 2). Complete failure of fat suppression was defined by the presence of fatty high signal intensity in epiphyseal bone marrow or periarticular soft tissues on all slices through the joint. Effective fat suppression was defined by the presence of homogeneous diffuse low signal intensity in epiphyseal bone marrow or periarticular soft tissues on all slices through the joint. Partial failure of fat suppression was defined as neither effective fat suppression nor complete failure of fat suppression. Joint declared not assessable was scored 0. Global scores for the Effectiveness of Fat Suppression in Bone Marrow (EFS^{BM}) and Soft Tissues (EFS^{ST}) were defined as the sum of the individual scores for fat suppression effectiveness in bone marrow and soft tissues respectively. Each score could range from 0 to 40.

Image quality was assessed by measuring the SNR in predefined regions of interest (ROIs). In May 2015, fat-suppressed images were exported into another PACS (Osirix 6.02; Pixmeo sarl, Geneva, Switzerland). The 5 sequences of each subject were uploaded and synchronized. Circled ROIs of 10 mm^2 each were manually placed in the bone marrow of 10 anatomical areas on the SE T1 CHESS sequence and automatically propagated to the other sequences (Fig. 1). Mean signal intensity (SI) and standard deviation (SD) were measured in each ROI to calculate the SNR based on the following formula: SNR = 0.655 x (mean SI)/(SD) [15]. Measurements of the SNR were performed by a single reader (T.K.).

2.4. Statistical analysis

A two-way ANOVA with random effects was performed to assess differences in EFS^{BM} and EFS^{ST} and determine which factor (sequence or reader) or combination of factors (interaction) was associated with the difference. MRI sequences were considered to represent a fixed factor, while readers were considered to represent a random sample drawn from a larger population (random factor). A third term was added to the ANOVA mixed model to account for potential interaction between both factors. In case where the *p*-value associated with that term was not statistically significant, the interaction term was removed and the ANOVA mixed model was repeated with only 2 main effects. A Bonferroni-like correction was applied (3 observers and 2 parameters) and a *p*-value less than 0.0083 was considered as statistically significant.

For analysis of SNR Kolmogorov-Smirnov test was used to test whether observations were normally distributed. Variance equality was assessed with an F-test. If the previous assumptions were rejected, a logarithmic transformation was applied and the assumptions were re-assessed. A paired *t*-test, or equivalently a non-parametric Wilcoxon rank-sum test, was used to assess statistical differences. A *p*-value less than 0.05 was considered statistically significant.

Inter-observer reproducibility was assessed based on observed agreement of individual scores in two-by-two comparison. Kappa statistic was not used due to the bias introduced by unbalanced marginal totals [16]. The strength of agreement was interpreted as follows: ≤0, poor; 0.01-0.20, slight; 0.21-0.40, fair; 0.41-0.20, slight; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, substantial and ≥0.81, excellent.

Statistical analyses were carried out with Matlab (Version R2011b, Mathworks®) using the *ANOVAN* function, and with Statsdirect® statistical software (http://www.statsdirect.com/).

3. Results

3.1. Assessability of joints

The three readers could assess all joints but the 2 distal radioulnar joints of one subject which were partially located outside of the imaging field.