Clinical applications of Dixon chemical shift MR imaging: Morbus Gaucher, Morbus Hansen
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Citation for published version (APA):
Ridderkerk: M. Maas

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Uniform fat-suppression in hands and feet through the use of two-point Dixon chemical shift MR imaging

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Radiology 1999; 210:189-193
ABSTRACT

Purpose:
To assess the potential of two-point Dixon chemical shift magnetic resonance imaging to achieve uniform fat-suppression in the distal parts of the extremities.

Materials and methods:
Two-point Dixon chemical shift imaging was performed in 31 consecutive patients clinically suspected to have bone marrow disease. In some patients, Dixon studies were performed before and after the intravenous administration of gadopentetate dimeglumine, and in some patients follow-up examinations were performed, for a total of 64 studies. Areas of interest were the hand, wrist, foot, ankle, and lower leg. There was a special interest in the neuropathic foot and osteomyelitis. The uniformity of fat-suppression in the entire field of view, the frequency of displacement artifacts, and the applicability of the technique in routine patient treatment were evaluated.

Results:
In 64 (100%) Dixon studies, uniform fat-suppression was achieved. In 59 (92%) studies, there were no displacement artifacts. In five (8%) studies, displacement artifacts occurred; however, in only one (2%) study did they severely hamper the reading. Thus, in 63 (98%) studies, adequate diagnostic quality was obtained.

Conclusion:
Two-point Dixon chemical shift imaging is a good technique for achieving uniform fat-suppression in the distal parts of the extremities. Because the frequency of displacement artifacts is low, the technique is applicable in a routine clinical setting.
**INTRODUCTION**

Fat-suppression techniques are frequently used in magnetic resonance (MR) imaging of the musculoskeletal system to better appreciate bone marrow abnormalities, soft-tissue disease, and cartilage [1-3]. The suppression of the relatively high signal of fat can lead to a more efficient use of the dynamic range of tissue contrast on MR images [4]. Similarly, the conspicuousness of enhancement after contrast medium administration can be increased by using fat-suppression [4,5]. The most widely used technique is frequency-selective presaturation. However, in areas of irregular shape and abrupt changes between soft tissue and air, such as the craniocervical junction and the distal extremities (hands and feet), this technique produces uneven fat-suppression and artifacts because the required magnetic field homogeneity cannot be achieved [1,6].

A good alternative technique for suppression of the fat signal is the short inversion time inversion-recovery (STIR) sequence. STIR is based on the rapid T1 recovery of fat and is, therefore, not substantially affected by field inhomogeneities. STIR is considered the most sensitive technique for identifying subtle bone marrow disease [1]. Unfortunately, STIR suppresses all short T1 species, including tissues that have absorbed gadolinium. Hence, it is not possible to use STIR fat-suppression to improve the detection of contrast medium enhancement [2]. For the detection of osteomyelitis, this is an important disadvantage, because previous studies [7,8] have suggested that MR imaging with both fat-suppression and gadolinium enhancement may be the imaging method of choice in clinically complicated situations.

An alternative method for fat-suppression is the phase-contrast method, described by Dixon in 1984 [9], that is based on the chemical shift phenomenon. This technique does not require a high field homogeneity to achieve adequate fat-suppression, thus field inhomogeneity is not a limiting factor [9]. This technique has been applied successfully in MR imaging of adrenal masses and bone marrow [10-13]. A potential problem in using this chemical shift technique is the occurrence of displacement artifacts that hamper its application [3,4]. The necessary postprocessing requires that the patient remains in the same position with absolutely no shift of the imaged structures between the in-phase and opposed-phase series [4,14].
In our hospital (Academic Medical Center, Amsterdam, the Netherlands), there is a relatively large population of patients with neuropathic foot disease, usually due to diabetes mellitus or leprosy. In this group, MR imaging is requested when infection is suspected. With our MR imager, the frequency-selective presaturation fat-suppression of the distal extremities is inhomogeneous. Because much of this problem is caused by physical properties of the patient, it is largely independent of the equipment used [1,6], so we looked for an alternative technique. In a pilot study, we found the two-point Dixon chemical shift MR imaging technique in combination with the administration of gadopentetate dimeglumine promising [15]. Subsequently, the present study was conducted to answer the following questions: a) Is two-point Dixon chemical shift imaging useful in obtaining uniform fat-suppression in the hands and feet? b) Is this technique applicable in a clinical setting for the evaluation of bone marrow disease in the extremities? c) At what frequency do displacement artifacts occur?

**Material & Methods**

**Patients**

Between November 1994 and January 1996, 31 consecutive patients (13 male, 18 female; mean age, 55 years; age range, 13-85 years) clinically suspected of having bone marrow disease were referred for MR imaging. The location of the suspected disease was the foot and ankle (n=23), lower legs (n=5), or hand and wrist (n=3). Indications were mainly infection and posttraumatic changes. In this group, there were 14 patients with neuropathic foot disease with possible osteomyelitis.

Two-point Dixon chemical shift imaging was performed as an extension of the routine clinical MR imaging examination. In four patients, follow-up two-point Dixon chemical shift imaging examinations were performed. In a previous study [15], the image quality of two-point Dixon chemical shift imaging was tested in four healthy volunteers.

**Two-Point Dixon Chemical Shift Imaging Technique**

All MR examinations were performed at our institution (Academic Medical Center, Amsterdam, the Netherlands) on a 1.5 T Magnetom 63SP/4000 imager (Siemens, Erlangen, Germany). The hand or foot of interest was placed inside the circularly polarized head coil.
Two-point Dixon chemical shift imaging

This coil was used because it provided the best signal-to-noise ratio; the quality of our dedicated extremity coil at that time was inferior to the quality of the head coil. The technique we used is based on the chemical shift technique described by Dixon [9]. A Dixon study consists of two spin-echo series. The first one is a conventional spin-echo series. The second series is identical to the first one, except that the 180° inverting radio-frequency pulse is shifted by a time \( \tau \), such that in the center of the readout gradient \( (k_x = 0) \) the signals of water and fat have opposed-phases [9,16]. The value of \( \tau \) depends on the field strength (1.5 T) and on the frequency difference between fat \((-\text{CH}_2-)\) and water \( (\text{H}_2\text{O}) \), which is approximately 3.4 ppm. Because of the presence of other resonances in the fat molecules, the optimal value for \( \tau \) varies a little with the chemical composition of the lipids [17]. For the extremities, we use an optimal \( \tau \) of 1.17 msec.

In the conventional spin-echo series, the water and fat signals are in-phase, yielding images in which water and fat signal intensities add up. The opposed-phase series yields images in which the water and fat signal intensities are subtracted. By combining the two sets of images with a proper postprocessing procedure, the water and fat signals are separated, which leads to images in which there is only a water signal, so-called water-only images, and therefore fat-suppression, and images in which there is only a fat signal, so called fat-only images. The postprocessing was performed on a workstation (SPARC 20-51; Sun Microsystems, Mountain View, Calif) by using a region-growing algorithm developed in our department [14].

In the present examinations, we used T1-weighted Dixon studies \( (570-620/17 \text{ [repetition time msec/echo time msec]} \); section thickness, 3 mm; number of signals acquired, two to three; matrix 256 x 256; field of view, 150-240 mm). The acquisition time was 5-7 minutes for one spin-echo series and therefore was 10-14 minutes for a Dixon study. The series were performed in succession, because it was not possible to image the in-phase and opposed-phase series interleaved.

Administration of Gadopentetate Dimeglumine

As mentioned in the introduction, the use of gadopentetate dimeglumine with STIR is not appropriate. Gadolinium produces a shortening of the T1 in water, and because STIR suppresses all short T1 species, it suppresses...
fat and gadolinium-containing water alike. The Dixon technique, on the other hand, like the conventional fat-saturation method, is based on the frequency difference between fat and water. So, T1-weighted Dixon water-only images will show gadolinium enhancement just as conventional T1-weighted images do. Gadopentetate dimeglumine (0.1 millimole per kilogram of body weight; Magnevist; Schering, Berlin, Germany) was administered intravenously when desirable, mainly for the demarcation of abscesses or the detection of osteomyelitis. We routinely performed one Dixon study before and one after the administration of gadopentetate dimeglumine.

Analysis
In retrospect, two musculoskeletal radiologists (M.M., P.F.D.) analyzed the consecutive Dixon studies by consensus and considered the following parameters: a) Uniformity was defined as overall uniform fat-suppression in the entire field of view. For this purpose, water-only images were evaluated. Uniformity was scored as "Yes" or "No". b) Displacement artifacts were scored by interpreting the water-only images as showing I) "no displacement" or good image quality, II) "little displacement" or acceptable, still diagnostic image quality; or III) "much displacement" or unacceptable, nondiagnostic image quality. The fat-only images were not used for diagnostic purposes.

Results
Dixon studies
Of the 31 patients, one patient with neuropathic foot disease could not refrain from moving during MR imaging, which led to motion artifacts on the conventional MR image; so, no Dixon postprocessing was performed. In the remaining 30 patients (12 male, 18 female; mean age 54.5 years; age range, 13-85 years), 64 Dixon studies were performed (Table 1). In seven patients (eight Dixon studies; one patient underwent two Dixon studies) there was no need for the administration of gadopentetate dimeglumine. Sixteen patients (32 Dixon studies; 16 studies before and 16 studies after contrast medium administration) underwent a single examination with the administration of gadopentetate dimeglumine. Two patients underwent an examination before and after the administration of gadopentetate dimeglumine and the same in a follow-up study.
Two-point Dixon chemical shift imaging

(eight Dixon studies), and two patients underwent an examination before and after the administration of gadopentetate dimeglumine and the same in two follow-up studies (12 Dixon studies). In three patients, Dixon studies were performed only after the administration of gadopentetate dimeglumine because there were logistic problems. This resulted in four Dixon studies, because one patient underwent two Dixon studies.

Table 1. Distribution of patients and Dixon Studies

<table>
<thead>
<tr>
<th>Examinations</th>
<th>No. of Patients (n = 30)</th>
<th>Neuropathic Feet (n = 13)</th>
<th>No. of Dixon Studies (n = 64)</th>
</tr>
</thead>
<tbody>
<tr>
<td>One examination:</td>
<td>7</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Dixon studies without Gadolinium enhancement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One examination:</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Dixon studies after Gadolinium enhancement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One examination:</td>
<td>16</td>
<td>7</td>
<td>32</td>
</tr>
<tr>
<td>Dixon studies before and after Gadolinium enhancement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two examinations (one follow-up):</td>
<td>2</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Dixon studies before and after Gadolinium enhancement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Three examinations (two follow-up):</td>
<td>2</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>Dixon studies before and after Gadolinium enhancement</td>
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</table>

Analysis

Uniformity.- In 64 (100%) Dixon studies, uniform fat-suppression in the entire field of view was attained. This was evident to both radiologists. There were no artifacts in the fat-water separation. The water-only images showed no areas of persistent fat signal intensity (Fig. 1). Also, in the phalanges, there was complete fat-suppression.
Figure 1. Sagittal, water-only, non-contrast medium-enhanced, MR image (620/17) of the foot. There is homogeneous fat-suppression in both the bone marrow and the subcutaneous fat. No displacement artifacts are seen.

Displacement-artifacts. - In 59 (92%) Dixon studies, there was no sign of displacement. In four (6%) Dixon studies, we found little displacement (Fig. 2a).

Figure 2. (a) Sagittal, water-only, unenhanced, MR image (620/17) of the foot shows minor displacement artifacts (arrow) best appreciated at the margins of the bones. (b) Axial water-only MR image (620/17) of the foot shows severe displacement artifacts (arrows), which hampered interpretation.
However, in this group of patients, the interpretation of the studies was not a problem, as an adequate evaluation was possible. In only one (2%) Dixon study was the displacement severe; in this patient, the in-phase and opposed-phase images were of good quality, but the patient had moved between the two series. Therefore, the postprocessed images were not of diagnostic quality (Fig. 2b). Consensus between the two radiologists about the degree of displacement artifact was readily achieved in all cases. Thus, in 63 (98%) Dixon studies, the MR image was of diagnostic quality, and interpretation was not hampered by displacement artifacts.

**Discussion**

For the detection of subtle bone marrow disease, use of fat-suppression sequences in state-of-the-art musculoskeletal MR imaging is mandatory [1]. The appreciation of subtle bone marrow changes is easier when the high signal of the fatty bone marrow is suppressed. The STIR sequence and the frequency-selective presaturation sequence, both of which are routine sequences on the modern MR imager, can fulfill this need adequately for most parts of the human body. In clinically complex situations, there is an additional value in using intravenously administered gadopentetate dimeglumine [7]. Because, from a diagnostic point of view, STIR is incompatible with this use of gadolinium (as gadolinium shortens T1), the use of frequency-selective presaturation is necessary. However, the high field homogeneity that is essential for this technique cannot be attained in hands and feet, which causes inhomogeneous fat-suppression. Inhomogeneous fat-suppression leads to problems in the investigation of neuropathic foot disease and osteomyelitis; this is a problem recognized in the literature [15,18]. Because chemical shift imaging, as described by Dixon [9], in combination with an appropriate postprocessing technique, such as that developed in our department [14,15], is a potentially good alternative for obtaining fat-suppressed images, we examined its use in a clinical setting on a routine basis.

We were able to obtain uniform fat-suppression in the entire field of view in every study. However, we did not perform another fat-suppression technique at the same time, which renders a comparative study of several techniques impossible.
A potential weakness of the Dixon technique is the shift of position between the in-phase and opposed-phase series, which leads to displacement artifacts \[1,3\]. Because the amount of displacement perpendicular to the imaging plane cannot be estimated from the image data, and because nonuniform displacement (eg, the bending of a toe) is even harder to quantify, we chose a qualitative analysis of this phenomenon. Displacement artifacts were encountered in only five (8\%) Dixon studies. Only one (2\%) Dixon study was inconclusive because of too much displacement between in-phase and opposed-phase images. To prevent displacement artifacts, we seek to develop a sequence in which both the in-phase and opposed-phase series can be acquired interleaved in one sequence. Thus, our clinical results with this Dixon technique are both applicable and promising.

Diagnosing osteomyelitis is a well-known challenge in diagnostic radiology \[19,20\]. In neuropathic foot disease, the discrimination between neuropathic osteoarthropathy and osteomyelitis is an additional problem. Because of inhomogeneous suppression of the high marrow signal on both T1-weighted spin-echo and fast T2-weighted spin-echo images, some parts of the foot cannot be judged adequately and are prone to misconception \[1\]. Therefore, homogeneous fat-suppression in the entire field of view both before and after the intravenous administration of gadopentetate dimeglumine is mandatory. The results of the present study indicate that our two-point Dixon chemical shift imaging technique leads to good uniform fat-suppression. Its potential to help obtain images both before and after the intravenous administration of gadopentetate dimeglumine is an important development and may be of benefit in diagnosing osteomyelitis in complex situations and in the distal parts of the extremities, such as the neuropathic foot (Fig. 3). Further studies in this field are necessary and will be performed.

With respect to the research questions posed in the introduction, we can conclude the following: a) Two-point Dixon chemical shift imaging can be used to obtain uniform fat-suppression in the hands and feet. b) Two-point Dixon chemical shift imaging is applicable in a clinical setting on a routine basis.
Figure 3. Sagittal water-only MR images (620/17) (a) before and (b) after the intravenous administration of gadopentetate dimeglumine in a patient with neuropathic foot disease and an arthrodesis in the tibiotalar joint. a shows slight hyperintensity in the cuboid bone (solid arrow) and the base of the fourth metatarsal bone (open arrow). b shows marked focal enhancement in the cuboid bone (solid straight arrow) and the base of the fourth metatarsal bone (open arrow), which supports the clinical diagnosis of osteomyelitis. Also, note the plantar ulcer with cellulitis (solid curved arrow).

Because of its potential to help obtain fat-suppressed images both before and after the administration of gadopentetate dimeglumine, the technique can be used in evaluating bone marrow disease in the hands and feet, where the magnetic field is less homogeneous. Therefore, this technique is of potential benefit in the diagnosis of osteomyelitis, especially in complex situations, such as those involving neuropathic foot disease. Further study is necessary to explore this. (c) Displacement artifacts occur in a minority of studies.

Acknowledgments
The authors thank Feikje M. Gubler, MD, PhD, Edwin J.R van Beek, MD, PhD, William R. Faber, MD, PhD, and Mirjam R.W. Evers-van Bavel for their aid in the preparation of this manuscript and Gerard J. den Heeten, MD, PhD, Jaap Stoker, MD, PhD, and Henk W. Venema, PhD, for their valuable suggestions during the revision process.
References

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