Magnetic Resonance Imaging 34 (2016) 1114–1120

Contents lists available at ScienceDirect

Magnetic Resonance Imaging

journal homepage: www.mrijournal.com

Original contribution

Fat fraction estimation of morphologically normal lumbar vertebrae using the two-point mDixon turbo spin-echo MRI with flexible echo times and multipeak spectral model of fat: Comparison between cancer and non-cancer patients

Seung Hyun Lee, Young Han Lee *, Seok Hahn, Jin-Suck Suh

Department of Radiology, Research Institute of Radiological Science, Medical Convergence Research Institute, and Severance Biomedical Science Institute, Yonsei University College of Medicine, 50-1 Yonsei-ro, Seodaemun-gu, Seoul, 03722, Republic of Korea

ARTICLE INFO

Article history:
Received 9 March 2016
Accepted 11 May 2016

Keywords:
Marrow imaging
Spine magnetic resonance imaging
Fat fraction
Malignancy
Fat water separation

ABSTRACT

Purpose: This study aims to compare fat fraction of lumbar vertebrae between cancer and non-cancer patients, using the two-point modified Dixon (mDixon) turbo spin-echo (TSE) MRI with flexible echo times and multipeak fat spectral model.

Materials and methods: Fat fraction was calculated from fat and water images reconstructed by the mDixon TSE technique. Fat fraction of fat–water phantoms measured with the mDixon TSE method was compared with actual fat percentages. Patients who had undergone mDixon spine MRI and dual-energy X-ray absorptiometry within one year and had no bone metastasis were divided into cancer ($n = 7$) and non-cancer ($n = 23$) groups. Fat fraction and bone mineral density (BMD) were compared between the two groups.

Results: Fat fraction of phantoms measured with mDixon MRI was highly correlated with their actual fat percentages ($P < 0.01$, $R^2 = 0.93$). Fat fraction of lumbar vertebrae was significantly lower in cancer patients ($58.27 \pm 3.16\%$) than in non-cancer patients ($70.48 \pm 1.83\%$) ($P < 0.01$). BMD was not different between cancer (0.912 ± 0.057 g/cm^2) and non-cancer patients (0.876 ± 0.032 g/cm^2) ($P = 0.58$). Fat fraction and BMD showed no significant correlation ($P = 0.95$, $R = 0.006$).

Conclusions: A two-point mDixon TSE method for assessing fat fraction was reliable. Fat fraction of morphologically normal lumbar vertebrae was significantly lower in cancer patients compared to non-cancer patients, using the two-point mDixon TSE technique.

1. Introduction

Bone marrow is a complex heterogeneous admixture of hematopoietic red marrow and fatty yellow marrow supported by varying proportions of structural trabecular bone [1]. Most lesions interfere with this medullary water–fat balance [1], therefore the assessment of bone marrow fat content and fat changes is very important in interpreting spine magnetic resonance imaging (MRI) [2]. Neoplastic areas tend to completely replace or displace fatty marrow components of bone, resulting in reduced fat and increased water content [3,4]. In circumstances in which hematopoietic demand increases, yellow marrow may reconvert to red marrow, eventually resulting in decreased bone marrow fat content [4,5], which occurs more quickly in flat bones such as the spine, sternum, and scapula [6]. To the best of our knowledge, the effect of primary cancers located outside the skeleton on vertebral bone marrow fat content and trabecular bone has never been addressed.

The evaluation of vertebral bone marrow fat content based on the water–fat chemical shift difference has gained significant attention [7–11]. Dixon, in 1984, suggested that from the in-phase image with water and fat signals being in-phase and out-of-phase images with water and fat signals being 180° out-of-phase, a water-only image and a fat-only image can be generated by simple summation and subtraction of the two images [12,13]. This water and fat separation method enables accurate fat quantification in many different types of pulse sequences and for many different clinical applications [13].

Recent advances in the Dixon technique have led to the development of a new two-point Dixon method, the modified Dixon (mDixon), with flexible choice of echo times (TE) for water–fat separation, using the referenced seven-peak spectral model of fat in the separation [14]. Three-point Dixon technique is more robust to B_0 heterogeneity than two-point Dixon method, but it requires longer examination time and lowers signal-to-noise ratio (SNR) efficiency [15]. Sampling only two instead of three echoes permits substantial

* Corresponding author. Tel.: +82 2 2228 7420; fax: +82 2 393 3035.
E-mail addresses: circle1128@yuhs.ac (S.H. Lee), sando@yuhs.ac (Y.H. Lee), andrew0668@yuhs.ac (S. Hahn), jss@yuhs.ac (J.-S. Suh).

http://dx.doi.org/10.1016/j.mri.2016.05.007
0730-725X/

shortening of scan time, compared to three-point Dixon methods [14]. The mDixon technique automatically calculates the two shortest echo times that are separated enough not to provide redundant information. The two sampled TEs do not need to be exact in- or opposed-phase values. Shortening of TE allows an improved SNR while maintaining high spatial resolution [14]. The use of a more accurate spectral model of fat, the seven-peak spectral model [16], instead of the standard single-peak spectral model, improves the consistency of fat quantification and fat suppression, considering the multiple spectral peaks of fat [14,16], while maintaining a clinically feasible scan time from the usage of the dual-echo sequence. Moreover, the utilization of the turbo spin-echo (TSE) can provide significantly better image quality as well as fat suppression compared to gradient-echo sequences. We consider that the two-point mDixon TSE sequence would replace conventional T2-weighted/fat-suppressed T2-weighted and contrast-enhanced T1-weighted/fat-suppressed contrast-enhanced T1-weighted MRI as it provides images with and without fat suppression in one acquisition requiring no additional scans.

Clinical application of the two-point mDixon TSE sequence has not been reported, especially regarding spine MRI. The purpose of this study was to compare the bone marrow fat fraction of lumbar vertebrae between cancer and non-cancer patients, using the two-point mDixon TSE MRI with flexible echo times and multipeak spectral model of fat at 3 Tesla (T).

2. Materials and methods

2.1. Fat–water phantom study

A phantom study was performed to assess the accuracy of fat fraction quantification of the two-point mDixon TSE technique with flexible echo times and multipeak spectral model of fat. To simulate various degrees of bone marrow fat fraction, a fat–water phantom composed of eight 30 mL vials in varying true fat volume percentages (0%, 10%, 20%, 30%, 60%, 80%, 90%, and 100%) was constructed, based on a modified version of the phantom described by Bernard et al. [17]. Appropriate volumes of peanut oil (P2144 Sigma-Aldrich, St. Louis, MO, USA) were dispensed by weight into vials, assuming the density of peanut oil (0.91 g/cm^3). A water solution comprising the water fraction of the phantom that contained distilled deionized water, 43 mM sodium dodecyl sulfate, 43 mM sodium chloride, 3.75 mM sodium azide, 0.3 mM gadoterate meglumine (Dotarem®, Guerbet, Aulnay-sous-Bois, France), and agar (2.0% *w/v*) was added over heat (40 °C) with stirring to reduce microbubbles until melted. All materials were purchased from Sigma-Aldrich, St. Louis, MO, USA. Volumes of the water solution were poured into vials containing premeasured peanut oil, mixed at 1000 rpm for approximately 2 min, and formed a solid gel when cooled to room temperature.

These eight emulsion phantoms were scanned all together in the axial plane, using the two-point mDixon TSE technique with the same parameters used for spine MRI (Table 1). Circular regions of interest (ROIs), with areas of 106.5 mm^2, were drawn on water images and fat images derived from T2-weighted two-point mDixon TSE MR axial images, in the center of each of the eight phantoms, representing fat fractions of 0%, 10%, 20%, 30%, 60%, 80%, 90%, and 100% (Fig. 1a, b, c), by a musculoskeletal radiologist with one year of subspecialty experience, using our institution's picture archiving and communication system (PACS) workstation (Centricity Radiology RA1000; GE Medical Systems, Milwaukee, WI, USA). Fat fraction of each phantom was calculated with the following equation: Fat fraction (%) = $[SI_{fat}/(SI_{fat} + SI_{water})] \times 100$, where SI_{fat} and SI_{water} were the signal intensities in the fat and water images, respectively.

2.2. Patient selection

This single-center study was approved by our hospital's institutional review board and informed consent was waived because of the retrospective design of the research. From April 2014 to May 2015, 361 patients had undergone lumbar spine or whole spine MRI with the two-point mDixon TSE technique in our institution. Inclusion criteria were bone mineral density (BMD) derived from dual-energy X-ray absorptiometry (DXA) performed within the previous year. Exclusion criteria were vertebral metastasis (including previous radiation therapy on the lumbar spine) or systemic metastasis elsewhere, and hematologic disorders such as multiple myeloma, leukemia, and lymphoma. Out of 83 patients fulfilling the inclusion criteria, 35 patients were excluded because of vertebral metastasis, and one patient was excluded because of brain metastasis from endometrial cancer. Fifteen patients were excluded due to multiple myeloma, while one patient each with acute myelogenous leukemia and lymphoma were also excluded from the study. There were 30 patients (10 men, 20 women; mean age, 69 years; range, 47–84 years) remaining whose lumbar vertebrae were morphologically normal on MRI and who had recent BMD results derived from DXA. Morphologically normal vertebrae on MRI were defined as vertebrae without any signal lower than the associated muscle or intervertebral disc on T1-weighted images [4]. Reasons for the performance of spine MRI included low back pain or radiating pain (n = 25), evaluation of bone metastasis (n = 4), and urinary and bowel incontinence (n = 1).

Patients were divided into cancer patients (n = 7; 4 men, 3 women; mean age, 68 years; range, 61–77 years) and non-cancer patients (n = 23; 6 men, 17 women; mean age, 69 years; range, 47–84 years) based on their medical history and clinical diagnosis. There was no significant difference in the mean age of cancer patients and non-cancer patients (P = 0.76), using the independent samples t-test. Cancer patients had various underlying primary malignancies

Table 1
Summary of magnetic resonance imaging (MRI) parameters.

	Sagittal T2-weighted mDixon	Sagittal T1-weighted	Axial T2-weighted	Axial T1-weighted	Sagittal T2-weighted whole spine	Sagittal T1-weighted mDixon CE	Axial T1-weighted mDixon CE
TR (ms)	2500–3000	400	3380–6310	400	2291.8	450	450
TE (ms)	80–100/Automatically calculated shortest TE	10	120	10	100	15/Automatically calculated shortest TE	15/Automatically calculated shortest TE
NEX	1	1–2	1.5–2	1–2	1	1	1
FOV (mm)	270–287	270–280	220	220	260–285	270–320	200–220
Matrix	448 × 220	448 × 220	320/350	320/350	448/220	448 × 220	320/312–348
Voxel size	0.547 × 0.547	0.547 × 0.547	0.430 × 0.430	0.430 × 0.430	0.547 × 0.547	0.547 × 0.547	0.469 × 0.469
Slice thickness (mm)	3–4	3–4	3–4	3–4	4	3–4	4
Slice gap (mm)	0.3–0.4	0.3–0.4	0.3–0.4	0.3–0.4	0.4	0.3–0.4	0.4
Bandwidth (Hz/pixel)	461.2	387.5	291.5	291.5	268.3	357.7	336.7
Imaging time (min:s)	4:30	3:34	3:19	3:04	3:30	5:12	6:12

Notes: mDixon = modified Dixon; CE = contrast enhanced; TR = repetition time; TE = echo time; NEX = number of excitations; FOV = field of view.