Comparison of Sequences for MR-based Cortical Bone Imaging and Tissue Classification in the Pelvis at 3.0T with subsequent Generation of Electron Density Maps and Digitally Reconstructed Radiographs

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INTRODUCTION:

Emerging applications based on magnetic resonance imaging (MRI), such as radiation therapy planning (RTP) and hybrid PET/MR systems, benefit from the superior display of soft tissue contrast and the delineation of tumor and critical organs. However, utilizing MRI for standalone radiation therapy simulation would require the generation of electron density (ED) maps as well as segmentation of cortical bone for the creation of digitally reconstructed radiographs (DRRs) in order to perform 2D patient matching. Just recently, it has been shown that ultrashort echo-time (UTE) sequences can be used to segment cortical bone in the brain. [1] Moreover, it has been demonstrated that the inherent lack of electron density information in MR images can be overcome by tissue classification on the basis of Dixon MR techniques and subsequent bulk electron density assignment. [2]

In this study, we introduce a new approach on the basis of a Cartesian T1-Dixon acquisition with subsequent reconstruction workflow for tissue classification and cortical bone imaging in order to generate ED maps and DRRs of the pelvis. Results of the Cartesian T1-Dixon acquisition are compared qualitatively with a combined UTE-multi-echo Dixon sequence.

MATERIALS and METHODS:

The data of five healthy subjects were acquired on a Philips 3.0T Ingenia TX System using the body coil for transmission, a 12-element phased-array posterior coil and a 16-element phased-array anterior coil for signal reception. As a preparation step, the gradient trajectory delay was calibrated, and the tune delay of both receive coil arrays was characterized for shortest switching time (50 µs). Cartesian T1-Dixon imaging parameters were as follows: 3D Cartesian fast-field echo acquisition, TE_1/TE_2 = 1.1 ms/2.1 ms, TR = 3.3 ms, $\alpha = 10°$, 1.7x1.7x2.5 mm^3 voxel size, 300x400x350 mm^3 FOV, and 1:49 min imaging time. A bone mask was generated by manually adjusting and thresholding the noise level of the contrast inverted in-phase image. Subsequent application of a region growing algorithm for background removal resulted in bone-enhanced images (Fig.1). Water and fat fractions were derived from a conventional Dixon reconstruction of the nearly in-phase (TE_2) and out-of-phase images (TE_1).

The combined UTE-Dixon sequence parameters were: 3D radial triple-echo acquisition, $TE_1/TE_2/TE_3$ = 90 µs/1.0 ms/2.1 ms, TR = 4.6 ms, $\alpha = 10°$, 2x2x2 mm^3 voxel size, 400x400x400 mm^3 FOV, 3:44 min imaging time. Bone-enhanced images were obtained by subtraction of the in-phase image (TE_3) from the FID (TE_1) (Fig.2). Manual adjustment of the noise level allowed for optimal delineation of cortical bone structures. A conventional Dixon reconstruction of the nearly in-phase (TE_3) and out-of-phase images (TE_2) allowed for water and fat classification. Subsequently, ED maps from both approaches were generated by encoding the classified voxels with known attenuation values of soft tissue, adipose tissue, air and bone and combining them into one image. DRRs were reconstructed from bone-enhanced images as well as from ED maps (Fig. 1, 2). A first attempt to reduce artifacts from bowel contents was made by filtering with a rigidly registered probabilistic bone atlas generated from a database of computed tomography data.[3]

RESULTS:

Figure 3 shows representative slices of bone-enhanced images and ED maps of one volunteer acquired with Cartesian T1-Dixon and UTE-Dixon approaches and their resulting DRRs. Both measurements allow segmenting cortical bone and the generation of ED maps by classification of soft tissue, adipose tissue and bone. Bowel content was misclassified as cortical bone or air in both of the imaging approaches which compromises the segmentation in some slices as well as in the DRRs. In UTE scans, slight trajectory errors during FID sampling result in an enhancement of edges in the outer region of the FOV. This propagates into an edge enhancement in the subtraction of the FID and the in-phase image and, thus, into false positives in the bone-enhanced contrast, which also compromises the quality of the ED maps and DRRs. Figure 4 demonstrates the application of a probabilistic atlas filtering that is capable to markedly reduce artifacts induced by bowel content without affecting pelvic bone structures.

DISCUSSION and CONCLUSION:

Cartesian T1-Dixon as well as UTE-Dixon measurements and subsequent post-processing of the data resulted in good segmentation of cortical bone in the pelvis and allowed for tissue classification in order to generate ED maps. Both sequences suffer from misclassification of bowel content, however, a probabilistic atlas filtering seems promising to overcome this problem, thereby, to enhance the image quality of the resulting DRRs. Images acquired with the UTE-Dixon approach present additional artifacts, which might arise from noisy areas and residual signal of ultra-short T_2-components as for example in the bowel or of the skin, but also from eddy current related trajectory errors, which require further investigation.[4] The Cartesian T1-Dixon acquisition seems more robust in terms of image quality and requires less scan time compared with the UTE-Dixon approach. However, the applicability of this method to other regions of the body with cortical bone structures adjacent to air cavities (e.g. in the head) remains to be investigated, since it would require a much more elaborate post-processing for a reliable differentiation between these two compartments.

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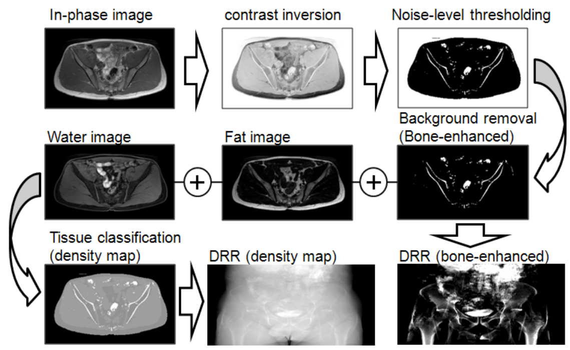

Figure 1: Workflow for generation of bone-enhanced images and tissue-classification for a Cartesian T1-Dixon sequence.

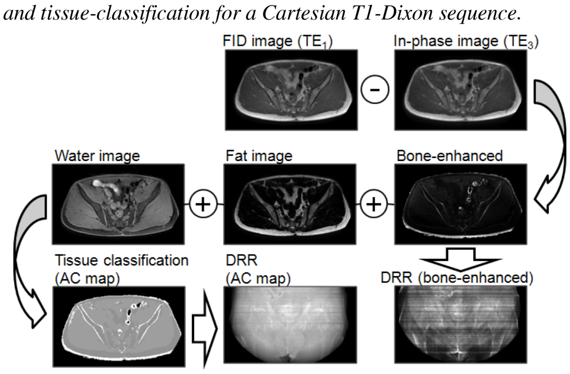

Figure 2: Workflow for generation of bone-enhanced images and tissue-classification for a UTE-multi-echo Dixon sequence.

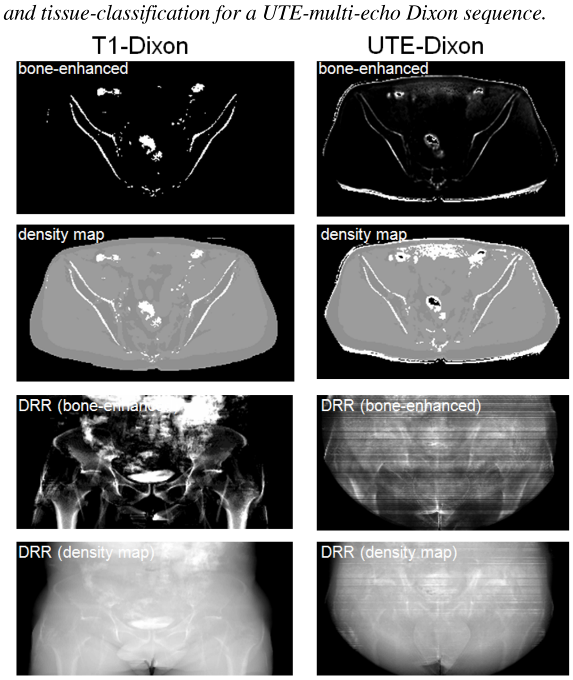

Figure 3: Direct comparison of bone-enhanced images and ED maps with subsequent construction of DRRs derived from Cartesian T1-Dixon as well as UTE-Dixon measurements.

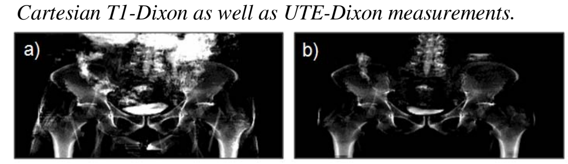

Figure 4: DRRs of non-filtered (a) and filtered (b) bone-enhanced images acquired with a Cart. T1-Dixon sequence. Probabilistic atlas filtering makes it possible to markedly reduce bowel content related artifacts without affecting pelvic bone structures.