Consistency of Intensity-based Density Value Assignment for Bone Voxels for MR-only Simulation in Radiation Therapy Planning

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INTRODUCTION

Radiation therapy planning (RTP) based on magnetic resonance imaging (MRI) is an emerging application that benefits from the superior display of soft tissue contrasts and the delineation of tumor and critical organs. Recently, a new approach based on a Cartesian T1-Dixon acquisition has been introduced which makes it possible to classify soft tissue and cortical bone structures in the pelvic region and to generate electron density (ED) maps for RTP (fig. 1) [1,2]. In this study, the consistency of the density value assignment of bone voxels is investigated on 13 patient datasets who received both MR and CT imaging. MR data from 85 patients are analyzed to evaluate group statistics.

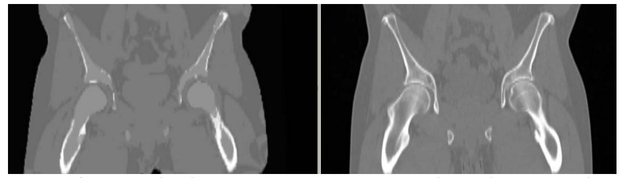

Figure 1: Example slice of one patient of a MR derived ED map (left) and corresponding stratified true CT (right) with tissue classified as air, adipose, water, bone marrow, and cortical bone structures.

MATERIALS and METHODS

The data of 85 patients scheduled for pelvic radiation therapy were acquired on a Philips 3.0T Achieva TX System using the body coil for transmission, and a 16-element phased-array coil for signal reception. T1-Dixon imaging parameters were as follows: 3D Cartesian fast-field echo acquisition, TE_1/TE_2 = 1.1ms/2.1ms, TR = 3.3ms, α = 10°, 1.7x1.7x2.5mm^3 reconstructed voxel size, 300x400x350 mm^3 FOV, and 1:49min imaging time. The images were segmented into an outside compartment, a bone compartment and a soft tissue compartment [1]. The soft tissue compartment was further subdivided into a "fat" and a "water-like" (muscle, connective tissue etc.) compartment based on the water and fat separation of the Dixon reconstruction; the respective voxels were assigned CT density values from the literature, which are known to be consistent across the patient population due to consistent chemical composition.

In order to find CT values to be assigned to the bone voxels classified on the MR images, first the density distribution of the bones on real CT images was analysed (see fig. 2). We separated the densities into two classes: cortical bone corresponding to high densities and spongy bone corresponding to low densities. Since the histograms do not show a clear distinction between both classes, we varied for the purpose of our evaluation the threshold such that 5%, 10%, 15% or 20% respectively of the total bone would be classified as "cortical" bone. The resulting CT threshold values together with the mean values of the parts below the threshold in the histogram ("spongy bone") and above it ("cortical bone") are listed in table 1.

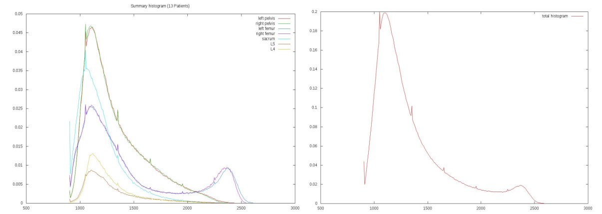

Figure2: Accumulated CT histograms for 13 patients for individual pelvis bones (left) and accumulated for all pelvis bones (right). Horizontal axis shows MR image intensities, vertical axis shows occurrence in arbitrary units.

"spongy bone" fraction	*"cortical bone" fraction*	*HU threshold*	*mean HU "spongy bone"*	*mean HU "cortical bone"*	*MR in-phase threshold*
0,8	*0,2*	*555*	*193*	*930*	*121*
0,85	*0,15*	*680*	*218*	*1033*	*103*
0,9	*0,1*	*860*	*248*	*1168*	*79*
0,95	*0,05*	*1175*	*288*	*1336*	*50*

Table 1: Parameters derived from the CT and corresponding MR histograms of pelvic bone structures.

A similar histogram was accumulated from the intensities of the parts segmented as pelvis bones from the Dixon MR images from 85 patients. The details of the segmentation are described elsewhere [1]; see fig. 3. In contrast to the CT images we assume that the low-intensity voxels comprise the cortical bone. Now, the bone voxels in the MR images were classified according to the MR in-phase image threshold value and the corresponding mean CT values for "cortical bone" was assigned to the voxels with lower MR intensity, and the "spongy bone" CT value was assigned to the voxels with higher MR intensity. Figure 1 shows one example for 10% cortical bone fraction.

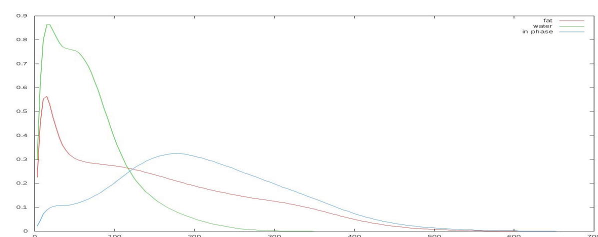

Figure 3: Accumulated histogram of 85 patients of intensities of bone voxels in fat (red), water (green) and in-phase (blue) Dixon MR images. Horizontal axis shows MR image intensities, vertical axis shows occurrence in arbitrary units.

RESULTS

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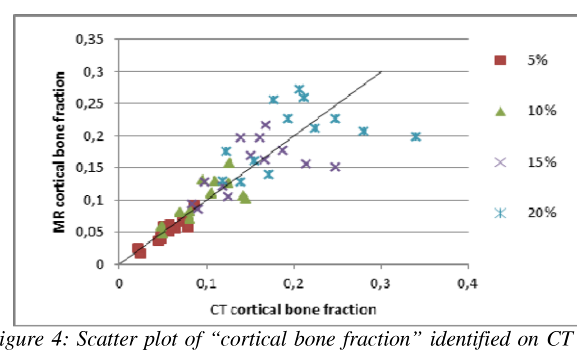

Figure 4: Scatter plot of "cortical bone fraction" identified on CT and MR images for 13 patients for the parameter combinations listed in table 1.

DISCUSSION AND CONCLUSION

Figure 4 shows a good correlation in particular for low cortical bone fractions, i.e. for patients showing a very small cortical bone on CT, we also find a small amount of cortical bone on MR classified by our scheme. If more voxels with higher MR intensities are included, the correlation is likely disturbed by partial volume effects and imaging artifacts to some extent. Nevertheless, the acceptable correlation justifies the use of absolute MR intensities, especially if patients are scanned on the same scanner with the same protocol.

Since a sufficiently accurate registration between MR and CT images of the same patient is difficult to establish, the spatial correlation of real CT densities and our densities estimated from the MR images is challenging to judge. The assignment scheme presented here provides correct overall mass densities on a population level. In view of the results published previously [2], this method seems to be adequate for RTP dosimetry.

REFERENCES:

[1]Helle M et al. Evaluation of Dixon based soft tissue and bone classification in the pelvis for MR-only-based radiation therapy planning, Proc. Ann. Meeting ISMRM 2014: #4238; [2] Schadewaldt N et al**.** Comparison of Dose Calculation On Automatically Generated MR-Based ED Maps and Corresponding Patient CT for Clinical Prostate EBRT Plans, AAPM 2014: # SU-E-J-141