PET-MR Attenuation Correction using an Ultrashort Echo Time Sequence

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I. Introduction

In the last decade the advent of multimodality PET-CT scanners has caused a revolution in medical imaging, providing the possibility to combine high sensitivity functional PET images with the anatomical reference frame of CT images. Recently the development of PET-MR scanners has started. MR has clear advantages over CT in soft tissue studies (e.g. brain) because of its much better soft tissue contrast. Another advantage is the use of non-ionizing radiation in MR.

To obtain quantitative data the PET images should be corrected for attenuation of the 511 keV photons. In this purpose an attenuation map needs to be obtained. In PET-CT the CT images can simply be rescaled to 511 keV attenuation coefficients, as CT Hounsfield units reflect photon attenuation values. The derivation of the attenuation map from MR images is much more difficult, as the MR signal bares no direct correlation with the attenuation coefficient[1]. MR signal intensity is related to the proton density and relaxation properties of the measured tissue. The low proton density and very fast relaxation of cortical bone gives this tissue type a very low signal intensity with conventional MR sequences, making it impossible to distinguish from air, while both have very different attenuation coefficients. The use of ultrashort echo time (UTE) MR sequences could enable the detection of bone on MR images[2].

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We first investigate the feasibility of visualizing cortical bone using a UTE sequence. In a second step the use of UTE images and a specific image processing method to derive PET attenuation maps from MR images is evaluated.

II. Materials and methods

A. Proton density and T_2 of cortical bone

We performed T_2 (spin-spin relaxation time) and proton density measurements on 5 samples of cortical bone taken from the shaft of a bovine femur using a 0.5 T Bruker relaxometer. The signal amplitude of the samples and of different volumes of water was measured. The volume of the samples was derived from a μ-CT scan. From this data an average signal-to-volume ratio was calculated for cortical bone and water. T_2 was measured with a multi spin-echo sequence using 50 echoes with 170 μs inter-echo spacing.

B. Clinical data acquisition

One clinical brain MR-CT data set was acquired. MR images were acquired on a Philips Achieva 3.0 T system. The UTE sequence measures two echoes (0.14 ms and 1.70 ms). Because the echo time of the first echo is much shorter than in conventional MR sequences, the signal from bone tissue can be recorded before it is lost. In the second echo most of the signal in bone will have disappeared. This makes it possible to discriminate between air (low in both echoes), soft tissue (high in both echoes) and bone (medium in first, low in second echo). Low-dose CT images were acquired on a Philips Gemini TF PET/CT system.

C. Image processing

From both MR images the R_2-map ($= 1/T_2$) was derived with the formula $R_2 = \frac{ln(I_1)-ln(I_2)}{T_{E2}-T_{E1}}$, in which I_x and T_{Ex} represent the image intensity and echo time of both echoes. R_2 is a quantitative parameter independent of the variability of MR image intensity. To set all voxels containing air to zero, the R_2-map was multiplied by a logical air mask derived from the first echo image by simple thresholding. This corrected R_2-map was then segmented into bone (high R_2), soft tissue (medium-low R_2) and air (zero). The CT was also segmented.

III. Results

A. Proton density and T_2 of cortical bone

Fig. 1 shows measured signal amplitude vs. volume of the cortical bone samples and 5 samples of distilled water. The results show that a unit volume of cortical bone will provide 29% (the ratio of the slope of both linear regression lines) of the signal intensity of a unit volume of water. The T_2 values measured in 5 samples were in the range of $1.37-1.70ms$, with an average of $1.51ms$. This result indicates that the visualization of cortical bone with MRI is possible if the signal can be acquired very shortly after the excitation pulse.

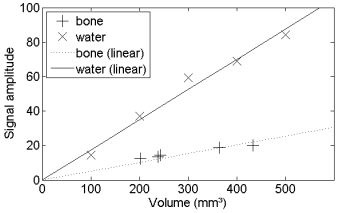

Figure 1. Signal intensity of water and cortical bone samples related to their volume.

B. Clinical data

Fig. 2 shows the corrected R_2-map and the CT of the same slice of the clinical data set. Comparable information is found in both images: the skull is clearly visible, as are the frontal sinuses and the brain soft tissue. Fig. 3 shows the results of a voxel-by-voxel comparison between both images. Over 90% of voxels were assigned to the correct tissue class.

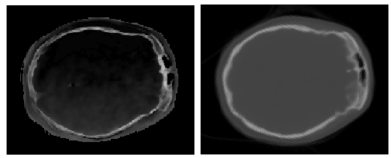

Figure 2. Transaxial slice of the corrected R_2-map (left) and CT (right) of a clinical brain data set.

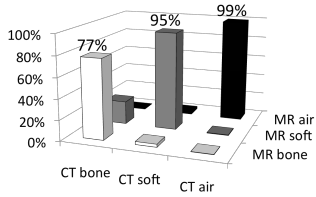

Figure 3. Voxel-by-voxel comparison of the segmented MR and segmented CT slice.

IV. Discussion

The T_2 and proton density of cortical bone were measured and show that cortical bone can be visualized with a UTE sequence. The possibility of discriminating bone, soft tissue and air from a corrected R_2-map derived from MR UTE images was shown with over 90% accuracy. Some voxels were assigned to the wrong tissue class. However, as most mistakes are made between bone and soft tissue, the effect on the reconstructed PET images will remain small compared to segmentation based on conventional MR images where bone and air may be confused.

References

[1] H Zaidi, "Is mr-guided attenuation correction a viable option for dual-modality pet/mr imaging?," *Radiology*, vol. 244, no. 3, pp. 639–642, Sep 2007.

[2] M D Robson, P D Gatehouse, P W So, J D Bell, and G M Bydder, "Contrast enhancement of short t2 tissues using ultrashort te (ute) pulse sequences.," *Clin Radiol*, vol. 59, no. 8, pp. 720–726, Aug 2004.