MR-based whole-body PET attenuation correction in hybrid PET/MRI: A computationally inexpensive algorithm for T1, T2, and proton density weighted images

H. R. Marshall[1,2], R. Z. Stodilka[1,2], B. Lewden[2], J. Theberge[1,2], E. Sabondjian[1,2], A. G. Legros[2], A. J. Mitchell[2], L. Deans[2], J. M. Sykes[2], R. T. Thompson[1,2], and F. S. Prato[1,2]
[1]Medical Biophysics, The University of Western Ontario, London, ON, Canada, [2]Imaging, Lawson Health Research Institute, London, ON, Canada

Introduction

Both magnetic resonance imaging (MRI) and positron emission tomography (PET) are remarkably versatile modalities, each capable of imaging numerous biological processes. It is therefore likely that their combination (i.e. hybrid PET/MRI) will yield a bounty of applications in the basic and clinical sciences[1]. PET image formation is based on detecting gamma rays emitted from the subject. Unfortunately, some of these gamma rays are absorbed or scattered away from the field of view by the subject and thus remain undetected. This physical phenomenon is termed attenuation. Attenuation severely degrades image quality and compromises quantitative accuracy. Attenuation can be corrected if a volumetric distribution of the subject's electron density (i.e. an attenuation map) is available. Traditional methods of obtaining this information are not practical in PET/MRI systems, so the MRI images must serve as the source of the attenuation map. Several groups are focusing on acquiring extra MRI scans solely for the purpose of attenuation correction, thereby lengthening clinical acquisition time. Our goal is to circumvent this problem by developing a method that can use MRI images already collected for diagnostic purposes. Previously, we demonstrated application of our methods in 3 canines using combined T_1, T_2, and proton density (PD) data[2]. We have now refined the algorithm to work with single contrast images (any of T_1, T_2, or PD), and demonstrate its application in nine whole-body canine scans on a 3T scanner.

Methods

Nine female canines were imaged from neck to pelvis with MRI and x-ray computed tomography (CT). The three canonical MRI contrasts were collected using a RARE sequence: T_1 weighted (TR/TE = 1910 ms / 13 ms), T_2 weighted (TR/TE = 12190 ms / 92 ms), and proton density (PD) weighted (TR/TE = 3000 ms / 15 ms). The algorithm used to convert MR images into PET attenuation maps was based on low-level image processing techniques (e.g. thresholding, edge detection, etc.) and shape analysis. The classes of material included in the segmentation were air, lung, soft tissue, and bone. These classes were assigned 511 keV attenuation coefficients of 0 cm^{-1}, 0.026 cm^{-1}, 0.1 cm^{-1}, and 0.172 cm^{-1}, respectively. The CT images were used to derive gold standard PET attenuation maps. The MRI and CT based attenuation maps were quantitatively compared by calculating geometrically concordant line integrals through axial slices and plotting them against one another on a scatter plot (Fig. 1). (These line integrals, not individual voxel values, are what are used mathematically to derive attenuation correction factors.) Least squares lines of best fit (LOBFs) were calculated for the scatter plots with ideal values of: slope (m) = 1, y-intercept (b) = 0, and correlation coefficient (r) = 1.

Results

Visually, the MRI based attenuation maps closely approximated the CT based attenuation maps (Fig. 2). LOBFs of the line integral scatter plots had average values +/- SEM as displayed in Table 1. The algorithm ran to completion in under one minute.

Discussion

Our algorithm is able to generate attenuation maps of similar quality to the gold standard using all of T_1 weighted, T_2 weighted, and proton density weighted MRI images. Furthermore, some of the limitations of previous works in the field[2,3] are addressed by avoiding computationally expensive procedures and accounting for bone. Given this algorithm's speed (completion in less than one minute) and applicability to many varieties of MRI images, it is a promising candidate for whole-body PET/MRI attenuation correction.

Table 1: Average parameters +/- SEM of LOBFs

Contrast	m +/- SEM	b +/- SEM	r +/- SEM
T_1	0.97 +/- 0.03	0.003 +/- 0.003	0.99 +/- 0.01
T_2	0.94 +/- 0.04	-0.005 +/- 0.010	0.98 +/- 0.01
PD	0.98 +/- 0.06	-0.016 +/- 0.060	0.98 +/- 0.01

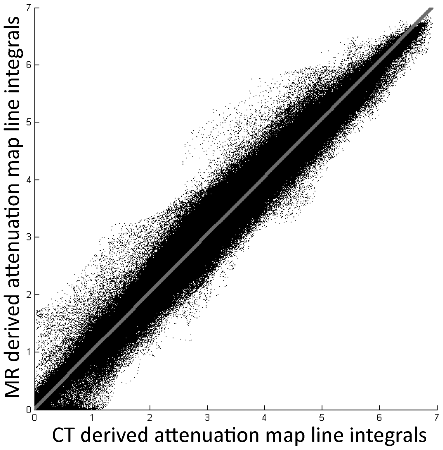

Fig. 1: Scatter plot of MR vs. CT based attenuation map line integrals.

References

1. Wehrl *et al*. Eur J Nucl Med Mol Imaging 2009;36(Suppl 1):S56-S68.
2. Marshall *et al*. ISMRM Hawai'i, 2009.
3. Hofmann *et al*. J Nucl Med 2008;49:1875-1883.
4. Martinez-Möller *et al*. J Nucl Med 2009;50(4):520-526.

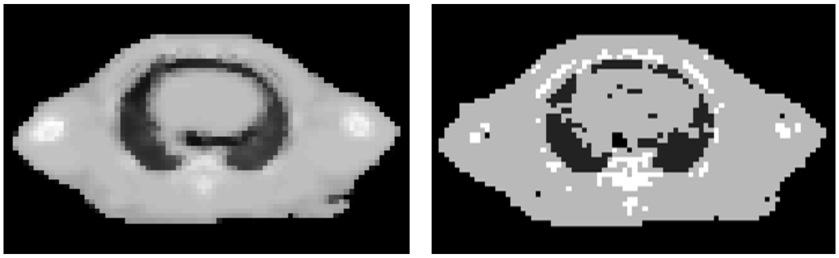

Fig. 2: Axial slice of a CT based attenuation map (left) and corresponding MR based attenuation map (right) derived from a T_1 weighted image.