Feasibility of PET Attenuation Characterization of MR Hardware using 3D data from a LINAC as Radiation Source

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Introduction

With the introduction of integrated MR-PET systems both for preclinical animal studies as well as full sized human scanners, the question of PET attenuation originating from MR hardware (MR-HW) which is located between the patient and the PET camera, has been a topic of increasing interest for research. Sander and Delso et al. [1, 2] have identified mechanical structures for the patient table, the housings of local coils as well as the electronics and antenna structures within these housings as the major contributions to PET signal attenuation. This attenuation map needs to be included in the PET reconstruction, as the line of response needs to be rescaled according to the integral of attenuation values along its way to the detectors. In addition, the PET scatter correction relies on a precise attenuation map in order to compute the scatter contribution. These two corrections are essential for quantitative and reliable PET image quality, especially when imaging humans. Characterizing the exact PET attenuation at an energy level of 511keV is challenging, because monochromatic radiation sources at this energy level generating 3D attenuation maps require scanners with transmission sources and large apertures. The goal of this paper is to evaluate the feasibility and the potential advantages of MR-HW attenuation correction based on 3D data coming from a LINAC instead of a CT.

Material and Methods

So far CT images have been used and Hounsfield units have been rescaled, so that the low-energy profile from a CT can be used to predict 511keV attenuation maps. This method is well established in the PET/CT scanners for human use. There a bilinear transformation is applied which scales the soft-tissue and bone CT attenuation values to 511 keV Attenuation values. The lower part of the bi-linear curve intersects zero and the attenuation of water at 511keV, while the upper part of the bi-linear curve intersects the lower curve at approximately 50 to 100 HU and has a variable slope depending on the accelerating voltage across the CT X-ray tube (usually 80, 100, 120, or 140 kV). For hardware attenuation, the dynamic range of attenuation values is much bigger and the CT-based measurement of the attenuation map benefits from the use of an extended CT scale with a maximum of 10,240 HU rather than 3,024 HU. Nevertheless, the bilinear transformation is no longer straight forward, due to the almost complete attenuation of the X-rays by the high-Z metals, for instance copper and solder, in the electronics, cables and antennas of the MR-HW. The almost complete X-ray absorption causes CT reconstruction artifacts, when analytic reconstruction is used, in the vicinity of larger metal structures and makes the hardware attenuation correction process based on CT data difficult.

The study compares images from local-coils housings and electronics structures examined by using a Siemens Somatom Definition Flash CT canner versus a Siemens Artiste LINAC. The acceleration voltages together with the carbon target used for the given experiment yield an average photon energy of 468keV [3], which is much closer to the 511keV required for the PET experiment than the Bremsstrahlung from a CT tube.

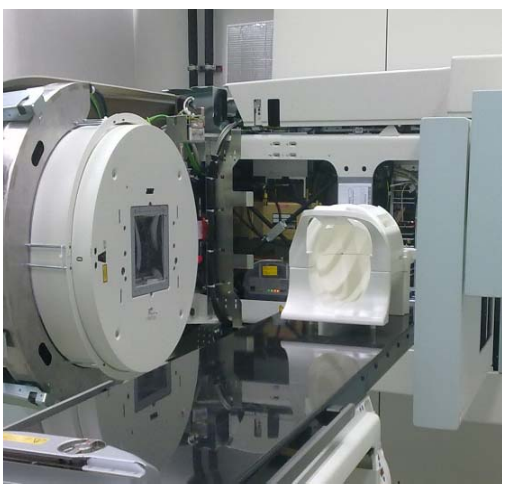

Fig 1: MR head coil mounted on LINAC for examination.

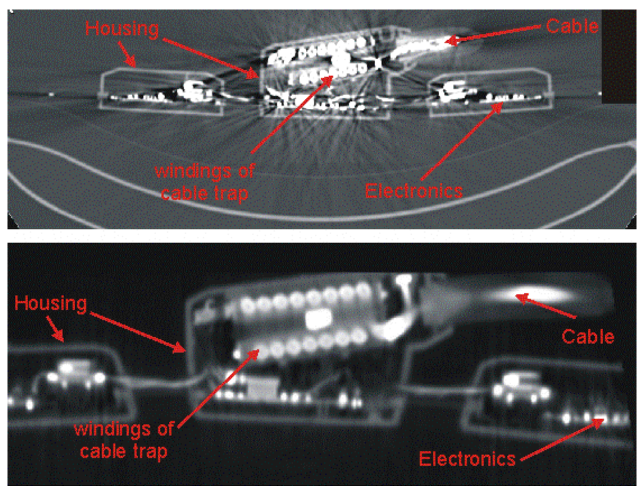

Fig. 2: cable trap and electronics of a local coil for thorax imaging (a) top: CT image; (b) bottom: LINAC image;

Results

Figure 1 shows the test setup of a 3T Siemens head-neck coil positioned on the LINAC table. Figures 2a and b show first results of a comparison of local coils structures (housing, electronics for preamplifier and detuning, cables and cable traps). Figure 2a comes from a CT and clearly shows the typical CT metal artifacts. The metal artifacts cause streaking in the neighborhood of those voxels consisting of metal (neglecting partial volume effects). The strong streaking in the CT images extends over most of the image making an accurate quantitative PET attenuation evaluation for other voxels very difficult or even impossible. Figure 2b comes from a LINAC and shows no streaking artifacts despite hard windowing of the DICOM image to strongly pronounce any artifacts.

Conclusions and Outlook

It has been shown that a LINAC-based characterization of MR hardware is possible free from the typical metal artifacts of a CT scan. Furthermore, the use of an appropriate acceleration voltage and target allows to generate a photon beam whose average energy is very close to the PET energy. Conversion from the LINAC attenuation to the actual PET attenuation also including the LINAC's spectral characteristics is subject for further research.

References:

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