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Errors in MR-based attenuation correction for brain imaging with PET/MR scanners

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ABSTRACT

Aim: Attenuation correction of PET data acquired by hybrid MR/PET scanners remains a challenge, even if several methods for brain and whole-body measurements have been developed recently. A template-based attenuation correction for brain imaging proposed by our group is easy to handle and delivers reliable attenuation maps in a short time. However, some potential error sources are analyzed in this study. We investigated the choice of template reference head among all the available data (error A), and possible skull anomalies of the specific patient, such as discontinuities due to surgery (error B).
Materials and methods: An anatomical MR measurement and a 2-bed-position transmission scan covering the whole head and neck region were performed in eight normal subjects (4 females, 4 males). Error A: Taking alternatively one of the eight heads as reference, eight different templates were created by nonlinearly registering the images to the reference and calculating the average. Eight patients (4 females, 4 males; 4 with brain lesions, 4 w/o brain lesions) were measured in the Siemens BrainPET/MR scanner. The eight templates were used to generate the patients' attenuation maps required for reconstruction. ROI and VOI atlas-based comparisons were performed employing all the reconstructed images. Error B: CT-based attenuation maps of two volunteers were manipulated by manually inserting several skull lesions and filling a nasal cavity. The corresponding attenuation coefficients were substituted with the water's coefficient (0.096/cm).
Results: Error A: The mean SUVs over the eight templates pairs for all eight patients and all VOIs did not differ significantly one from each other. Standard deviations up to 1.24% were found. Error B: After reconstruction of the volunteers' BrainPET data with the CT-based attenuation maps without and with skull anomalies, a VOI-atlas analysis was performed revealing very little influence of the skull lesions (less than 3%), while the filled nasal cavity yielded an overestimation in cerebellum up to 5%.
Conclusions: The present error analysis confirms that our template-based attenuation method provides reliable attenuation corrections of PET brain imaging measured in PET/MR scanners.

1. Introduction

Absolute quantification is the great benefit of PET imaging. This advantage should also be expected with hybrid MR/PET imaging. Due to the limited space available inside the MR scanner bore as well as to the technical limitations, neither a transmission nor a CT-based system could be installed, thus leading to the search for new MR-based attenuation correction (AC) methods. This fact remains, however, a challenge even if several methods for brain as well as whole-body scans have been developed recently [1–6]. A template-based AC for brain imaging was proposed [1] which is easy to be applied delivering reliable attenuation maps in a short time. In the present study we investigated some potential errors inherent to this method: Based on the way how the template is created, the influence of the choice of the reference head among all the available data (error A), and the presence of possible skull anomalies, such as discontinuities due to surgery (error B), were analyzed. In this work the template-based AC method will be first shortly explained (Section 2.1) following with the description of the template generation (Section 2.2).

2. Materials and methods

2.1. Template method

Fig. 1 shows schematically the workflow generating the patient's attenuation map. It starts with an MR (a) and a PET (c) attenuation template. The MR template is non-linearly registered to the patient's

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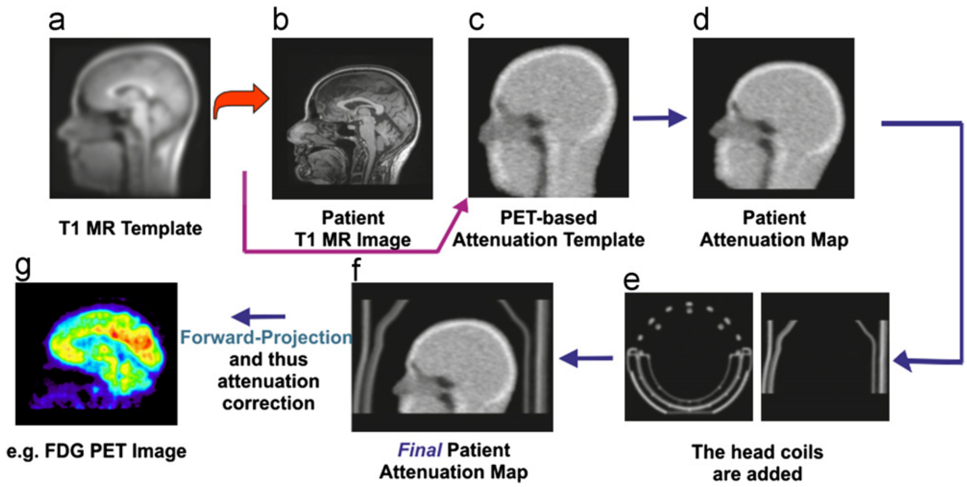

Fig. 1. Workflow generating the patient's attenuation map.

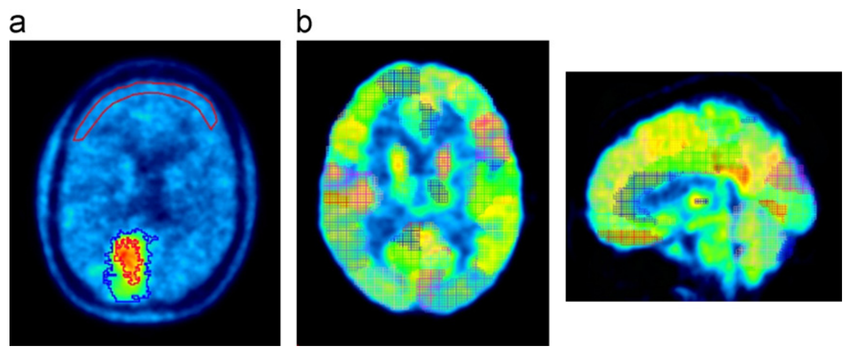

Fig. 2. VOIs for analysis of FET (a) and FDG images (b).

MR image (b). The registration parameters are applied to the PET attenuation template (c) yielding a preliminary patient's attenuation map (d) to which the head coils (e) are added resulting into the final patient's attenuation map (f). This is forward projected to correct the PET data (g).

2.2. Template generation

To comprehend the idea related to the error A it is necessary to understand how the template pair is generated. For this purpose, an anatomical T1 weighted MR sequence in a Siemens 3T Magnetom Tim Trio scanner and a 2-bed-position transmission scan in the Siemens ECAT HR+ PET scanner covering the whole head and neck region were performed in eight normal subjects (4 female and 4 male). After a pairwise linear registration, one image pair was selected to be the reference pair. Then, all other pairs were non-linearly registered to it. The reference and the modified seven image pairs were then averaged resulting into the final MR and PET attenuation template pair.

2.3. Influence of choice of the template reference pair (error A)

Each of the eight image pairs, used in Section 2.2 to create the final template pair, was alternatively selected to be a new reference pair. For each selected pair all the other pairs were non-linearly registered to it and averaged together with the reference pair resulting into eight final template pairs (Template 1–Template 8). To examine possible differences related to the choice of the reference pair, eight patients (4 female, 4 male) were selected from ongoing studies on the hybrid MR/BrainPET scanner: four patients (P1–P4; 2 female, 2 male) were measured with [^{18} F]–FET (amino acid tracer for brain tumors) and four patients (P5–P8; 2 female, 2 male) without neurological diseases were measured with [^{18} F]–FDG. In all patients a T1-weighted MR scan was performed with an image volume of $256 \times 256 \times 190$ and an isotropic resolution of 1 mm^3, while the BrainPET measurements were performed over 50 min starting at the injection time for the FET patients and over 30 min about 2 h after injection for the FDG patients. In all cases a PET image volume of $256 \times 256 \times 153$ with a voxel size of 1.25 mm^3 was reconstructed.

After image reconstruction of all patient data using the eight different templates for AC, a VOI analysis was performed. The FET data (P1–P4), i.e., a patient group which requires individual Volumes of Interest (VOIs) according to the tumor size, were investigated with VOIs obtained by two different thresholds on the tumor area (TA1&TA2) and one VOI on the healthy brain tissue (B) (Fig. 2a). The FDG data (P5–P8) were analyzed with VOIs of the AAL-Atlas available in Pmod. The regions chosen were frontal (V1), temporal (V2), parietal (V3), occipital (V4), caudate nucleus (V5), putamen (V6), thalamus (V7), and cerebellum (V8) (Fig. 2b), some of them averaged over more VOIs. Because of the relatively large size of these regions it was decided to also investigate the behavior of smaller regions. For this purpose, among all the AAL-Atlas VOIs we choose the cerebellum which is divided into nine sub-regions with volumes ranging from 0.75 cm^3 to 20.10 cm^3. For all VOIs SUV values were finally calculated.

2.4. Influence of skull anomalies (error B)

The aim of this analysis should be the comparison of emission data with injured skull with the same emission data, but with