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Original article

The effect of tissue-segmented attenuation maps on PET quantification with a special focus on large arteries

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ABSTRACT

Objectives: Accuracy on quantitative PET image analysis relies on the correct application of attenuation correction which is one of the major challenges for PET/MRI that remains to be solved. The purpose of this study is to evaluate the effect of MRI-based attenuation maps and the use of flexible coils on the quantitative accuracy of PET images with a special focus on large arteries.
Materials and methods: PET/CT data from eight oncologic patients was used. PET data was reconstructed using attenuation maps with different level of detail emulating several approaches available on current PET/MRI scanners. PET images obtained with CT-based and MRI-based attenuation maps were compared to evaluate the quantitative biases obtained. The quantitative effect produced by flexible MRI receiver coils on the attenuation maps was also studied.
Results: The use of simpler attenuation maps produced increased biases between PET data reconstructed with CT-based and MRI-based attenuation maps for fat, non-fat soft-tissues and bone. Biases in lung were very high due to the large heterogeneity and inter-patient variability of the lung. The quantification on large arteries had small deviations except for the case when flexible coils were used. The *TBR* provided smaller biases in all cases as it cancelled out the similar deviations obtained for arteries and reference veins.
Conclusions: Simplified attenuation maps used on PET/MRI significantly increase the quantitative variability of PET images especially on lungs and bones. The quantification of PET images acquired with PET/MRI scanners applied to studies of atherosclerosis has small deviations, especially when the *TBR* is considered.

Efecto de la segmentación por tejidos en los mapas de atenuación sobre la cuantificación PET con especial hincapié en grandes arterias

Palabras clave:
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RESUMEN

Objetivos: La precisión cuantitativa en PET requiere una adecuada aplicación de la corrección de atenuación, lo cual representa uno de los mayores retos que aún están por resolver en la técnica PET/RM. El propósito de este estudio es evaluar el efecto de utilizar mapas de atenuación basados en RM y el uso de antenas flexibles sobre la precisión cuantitativa en PET con especial hincapié en grandes arterias.
Materiales y métodos: Se utilizaron datos PET/TC de 8 pacientes oncológicos. Los datos PET fueron reconstruidos utilizando mapas de atenuación con diferente nivel de detalle emulando las distintas aproximaciones utilizadas actualmente por lo equipos PET/RM. Las imágenes PET obtenidas con mapas de atenuación basados en TC y RM fueron comparadas para evaluar las desviaciones cuantitativas obtenidas. El efecto producido por las antenas flexibles fue también estudiado.
Resultados: El uso de mapas de atenuación más simplificados da lugar a un incremento en las desviaciones cuantitativas en grasa, tejido blando y hueso. Las desviaciones en pulmón son altas debido a su heterogeneidad y a la variabilidad entre pacientes. La cuantificación en grandes arterias muestra pequeñas desviaciones excepto en el caso de utilizar antenas flexibles. La cuantificación mediante *TBR* proporciona menores desviaciones al cancelarse las desviaciones medidas en arterias y las venas utilizadas como referencia.

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Conclusiones: Los mapas de atenuación simplificados que se utilizan en PET/RM producen un incremento significativo de variabilidad cuantitativa especialmente en pulmones y huesos. La cuantificación aplicada al estudio de la aterosclerosis produce pequeñas desviaciones, especialmente cuando se utiliza el *TBR*.

Introduction

Positron Emission Tomography (PET) is a non-invasive medical imaging technique that allows the visualization of the distribution of a particular tracer inside the body.[1] It is based on the administration of a radiopharmaceutical (usually 2-fluoro-deoxyglucose ^{18}F-FDG) obtained by the synthesis of a specific molecule that is labelled with a radioactive isotope (such as ^{18}F) which decays emitting a positron.[2]

The enormous potential of the combination of various medical imaging techniques has become more evident in the last years. PET and Magnetic Resonance Imaging (MRI) are two established medical imaging modalities which provide complementary information in a wide range of routine clinical and research applications.[3] MRI is capable of visualizing anatomy with excellent spatial resolution and high diagnostic sensitivity without extra radiation. On the other hand, PET provides the possibility of mapping functional processes at a cellular and sub-cellular level with exceptional diagnostic specificity and sensitivity.

One of the emerging applications for PET/MR is the study of atherosclerosis. This disease is caused by the build-up of plaques and cholesterol in the intima/media layer creating an inflammatory process that attracts and stimulates macrophages in the inner artery wall. Atherosclerosis is the basis of the onset of cardiovascular diseases, which are the leading cause of death and disability in the World[4] causing 1.9 million deaths every year in the European Union. ^{18}F-FDG PET allows measuring and characterizing plaque inflammation,[5] as FDG is retained within plaque macrophages. Therefore, it allows characterizing higher-risk features of plaque composition, and thus, it has the potential to become a crucial tool for individual cardiovascular risk assessment.

The Progression of Early Subclinical Atherosclerosis (PESA) project is an ongoing study performed at Centro Nacional de Investigaciones Cardiovasculares (CNIC) that examines the presence of subclinical atherosclerosis by means of noninvasive imaging and prospectively analyzes the determinants associated with its development and progression in a middle-aged population.[6] This project includes about 4000 human subjects from which about 25% of them undergo a PET/MRI scan of different peripheral and extracardiac arterial regions as part of the study.

Accurate quantitative PET images can only be obtained after proper correction for several factors: attenuation, random, scatter, dead-time, decay, normalization. The attenuation effect reduces the number of photons detected in each line of response. The attenuation probability depends exponentially on the attenuation coefficient (μ) of the crossed material and the length travelled inside it. If the photon attenuation properties of each tissue are known, the measurement along each line of response can be corrected for this effect.[7] In PET/MRI, accurate attenuation maps cannot be derived from the MRI scans. MRI signal generation is based on proton density and proton relaxation times after excitation and therefore it has no correlation with the electron density.[8] As a consequence, no contrast between air, lung and cortical bone is obtained in images acquired with conventional MRI sequences because the three tissue types have low proton density and their relaxometric properties provide no MRI signal at the normal acquisition sequences and parameters normally available in clinical scanners.[9] Alternative methods for MRI-based attenuation maps are based on anatomical atlases, segmentation of images obtained with specific MRI sequences, or a combination of both.[10]

It is important to consider that photon attenuation happens not only within the patients' body but also within the devices placed between the patient and PET detectors (patient table, rigid and flexible coils). The attenuation caused by these components is significant because the coils include metallic parts, but they are not part of the information acquired with MRI. Their effect, in most cases, can be corrected by introducing templates in the reconstruction algorithm. However, flexible coils, which are placed directly on the patient's body, are currently omitted because their exact position and geometry is unknown. Some strategies have been already suggested to include these coils in the attenuation map.[11] However, new coils with reduced attenuation impact are being introduced to minimize this problem.[12]

The aim of this study is to evaluate the effect of MRI-based attenuation maps and the use of flexible coils on PET quantification with a special focus on the assessment of plaque inflammation. For this purpose, we used PET/CT data acquired on oncologic patients with MRI-based attenuation maps derived from segmentation of CT images. Direct comparison of PET/CT and PET/MRI images of the same patient was not pursued as it is limited by other factors such as CT and MR registration accuracy.[13]

Materials and methods

Imaging protocol

Eight whole body PET/CT scans of oncologic patients were acquired at the Hospital General Universitario Gregorio Marañón (HGUGM, Madrid) (see Table 1). All patients gave consent informed and the study was approved by the reference ethics Committees from HGUGM and CNIC.

All patients followed the usual preparation protocol for the diagnostic PET/CT examinations which consists in performing a complete medical history, 6 h of fasting, blood glucose monitoring and puncture of an antecubital vein for administration of the corresponding ^{18}F-FDG dose. The resting time required before acquiring the PET/CT scan was at least 45 min (66 ± 12 min). The injected dose was calculated according to body weight at the 5 MBq/kg dosage of ^{18}F-FDG. The average injected activity was 277 ± 26 MBq.

PET/CT studies were performed using the Siemens Biograph™ mCT (Siemens Healthcare) placed at the HGUGM. The low dose CT scan was performed in first place operating the X-ray tube at 130 kVp. The PET protocol consisted of 3 min acquisition time per bed position with a 30% bed overlap. The images were

Table 1
Patient details.

Patient	Sex	Age (years)	Weight (kg)	Dose (MBq)
1	Male	66	87	302
2	Male	33	83	272
3	Male	80	56	266
4	Male	52	90	279
5	Male	63	76	307
6	Male	58	108	303
7	Female	68	77	241
8	Male	61	78	246

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