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Reliability of semiquantitative ^{18}F-FDG PET parameters derived from simultaneous brain PET/MRI: A feasibility study

Amarnath Jena [a], Sangeeta Taneja [a], Reema Goel [a,*], Pushpendranath Renjen [b], Pradeep Negi [a]

[a] Department of Molecular Imaging and Nuclear Medicine, Indraprastha Apollo Hospitals, Sarita Vihar, Mathura Road, New Delhi 110076, Delhi, India
[b] Department of Neurology, Indraprastha Apollo Hospitals, Sarita Vihar, Mathura Road, New Delhi 110076, Delhi, India

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ABSTRACT

Purpose: Simultaneous brain PET/MRI faces an important issue of validation of accurate MRI based attenuation correction (AC) method for precise quantitation of brain PET data unlike in PET/CT systems where the use of standard, validated CT based AC is routinely available. The aim of this study was to investigate the feasibility of evaluation of semiquantitative ^{18}F-FDG PET parameters derived from simultaneous brain PET/MRI using ultrashort echo time (UTE) sequences for AC and to assess their agreement with those obtained from PET/CT examination.

Methods: Sixteen patients (age range 18–73 years; mean age 49.43 (19.3) years; 13 men 3 women) underwent simultaneous brain PET/MRI followed immediately by PET/CT. Quantitative analysis of brain PET images obtained from both studies was undertaken using Scenium v.1 brain analysis software package. Twenty ROIs for various brain regions were system generated and 6 semiquantitative parameters including maximum standardized uptake value (SUV max), SUV mean, minimum SUV (SUV min), minimum standard deviation (SD min), maximum SD (SD max) and SD from mean were calculated for both sets of PET data for each patient. Intra-class correlation coefficients (ICCs) were determined to assess agreement between the various semiquantitative parameters for the two PET data sets.

Results: Intra-class co-relation between the two PET data sets for SUV max, SUV mean and SD max was highly significant ($p < 0.00$) for all the 20 predefined brain regions with ICC > 0.9. SD from mean was also found to be statistically significant for all the predefined brain regions with ICC > 0.8. However, SUV max and SUV mean values obtained from PET/MRI were significantly lower compared to those of PET/CT for all the predefined brain regions.

Conclusion: PET quantitation accuracy using the MRI based UTE sequences for AC in simultaneous brain PET/MRI is reliable in a clinical setting, being similar to that obtained using PET/CT.

1. Introduction

Fluorine 18 fluorodeoxyglucose (FDG) PET or dual-modality PET and computed tomographic (CT) imaging (PET/CT) is currently the most accurate and widely available in vivo method for the investigation of regional human brain metabolism. Its diagnostic use has emerged as an important problem solving tool in neurology, neurosurgery and psychiatry [1–5]. Since magnetic resonance imaging (MRI) represents the first-line diagnostic imaging modality for several indications in the field of neuroimaging, fusion of PET and MR images has been attempted combining the high resolution of MR imaging with the low-resolution functional capability of PET. Fully integrated scanners capable of simultaneous acquisition of PET and MRI have now been developed [6–8], thus eliminating CT co registration for PET and reducing radiation exposure to the patient.

An accurate attenuation-correction (AC) method is necessary for quantification of ^{18}F-FDG brain PET studies. However validation of a MRI-based AC method remains an important issue in simultaneous PET/MRI systems unlike in PET/CT for which standard, validated CT transmission scan for AC is routinely available. This is because the signal obtained from MRI reflects tissue hydrogen densities and relaxation times and not electron density, thus the MR images are not directly related to the tissue linear attenuation coefficients as opposed to the CT images 9. Although several attenuation maps

* Corresponding author. Tel.: +91 1129873079; mobile: +91 9654343326.
E-mail addresses: drjena2002@yahoo.com (A. Jena), s.taneja1974@yahoo.com (S. Taneja), reemagoell@gmail.com (R. Goel), pnrenjen@hotmail.com (P. Renjen), pradeepmri@rediffmail.com (P. Negi).

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have been previously estimated from segmented MR images 10, and atlas based methods [11], the most challenging task consists of differentiating bone tissue from air filled spaces which is especially important for obtaining accurate correction in head datasets. In this aspect new ultrashort echo time (UTE) sequence has been proposed and shown to be as accurate as the segmented CT method [10,12].

Precise quantitative measurements of pathologic processes in the brain such as in neurodegenerative diseases, epilepsy, tumors especially before and after treatment and vascular disturbances using simultaneous brain PET/MRI could improve the clinical evaluation of these various disorders of the central nervous system. In this work we investigated the feasibility of evaluation of semiquantitative ^{18}F-FDG PET parameters obtained from simultaneous brain PET/MRI using UTE sequences for AC and assessed their agreement with the parameters obtained from conventional PET/CT.

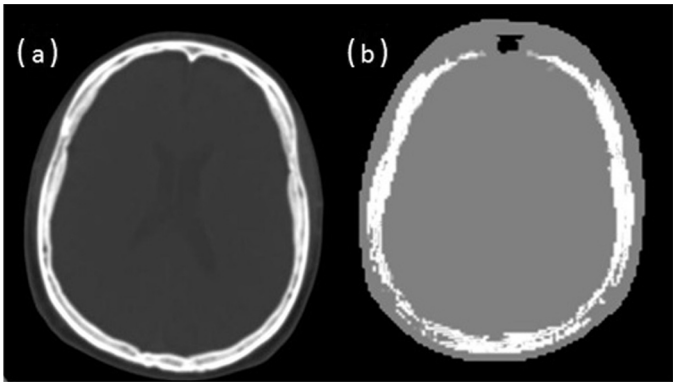

Fig. 1. Attenuation map of head as obtained from CT based AC (a) and MRI UTE sequence based AC (b).

2. Material and methods

2.1. Patient population

It is a prospective study which included 16 patients, 12 of whom were referred for simultaneous brain PET/MRI for various neurological indications and 4 for simultaneous whole body PET/MRI for non neurological complaints. Of these twelve patients, three were suspected cases of Parkinson's disease, three with dementia, one with a clinical suspicion of multiple system atrophy, one a suspected case of Creutzfeldt–Jakob disease, one with multiple cavernous hemangiomas while three presented with epilepsy. All patients signed a written informed consent for the brain PET/MR and PET/CT examinations and the scientific evaluation of the datasets. This study was approved by the local institutional review board. The inclusion criteria were written informed consent and ability to undergo another scan after the PET/MRI examination. Exclusion criteria were pregnancy, age below 18 years, and standard contraindications for MRI examinations (magnetic metal implants, pacemakers, etc.)

2.2. Instrumentation

2.2.1. PET/MR

Simultaneous PET/MR was performed on the Biograph mMR (Siemens Co, Erlangen, Germany). This system consists of a 3-T MRI scanner harboring a fully functional PET system, equipped with the avalanche photodiode technology [13]. MR scanner features high-performance gradient systems (45 mT/m) with a slew rate of 200 T/(m s) and is equipped with total imaging matrix coil technology, covering the entire body with multiple integrated radiofrequency surface coils [14]. The PET scanner has a spatial resolution of 4.3 mm at 1 cm and 5.0 mm at 10 cm from the transverse field of view (FOV); its sensitivity being 1.47% at the center of the FOV and 1.38% at 10 cm.

2.2.2. PET/CT

PET/CT was performed on Biograph^{TM} mCT (128 S, Siemens Co, Erlangen, Germany). The PET scanner has a spatial resolution of 4.4 mm at 1 cm, a sensitivity of 0.97% at the center of the FOV and 0.95% at 10 cm.

2.2.3. Imaging protocol

Patients fasted for at least 6 h before intravenous tracer injection of ^{18}F-FDG. All patients underwent a dual-imaging protocol including brain PET/MRI followed by PET/CT with the smallest possible temporal delay, to allow for using the remaining activity of the initial ^{18}F-FDG injection, thus avoiding additional radiation exposure to the patients.

Simultaneous PET/MRI examination comprised of a transversal T1-weighted UTE for attenuation correction (repetition time (TR)/echo time (TE1) (TE2), 11.94/0.07/22.46; excitation angle, 10°; matrix size, 192 × 192 × 192; resolution, 1.6 mm × 1.6 mm × 1.6 mm; bandwidth, 1532 Hz/pixel (Fig. 1)).

MRI sequences for complete diagnostic evaluation of brain included transversal 2D-encoded fluid attenuated inversion recovery (FLAIR) sequence (TR/TE, 7000/94; inversion time (TI), 2215.2 s; matrix size, 418 × 512; resolution, 1 mm × 0.9 mm × 5 mm; slice thickness, 5 mm; and bandwidth, 260 Hz/pixel); T2-weighted 2D-encoded turbo spin-echo sequence in axial, sagittal, and coronal orientations depending on the disease pattern (TR/TE, 4300/100; matrix size, 278 × 512; resolution, 0.7 mm × 0.4 mm × 0.5 mm; slice thickness, 5 mm; and pixel bandwidth, 222 Hz/pixel); and sagittal 3D-encoded magnetization-prepared rapid-acquisition gradient-echo (MPRAGE) sequence (TR/TE, 1500/2.33; TI, 900 s; matrix size, 410 × 512; resolution, 1.2 mm × 1 mm × 1 mm; bandwidth, 180 Hz/pixel; and parallel imaging GRAPPA factor 2). Other optional sequences included diffusion weighted imaging (DWI) (TR/TE, 4600/101; matrix size 160 × 160; resolution, 1.4 mm × 1.4 mm × 5 mm; band-width, 1008 Hz/pixel; and parallel imaging GRAPPA factor 2), Susceptibility weighted imaging (SWI) (TR/TE, 26/20; matrix size 238 × 320; resolution, 0.8 mm × 0.7 mm × 4 mm; band-width, 170 Hz/pixel) and perfusion echo planar imaging (EPI) (TR/TE, 2550/31; matrix size 128 × 128; resolution, 1.8 mm × 1.8 mm × 5 mm; band-width, 1446 Hz/pixel).

Total MRI acquisition time was 15 min with simultaneous PET data acquisition. All PET data were acquired in sinogram/frame mode. After the scan all coincidence data were sorted into a 2D PET sinogram, which was subsequently reconstructed into transaxial slices corresponding to a FOV of 25.8 cm using an iterative three-dimensional-ordered-subset expectation maximization (OSEM) algorithm with 3 iterations and 21 subsets, Gaussian smoothing of 4 mm in full width at half maximum, and a zoom of 1. The attenuation maps were computed from UTE sequences [9,12].

Subsequent to PET/MRI all patients underwent PET/CT according to standard clinical protocols. Non-contrast-enhanced CT scan (309 mA/120 kV) of the brain was acquired for all patients followed by PET data acquisition for 15 min. Subsequent reconstruction of the data into transaxial slices (matrix size, 400 × 400, corresponding to an axial FOV of 21.8 cm, voxel size 3.18 mm × 3.18 mm × 2.03 mm) was undertaken using the standard software of the scanner (Fourier rebinning, two-dimensional OSEM with 6 iterations, 21 subsets). Attenuation maps obtained from the CT data by bilinear transformation were used for attenuation correction of the PET/CT data.

For both modalities, emission data were corrected for randoms, dead time, scatter, and attenuation.

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