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Original article

Deep Inspiration Breath Hold [^{18}F]FDG PET-CT on 4-rings scanners in evaluating lung lesions: Evidences from a phantom and a clinical study

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ABSTRACT

Objective: To investigate the clinical feasibility of a Deep Inspiration Breath Hold (DIBH) ^{18}F-FDG PET-CT acquisition in apnea and compare the results obtained between these acts of acquisition in apnea and in Free Breathing in the evaluation of lung lesions.
Material and methods: A pre-clinical phantom study was performed to evaluate the shortest simulated DIBH time according to the minimum detectable lesion that can be detected by our ultrasound scanner. This study was conducted by changing acquisition time and sphere-to-background activity ratio values and by using radioactivity densities similar to those generally found in clinical examinations. In the clinical study, 25 patients with pulmonary lesions underwent a standard whole body ^{18}F-FDG PET-CT scan in free breathing followed by a 20 s single thorax acquisition PET/CT in DIBH acquisition.
Results: The phantom study indicated that a 20-s acquisition time provides an accurate evaluation of smallest sphere shaped lesions. In the clinical study, PET-CT scans obtained in DIBH studies showed a significant reduction of misalignment between the PET and CT scan images and an increase of SUV_{max} compared to free breathing acquisitions. A correlation between the %BH-index and lesion displacement between PET and CT images in FB acquisition was demonstrated, significantly higher for lesions with a displacement > 8 mm.
Conclusion: The single 20 s acquisition of DIBH PET-CT is a feasible technique for lung lesion detection in the clinical setting. It only requires a minor increase in examination time without special patient training. 20 s DIBH scan provided a more precise measurement of SUV_{max}, especially for lesions in the lower lung lobes which usually show greater displacement between PET and CT scan images in FB acquisition.

[^{18}F]FDG PET-CT en ausencia de respiración utilizando escáneres a 4 anillos en la valoración de lesiones pulmonares: evidencias de un estudio clínico y con maniquí

Palabras clave:
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RESUMEN

Objetivo: Estudiar la viabilidad clínica de la adquisición ^{18}F-FDG PET-TC en apnea y comparar los resultados obtenidos entre las adquisiciones en apnea y en respiración libre en la valoración de lesiones pulmonares.
Material y métodos: Se ha realizado un estudio preclínico en maniquí con objeto de establecer el tiempo mínimo de adquisición en apnea en función de la más pequeña lesión evidenciable con nuestro tomógrafo. Este estudio se obtuvo modificando los tiempos de adquisición y la relación de actividad entre esfera y fondo utilizando actividades parecidas a las encontradas en la práctica clínica. En el estudio clínico, 25 pacientes con lesiones pulmonares fueron evaluados mediante PET-TC con ^{18}F-FDG en respiración libre y posteriormente en apnea de 20 segundos.
Resultados: El estudio en maniquí indicó que una adquisición de 20 segundos es adecuada para la valoración de las esferas más pequeñas. En el estudio clínico, las adquisiciones PET-TC obtenidas en apnea mostraron una significativa reducción de la desalineación entre la imagen PET y la imagen TC y un incremento en el valor del SUV_{max} respecto a las adquisiciones en respiración libre. Hemos demostrado la existencia de correlación entre el %BH-index y la desalineación en respiración libre, significativamente mayor en las lesiones con desalineación superior a 8 mm.
Conclusiones: La adquisición PET-TC de 20 segundos en apnea es una técnica viable para la detección de la lesión pulmonar en el entorno clínico y requiere solo un pequeño aumento en el tiempo de examen sin requerir especial entrenamiento del paciente. La adquisición en apnea aporta una medida más precisa del SUV_{max}, especialmente en las lesiones de los lóbulos inferiores que normalmente presentan una marcada desalineación entre las imágenes PET y TC.

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Introduction

[^{18}F]FDG PET/CT is an important nuclear medicine imaging tool for diagnosis, staging, restaging, therapy monitoring and radiotherapy planning of malignant lesions. Hybrid PET/CT scanners provide both anatomical and functional information with high sensitivity, specificity and accuracy in the detection of malignant lesions, in particular those located in lungs.[1]

However, the CT scan is acquired during a single-state of the breathing cycle, whereas a PET scan acquisition occurs over many breathing cycles for the same length of CT scan. This discrepancy in acquisition time may introduce misalignment between PET and CT images. When a misalignment is present, the quantification of Standardized Uptake Value (SUV), an important parameter in lesion evaluation, may not be feasible due to the incorrect attenuation correction map obtained from the CT scan.[2]

Furthermore, respiratory motion blurs the PET images with an overestimation of tumour volume, degrades the contrast, and interferes with SUV evaluation resulting in reduced PET/CT accuracy.[2]

In order to have a solution to misalignment and blurring, three different techniques have been proposed.

Nehmeh et al. proposed the use of the four-dimensional 4D-PET/CT.[3] This is a feasible technique but has some limits such as long acquisition and post processing time.

Another possibility, proposed by other authors,[4–8] is the use of Deep Inspiration Breath Hold (DIBH) PET/CT technique. Their studies have demonstrated better alignment between PET and CT and higher SUV_{max} using DIBH versus free breathing (FB); anyway, the short acquisition time of a PET scan in DIBH affected the image quality and provided poorly reproducible results.

A third possibility, as proposed in a recent paper by Mitsumoto et al.[9] is to perform a summation of a few acquisitions in DIBH, thus reducing the effect of noise, which could affect image quality as well.

Since previous studies were characterized by a lower sensitivity due to the use of 3-rings scanner types, it seemed even more effective to perform a study to investigate feasibility and advantages of DIBH technique for clinical purposes using a 4-rings PET/CT scanner, which allows an increased sensitivity (9.5 cps/kBq).[10]

We therefore performed a phantom study to determine the minimum breath hold time versus the minimum detectable lesion size in different lesion-to-background ratio and different acquisition times. Subsequently, a clinical study was performed in order to evaluate the improvement of image contrast for clinical purposes.

Material and methods

PET/CT scanner

Image data were acquired with a Biograph mCT TOF PET/CT scanner (Siemens Medical Solution AG). PET component consists of 4 rings with a total number of 32.448 detector elements of lutetium oxyorthosilicate (LSO). This 3D scanner has a transaxial FOV of 700 mm and an axial FOV of 216 mm. Transverse and axial resolution are 4.4 mm and 4.5 mm, respectively, both in *full width at half maximum* (FWHM) at 1 cm from the centre according to the NEMA standards. Using a reconstruction protocol that uses a 3-D iterative OSEM reconstruction technique accounting for the Point Spread Function of the PET system and using TOF information (commercial name: ULTRA HD[11]), the transverse and axial resolution (FWHM) at 20 cm from the centre is 2.1 mm. The CT component consists of 40 slices with a slice increment of 0.1–10 mm, FOV = 780 mm.

Phantom study

The PET Emission phantom (model type L981606, PTW, Freiburg, Germany) was used in pre-clinical study to investigate the detectability of small size objects with PET/CT scanner in our institution. This phantom complies the NEMA standard NU2 – 2007; therefore its shape simulates the human body in the range of thorax and six hollow solid spheres, with nominal volume of 24.65, 12.08, 5.75, 2.51, 1.10 and 0.53 cm^3, are embedded in the phantom.

The torso cavity of the phantom and the six hollow spheres were filled with different amounts of a [^{18}F]FDG solution in order to get two different radioactivity densities for spheres and for torso cavity, which simulates the background. Four values of spheres-to-background (S/B) ratio of radioactivity density were investigated: 3:1, 7.4:1 12.1:1 and 17.2:1. Precisely, concentration values are respectively 3.61, 9.33, 13.70 and 18.52 kBq/ml for all hollow spheres and 1.20, 1.26, 1.13 and 1.075 kBq/ml for the phantom torso cavity. These concentration values of torso cavity were chosen since they are in the range of those of a typical clinical exam.

For every S/B activity ratio studied a PET/CT scan of the phantom was performed at a single bed position by using a 2550 s acquisition in list-mode collection method. This static acquisition was subdivided in six time frames of different duration, consecutively in time: 5, 10, 15, 20, 30 and 90 s. Each time frame was collected 15 times, for a total of 90 frames. Tomographic data were reconstructed with a 3-D iterative Ordered-Subset-Expectation-Maximization (OSEM) algorithm accounting for the Point Spread Function of the PET system and using time of flight (TOF) information with CT based attenuation correction (precisely: 2 iterations, 21 subsets, Gaussian filter with 4 mm Full Width Half Maximum (FWHM), matrix size 200 pixel × 200 pixel, zoom 1).[11]

PET and CT phantom images were then co-registered and merged with a dedicated software (Syngo MI. PET/CT 2009C Sevice Pack 1, Siemens AG) supplied by the PET/CT scanner manufacturer. By using this software, image analysis was performed as follows. Displaying the PET tomographic image of this dynamic PET and CT merged image, volumes of interest (VOIs) were drawn over each sphere with VOIs' sizes equal to nominal spheres dimensions. A further VOI, with size equal to that of the biggest sphere, was placed among the six spheres images in order to take background into account. Average activity density inside each single VOI was computed. All these seven VOIs were drawn for each acquisition that belongs to a single time frame; therefore, a total of 7 × 15 × 6 VOIs were drawn.

For a given sphere and for a given time frame, mean and standard deviation (SD) of activity densities of the 15 drawn VOIs were calculated. Coefficient of variation (CV) was also computed with the following formula:

$$CV = \frac{SD}{mean} \times 100 \quad (1)$$

where the mean and SD of the formula refer to the 15 acquisitions of a single time frame and for a given sphere.

Moreover, contrast of the sphere was calculated as:

$$C = \frac{\text{sphere activity density} - \text{background activity density}}{\text{background activity density}} \quad (2)$$

Also sphere contrast was computed for each acquisition of a given time frame; therefore, mean, SD and CV of the 15 contrast data were then computed.

Clinical study

Patients data and preparation

Twenty-five consecutive patients (20 males; 5 females) referring to our Department in order to perform a ^{18}F-FDG PET/CT for