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Significant dose reduction is feasible in FDG PET/CT protocols without compromising diagnostic quality

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ABSTRACT

Purpose: To reduce the radiation dose to patients by optimizing oncological FDG PET/CT protocols.
Methods: The baseline PET/CT protocol in our institution for oncological PET/CT examinations consisted of the administration of 5.18 MBq/kg of FDG and a CT acquisition with a reference current–time product of 120 mAs. In 2016, FDG activity was reduced to 4.44 and 3.70 MBq/kg and reference CT current–time-product was reduced to 100 and 80 mAs. 322 patients scanned with different protocols were retrospectively evaluated. For each patient, effective dose was calculated. The overall image quality was subjectively rated by the referring physician on a 4-point scale (IQ score: 1 excellent, 2 good, 3 poor but interpretable, 4 poor not interpretable). Image quality was quantitatively evaluated measuring noise in the liver.
Results: CT Results: Effective dose was progressively reduced from 9.5 ± 2.8 to 8.0 ± 2.3 and 6.2 ± 1.5 mSv ($p < 0.001$). A mean dose reduction of 34.9% was achieved. There was a significant degradation of IQ score ($p < 0.05$) and noise ($p < 0.001$). Nevertheless, the number of poor quality studies (IQ score > 2) did not increase.
PET Results: Effective dose was gradually reduced from 6.5 ± 1.4 to 5.7 ± 1.3 and 5.0 ± 1.0 mSv ($p < 0.001$). Average dose reduction was 23.4%. IQ score ($p < 0.05$) and noise ($p < 0.001$) significantly degraded for lower activity protocols. However, all images with reduced activity were scored as interpretable (IQ score ≤ 3).
Conclusions: A significant radiation dose reduction of 28.7% was reached. Despite a slight reduction in image quality, the new regime was successfully implemented with readers reporting unchanged clinical confidence.

1. Background

Positron emission tomography (PET) has become an essential imaging modality for a wide spectrum of diseases in oncology, cardiology and neurology. Since the development of hybrid tomographs combining a PET and an X-ray computed tomograph (CT) [1], the use of PET/CT has rapidly increased worldwide. However, radiation exposure can be a thoughtful concern due to the ionizing nature of both PET and CT radiation [2].

Several strategies can be used to minimize the radiation dose to the patient undergoing a PET/CT scan. For the PET component the amount of radiotracer activity can be reduced while for the CT component several acquisition parameters can be modified (reduction in voltage, current time product or tube rotation speed or increase in helical pitch). However, a reduction in patient exposure will affect the image quality and may compromise clinical evaluation of the PET/CT study [3]. A proper PET/CT procedure should achieve the clinical purpose while maintaining radiation dose as low as reasonably achievable (ALARA) [4].

International recommendations for PET/CT procedures for tumor imaging provide appropriate values for dose related parameters. Regarding the amount of ^{18}F-fluorodeoxyglucose (FDG) activity administered to the patient, the Society of Nuclear Medicine and Molecular Imaging (SNMMI) guidelines [5] suggests a range of activities (370–740 MBq) while the European Association of Nuclear Medicine (EANM) guidelines [6] recommends dosage based on subject weight and acquisition time [7].

Regarding CT, none of the mentioned recommendations [5,6]

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specify optimum CT parameters, but establish a clear differentiation between CT studies with different purposes: attenuation correction, anatomical localization or radiological diagnosis [6]. On the other hand, the recommendations agreed by the American Association of Physicists in Medicine, the American College of Radiology, the Radiological Society of North America and the SNMMI suggest current time product ranges depending on the purpose of the CT (www.imagewisely.org).

For pediatric patients, specific guidelines have been proposed both to adapt tracer activity to patient weight [8] and to adjust CT acquisition protocol [9].

In the literature, several publications have proposed reduction of either CT dose [10–12] or PET radiotracer activity [13]. However, a comprehensive study with the aim to reduce both contributions and to evaluate the impact in clinical images has not been previously published. The main objective of this study was to reduce the radiation dose in whole body FDG PET/CT procedures for tumor imaging of adult patients while maintaining protocols within international recommendations, and to evaluate the impact of this dose reduction in image quality.

2. Methods

2.1. PET/CT tomograph

Imaging was performed at a Siemens Biograph mCT PET/CT scanner (Siemens Medical Solutions, Hoffman Estates, IL) equipped with a 64-slice spiral CT scanner and a 4-ring LSO PET covering a 21.8 cm axial field of view [14]. All patients were placed supine, with the arms above the head. Whole body PET/CT examinations began with the acquisition of a scout scan (120 kV, 35 mA, anteroposterior projection) to set scan limits from the base of the skull to mid-thigh.

The CT scan was acquired for attenuation correction and anatomical localization and no contrast agents were used. All patients were scanned in craniocaudal direction with a peak tube voltage of 120 kV, a rotation speed of 0.5 s and a pitch of 1. The collimation was 16 × 1.2 mm. For all exams the automatic exposure control (AEC, “CARE Dose” package by Siemens) was used, based on the selected reference tube current-time product (reference mAs). The CT images were reconstructed with filtered back projection.

The PET acquisition was performed in caudocranial direction and in stop-and-go imaging mode, with an overlap of 9.5 cm between contiguous bed positions. Each exam consisted of 4 to 8 bed positions. The acquisition time was 3 min per bed position. Data were reconstructed according to the standard protocol consisting of 3D ordinary Poisson ordered-subset expectation maximization (OSEM) iterative reconstruction with time of flight and point spread function modelling using 3 iterations and 24 subsets, a 2.0 mm full-width at half-maximum Gaussian post-filter and a 200 × 200 image matrix [15].

2.2. Study design

The baseline PET/CT protocol for oncological indications in our center consisted of the administration of 5.18 MBq/kg of FDG with 1 h uptake period and the acquisition of a CT study with a reference current-time product of 120 mAs covering from the base of the skull to mid-thigh and a PET scan of 3 min per bed position. The effective dose to a reference person associated to this protocol was estimated to be 16.5 ± 4.5 mSv in a previous publication [16].

During 2016, acquisition protocol was modified to reduce radiation dose to patient, within recommendations of international guidelines. Both CT and PET acquisitions were modified. To avoid an abrupt degradation in image quality, parameters were modified progressively in two steps. In February 2016, FDG activity was reduced from 5.18 to 4.44 MBq/kg and reference CT current-time-product was reduced from 120 to 100 mAs. Then, in May 2016 FDG activity was reduced to 3.70 MBq/kg and reference CT current-time-product was reduced to 80 mAs. Primarily, PET/CT studies were performed according to the baseline protocol during one week. Then, the modification in each period (February and May) was outlined as follows. At the beginning of the first week, the CT adjustment was introduced (change in mAs). The second week, the modification in PET (change in MBq/kg) was combined with the baseline CT protocol. In the third week, both modifications were definitively established as the new protocol. The assignment of protocol to a patient was determined by the current protocol in each date.

A total of 322 adult patients (197 males and 125 females, age 61.5 ± 13.9 years) referred for clinical oncological FDG-PET/CT during the evaluation period were retrospectively selected.

This investigation was approved by the Research Ethics Committee of Clínica Universidad de Navarra. The need for informed consent was waived due to the retrospective nature of the study and data anonymization provided the privacy guarantee.

2.3. Data analysis

For each patient, demographic data (sex, age, weight, height and body mass index BMI), CT parameters (kV, effective mAs, CT volume dose index $CTDI_{vol}$ and dose-length-product DLP), actual FDG activity (MBq) and the number of PET bed positions were recorded.

Effective dose associated to the CT examination was calculated from DLP using a conversion factor of 18.6 μSv/mGy·cm, determined by Huda et al. [17] based on the ICRP 103 weighting factors for a CT exploration covering chest, abdomen and pelvis. The effective dose associated with the PET radiotracer activity was calculated based on the ICRP coefficient of 19 μSv/MBq for a 70 kg adult [18].

Images were interpreted (Siemens Syngo via software) by an experienced nuclear medicine physician blinded to any information concerning FDG activity or current-time product. The overall image quality (IQ score) of both PET and CT images separately was rated on a 4-point scale: 1 excellent, 2 good, 3 poor but interpretable, 4 poor non-interpretable. A spherical volume of interest (100 cm^3 approximately) was defined in a uniform area of the patient’s liver. Mean and standard deviation (SD) of standard uptake value (SUV) and Hounsfield Units (HU) were recorded. Percentage coefficient of variation (COV) was calculated as the SD divided by the mean and multiplied by 100. Patients with liver metastasis or any other hepatic pathology (i.e. steatosis, cirrhosis) were discarded for noise evaluation.

Statistical analyses were performed with STATA/IC (Version 12 for Windows, StataCorp LP, College Station, Texas). Data were described as mean ± SD. Differences in quantitative variables (i.e. age, weight, height, effective dose, FDG activity, noise) among protocols were evaluated by analysis of variance (ANOVA) with post hoc Bonferroni adjustment for pairwise comparison. Categorical variables (i.e. sex, IQ score, number of beds) were compared using the chi square test. All reported probabilities (p-value) were two-sided, and < 0.05 was considered statistically significant.

3. Results

Patients’ distribution among protocols is presented in Table 1. There were no significant differences among groups in age (one-way ANOVA $p = 0.25$), height (one-way ANOVA $p = 0.49$), weight (one-way ANOVA $p = 0.29$), BMI (one-way ANOVA $p = 0.15$) or sex (chi square 3.91, $p = 0.69$). There were neither differences in the number of bed positions explored (chi square 23.98, $p = 0.46$), nor in the length of the CT scans.

3.1. CT analysis

Effective current-time-products were 81 ± 20, 70 ± 18 and 54 ± 12 mAs for the 120, 100 and 80 reference mAs groups,