Personalized patient dosimetry in PET imaging using 18-F

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Context

Positron emission tomography (PET) is now increasingly used in the field of medical imaging, particularly in neurology, cardiology, and oncology. In the latter category, the indications for PET are numerous and increasing every year. The main radiotracer used for PET imaging remains fluoro-deoxyglucose (18F-FDG), a fluorine-18-labeled glucose analogue, due to its high sensitivity to the detection of cancerous lesions with high carbohydrate metabolism. The clinical contribution of this examination extends from the initial extension to the end-of-treatment evaluation, through the early evaluation of the response to treatment and the follow-up of tumor evolution. This implies a recurrent exposure of patients to radiation and consequently the need to establish a personal dosimetry for each of them.

The impact of these low doses over the life of a patient deserves to be quantified with adapted tools [1]. The use of dosimetric quantities describing stochastic effects is proposed by the ICRP, thus responding to problems of diagnostic nuclear medicine. The concepts of equivalent dose and effective dose, specific to radiation protection, were introduced in 1991 by the ICRP in its publication 60 updated in 2007 [2] in order to associate the notion of risks related to the type of radiation or the sensitivity of the various tissues. The radiative weighting factor introduces the notion of relative biological efficiency (RBE), which makes it possible to distinguish the biological effect induced by a given ionizing radiation compared to another for the same amount of energy absorbed. The stochastic risks associated with the type of radiation are therefore estimated and taken into account in the dosimetric calculation.

Currently, only the injected activity and the Product Dose Length (PDL) are used to perform a dosimetric calculation related to a PET imaging examination. The determination of the dose absorbed by the organs remains approximate and remains little used in diagnosis. The most commonly used tools (OLINDA [3], MIRDOSE[4], DOSE3D[5], MABDOSE[6] [7], …) do not make it possible to establish with precision and in a personalized way the dose received by each patient and therefore the assessment of the risks associated with the diagnostic tests.

The implementation of a tool allowing a personalized dose calculation for the patient would make it possible to follow-up dose delivered for each PET imaging examination. A reliable and ergonomic tool would also allow medical centres to meet legal requirements for dose control.

LPC and General Electrics wish to combine their efforts to develop a dosimetric monitoring platform for PET imaging patients. For more than 10 years, LPC has acquired expertise in dose evaluation for internal and external radiotherapy and hadrontherapy; it is participating in the development of an opensource Monte Carlo simulation platform, GATE

(www.opengatecollaboration.org) [8–10], for modeling medical devices, calculate dose delivered for different types of radiation. LPC proposes to use this simulation platform to perform personalized dosimetric calculations of PET exams in order to establish a modular database that General Electrics would propose in the DoseWatch dose calculation tool. DoseWatch is a software managing doses delivered to patients. It allows to collect data, to follow-up over time and to generate reports directly from imaging systems or PACS. However, the evaluation of the dose received by the patient during an exam needs to be improved.

This project is supported by Unicancer facilitating intercomparisons across several cancer centers (CLCC). Jean Perrin cancer center of Clermont-Ferrand will be a privileged partner.

Objectives

Goal

The objective is to develop a clinical routine tool allowing the estimation of an effective dose taking into account all the risks associated with a PET scan for each patient. The calculations used would make it possible to establish the absorbed dose to each organ at risk after a PET exam and then deduce the effective dose. The results could be presented in the form of dose-volume histograms (DVH) that can be cumulated over the period of patient care. The development of this tool would allow a "live" monitoring of the patients which could lead to an optimization of the examination parameters (with, for example, a decrease in the injected activity).

Methods

The stochastic nature of processes involved for the emission and the transport of particles in materials makes the Monte Carlo methods perfectly adapted to the estimation of energies deposited in a geometry. Thus, calculations will be carried out on the GATE Monte-Carlo simulation platform dedicated to the simulation of applications in SPECT, PET, CT-scan, internal and external radiotherapy.

The dosimetric evaluation of a PET scan is based on the distribution of activity over time in organs and on the determination of associated S factors [11]. S factor corresponds to the dose absorbed to a target organ by disintegration in a source organ. Usually, S factors are calculated assuming a homogeneous distribution of activity in organs. However, this assumption is rarely verified. Consequently, the calculations developed within the framework of this project would be based on a voxel-scale approach. For this purpose, we will use the PET images from which we could model heterogeneities of fixation within organs. S factors will be then calculated by modeling each patient (adult male and female) using a hybrid anthropomorphic phantom combining NURBS surfaces (Non-Uniform Rational Basis Splines) and polygon (mesh) surfaces. A computer library of hybrid phantoms, created by the University of Florida [12], and containing more than 350 digital phantoms for the modeling of morphologies adjusted in weight and size to the patient's morphology, will be tested and

integrated in the Monte Carlo GATE simulations. A comparison will be made with S factor calculations using different patient CT-scans.

This work would therefore lead to a series of S factor tables adapted to the morphology and fixation of the FDG-18 for each patient.

Moreover, one of the main obstacles to precise quantification of the absorbed dose in PET exams remains in the fact that one image is produced one hour after injection, the quality of the image in terms of resolution is necessary. The study of compartmental models developed by the ICRP will be taken into account in order to compensate for the lack of biokinetic data of the tracer and consequently to obtain the cumulative activity [13–20].

Dosimetric studies will be performed for 18F-FDG exams on a significant number of patients (men, women with different morphologies and ages). Studies may be extended to other isotopes used in PET. An intercomparison between different cancer centres will be carried out including sites to be defined. This would make it possible to evaluate the impact of different reconstruction algorithms (different depending on the devices) on doses received by patients.

Work plan

The PhD student will be under the direct responsibility of Dr Lydia Maigne (LPC) and Dr Federica Zanca (General Electrics). The PhD student will share his time between LPC (80%) and General Electrics (20%). Regular meetings (once a month) will be scheduled with General Electrics. Regular meetings will also be scheduled with Unicancer in order to properly coordinate medical data sharing between different cancer centers. One paper and one conference are planned per year over the period of the thesis.

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