DOSIMETRIC EVALUATION FOR WORKERS OPERATING INTO A PET DEPARTMENT

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1. INTRODUCTION

Positron emission tomography (PET) is considered one of the most relevant diagnostic imaging technique having the peculiar characteristic to provide functional and quantitative information of the organ of interest (1). During the last five years, great efforts have been done to improve the diagnostic accuracy of this imaging modality through the development of new data acquisition/processing systems and the introduction of new β+ emitting radiopharmaceuticals increasing the interest of clinicians (2). The turning point in clinical PET development is represented by the introduction and FDA approval of ^{18}F-FDG as an oncological PET radiotracer. Nowadays, there is increasingly wide PET application for clinical diagnosis, even in centres without a cyclotron unit, thanks to the availability of ^{18}F-FDG produced in licensed sites that are located within a reasonable distance of the imaging units.

PET radiopharmaceuticals are positron emitters with their characteristic 511 keV annihilation photons detected with coincidence systems. This high energy radiation poses different radiation safety problems in a conventional nuclear medicine department where usually more than 90% of examinations are performed with ^{99m}Tc radionuclide emitting 140 keV photons. Particular attention is required on dealing with radioprotection aspects in PET facility to optimize absorbed dose for workers (3). A primary assessment of different levels of exposure dose due to both ^{99m}Tc and ^{18}F radionuclides is possible by considering the Γ values which clearly demonstrate the different safety concerns. However, to estimate the final dose absorbed by workers other variables should be considered as the workload, shielding, injected activity, in vivo uptake-clearance of the tracer, time spent by the operator to take care of the administered patient.

Aim of this work is to present absorbed dose values, during a 1 year, of four workers, two physicians and two technologists, full time dedicated to the PET centre activities of the Ospedale Maggiore di Milano. In this centre an ECAT EXACT HR+ state-of-the-art-scanner (SIEMENS/CTI) is installed and ^{18}F-FDG whole-body imaging represents the principal clinical activity (about 96% of patients workload). Some considerations on possible points susceptible of further improvements were also discussed in the mean to optimize the radioprotection program (4).

2. MATERIAL AND METHODS

Clinical procedures

All information about the PET imaging procedures are given to the patient by the physician, after the anamnesis and before injecting the radiocompound. For oncological examinations about 7 MBq/Kg of ^{18}F-FDG were administered intravenously to patient in 0,5min (on average) by the nuclear medicine physician. FDG-dose activity is prepared by technologists as described below.

Patients wait about 40-60 min before PET scan in a dedicated room. During this time the patient is invited to assume some water per os to increase urinary excretion.

The scanner used for PET examinations is an ECAT EXACT HR+ (CTI-Siemens,USA). This state-of-the-art PET system (5) (58cm transaxial, x 15.5 axial field of view) is able to perform 2D/3D mode emission acquisitions and transmission data are obtained by using internal rod sources automatically extended/retracted. When rod sources are extended (^{68}Ge solid maximum activity 555 MBq) warning message appears on the gantry control panel and on the acquisition console to avoid undue irradiation to personnel. For whole-body acquisition a single positioning of the patient under the PET scanner is required and the technologist performs this procedure in 3 min on average. Usually 6-7 contiguous bed positions are necessary to cover on average 90-100 cm of patient body and bed movements are automatically performed during acquisition protocol. At the end of data

acquisition, technologist returns to PET room and helps the patient to stand up and escorts him to exit (other 3 min).

In the period considered, the first year of full PET activity of our department, 1921 patients of which 1919 with ^{18}F-FDG (1838 whole-body, 75 brain and 6 cardiac studies) and 2 with 13N-ammonia (2 cardiac studies) were examined. In this year 2 out of 7 technologists and 2 out of 8 physicians of the staff were exclusively dedicated to PET facility.

Workplace and shielding description

The PET facility includes the administration-waiting room, the radiochemistry laboratory, the counter laboratory, the PET room and the scanner control room. All these workplaces, except the control room, have been classified as controlled area (6). On designing the layout of this area, great care was giving to shielding barriers (at least 10cm of concrete + 0.4 cm of lead) and to the ventilation system (rate of 10 volume/h) to limit respectively the external and internal radiation risk during the use of high energy unsealed radionuclides. A hot cell shielded with 7 cm of lead has been also installed in the radiochemistry laboratory and used for syringe preparations. During this phase, only the technologist's hands are irradiated. The radioactivity is drawn manually with a 10cm long steel needle from the multi-doses vial contained in a 5cm lead box. The ^{18}F-FDG, synthesised by the cyclotron unit of the department, is shared automatically among three main vials which are individually transferred to the up-stair radiochemestry laboratory when requested during the day (the 1st at about 8:30 a.m.) and containing on average 14GBq the 1st, 2.5GBq the 2nd and 1.5 GBq the 3rd at the moment of the storage into the hot cell.

Dose measurements

To estimate the effective dose ($H_p(10)$) and the equivalent dose deriving from external exposure, each worker had, respectively, film badges, worn at the upper pocket of overalls, and TLD rings. Film badges and TLD rings had a sensitivity of 100μSv at 511 keV and dose readings were performed monthly. To verify the accuracy of film badge readings a digital dosimeter (MINI 6100- Saint Gobain Crystal and Instruments, UK) was worm by technologist 1 for 2 months (June – July 2001). Integrated dose values were registered by worker daily .

The internal dose was derived from intake by monitoring the air contamination. The radioactivity concentration in air (Bq/ml) was measured by mean of a calibrated Marinelli detector coupled to a NaI(Tl) scintillator. Volumes of 3 litres of air, at 20 min intervals and counted for 5 min, were monitored continuously in the PET scanner room and in the radiochemistry laboratory, which are the workplaces with the highest risk of contamination. Effective dose was estimated only for concentration values higher than the minimum detectable level (0.7Bq/l).
To assess the irradiation level along the different phases of clinical settings, monitoring of dose rates around 10 patients (weight range 53 – 100 Kg) injected with about 320-550 MBq of ^{18}F-FDG was performed by mean of a LB1236 proportional counter (EG&G-Berthold-Germany). These measurements were obtained in the administration room soon after the injection (T0) and PET scanner room at the end of the scanning (T2) and at different distances (D) from the patient (D= 0, 50cm and 100cm). Dose rate measurements obtained at time T2 were corrected for physical decay of ^{18}F during scanning time to extrapolate dose rates at the time of patient positioning (T1).

3. RESULTS

Dose values of PET personnel, measured with film badges and TLD rings, over 1 year of full clinical activity consisting of a workload of about 10 patients/day for a total of 195 working days (from April 2001to April 2002) were reported on Table 1. Internal dose contributes were not considered for effective dose evaluation as the air-radioactivity concentration resulted always lower than the detector sensitivity. The periodical measurements of surface contaminations such as floors and working surfaces resulted always lower than the imposed limits.
Dose values (see Table 1, column 1) were quite similar between physicians while dose of technologist 1 resulted a factor 1.7 higher than technologist 2. This finding can be attributable to individual differences in behaviour and to non-uniform distribution of the patient workload between the two technologists. Furthermore, as shown on Table1, technologists have dose values at least twofold higher than those of physicians and represent the main group of workers to consider into a radioprotection optimisation program of our PET unit.
By comparing the effective dose values and the equivalent dose to the hands of PET workers in the previous year when they were only involved in conventional nuclear medicine procedures, it was evident a two fold increase

during PET working, demonstrating the different relevance of radiation risk related to PET diagnostic procedures.
Table 2 shows average exposure rates measured on 10 patients soon after the administration (T0), at the moment of patient positioning on the PET scanner about 40min later (T1) and at the end of examination about 80 min later (T2) obtained with the proportional counter (patients received 320 - 550 MBq of ^{18}F-FDG). During the whole-body scan the level of rate exposure at the console workstation of the control room was comparable with the natural background radioactivity validating the good efficacy of designed barriers.
On table 3, the effective dose values of technologist 1 monitored for a two months period of work are shown, a good agreement between the two different detectors is observed, even if digital data are slightly higher. By normalising the monthly dose with the number of working days, 27 μSv/day has been determined and can be assumed, conservatively, the typical average effective dose/day of one technologist working in our PET facility. It is worth of consideration that this dose/day is in good agreement with the one (25 μSv/day) computed by using exposure average-rates of patients at 50 cm and considering a mean time of exposure of 1min soon after the injection, 3 min for the positioning and 3 min at the end of examination. This last evaluation confirms that patient irradiation represents the principal contribute to technologist's effective dose as reported by other authors (7-8).

Table 1. Dose values measured in 1 year for the PET workers.

Worker	Effective Dose (mSv)	Hands-Equivalent Dose (mSv)	Film monthly dose Range (mSv)	Ring monthly dose Range (mSv)
Technologist 1	8.0	90.0	0.4 – 1.1	4.1 – 9.9
Technologist 2	4.6	63.5	0.3 – 0.7	0.7 – 9.1
Physician 1	2.2	5.2	0.1 – 0.7	0.2 - 1.2
Physician 2	1.9	6.0	0.1 – 0.7	0.3 – 4.2

Note : Effective dose limit 20 mSv/y ; Equivalent dose limit for the hands: 500 mSv.

Table 2. Rate exposure levels (average ± standard deviation) generated by patient irradiation. Values referred to 10 patients injected with an amount of 320-550MBq of ^{18}F-FDG.

DISTANCE	Time from injection		
(cm)	T0	T1	T2
0	400 ± 140 μSvh^{-1}	230 ± 80 μSvh^{-1}	170 ± 65 μSvh^{-1}
50	65± 20 μSvh^{-1}	45 ± 20 μSvh^{-1}	35 ± 15 μSvh^{-1}
100	22 ± 6 μSvh^{-1}	18 ± 3 μSvh^{-1}	13 ± 4 μSvh^{-1}

Table 3. Individual effective dose values of June and July 2001 obtained with the film badges and the digital dosimeter worn by technologist 1.

DETECTOR	June 2001	July 2001
Film badge	0.60 mSv	0.85 mSv
MINI 6100	0.69 mSv	0.86 mSv

4. DISCUSSION and CONCLUSION

The dosimetric evaluation of this one year of PET activity allowed firstly to verify the adequacy of the radioprotection program adopted for the exposed workers and highlighted possible items susceptible of improvement. As already known from published data, the high energy photons of β+ radionuclides used in coincidence imaging poses different degrees of dose levels with respect the low energy isotopes used in conventional nuclear medicine diagnostic procedures. The preliminary data presented in this work have been also discussed directly with the involved personnel and the director of the nuclear medicine department to find some better solution to further optimize the radioprotection program. Toward the reduction of the effective dose, in our PET facility, a proposal of optimisation was to extend to PET facility all the staff of the nuclear medicine department, to allow a more uniform distribution of absorbed dose among exposed workers. Nevertheless, some practical procedures as to interact with injected patient only when required and speed patient management when possible should be further exploited.
As a general consideration some effective reduction of dose to personnel seems to be possible with the introduction of 3D PET scanning with 5-6 fold increase of sensitivity with respect 2D one, this can allow an

important decrease of the activity amount to inject to the patient with consequent reduction of workers exposure. This shift is strictly related to new technological developments of PET scanners and acquisition/processing protocols. With our PET scanner, 3D mode is currently used for brain examinations while for whole-body is still working in progress.
A possible reduction of dose to the hands of technologists can be achievable with a full automatic activity-dose dispenser now available on commerce which prepares the syringe avoiding any kind of manipulation except to pick up the final box containing the syringe for patient administration.

5. ACKNOWLEDGMENTS

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