Impact on dosimetry of occupationally exposed individuals on the patient management for PET/MRI studies: a comparison study with dosimetry on PET/CT

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Abstract. The advent of the PET/MRI technology has expanded the boundaries of investigation in nuclear medicine, supported by the high sensitivity of solid-state PET detectors . Nonetheless, the coil positioning might lead to an increased exposure period of the worker to the injected patient. This procedure does not occur on PET/CT and, therefore, exposure period is reduced on such scanner. The aim of our study was to evaluate the dosimetry of two occupationally exposed individuals (OEI) working at the Center of Nuclear Medicine of Hospital das Clínicas of the University of Sao Paulo. We used thermoluminescent (TLD) dosimeters in pulse, thorax and crystalline for both PET/MRI and PET/CT procedures during five months of clinical and research routine. We also monitored the time for positioning/removing the patient on both scanners. For this study, OEI1 performed 76 PET/MRI studies and 102 PET/CT studies while OEI2 performed 26 and 56 PET/MRI and PET/CT studies, respectively. The mean equivalent dose value on PET/CT was slightly higher than PET/MRI ($p < 0.01$). We found no evidence of differences for the effective dose values between both scanners ($p = 0.22$). The mean time of patient management (positioning/removing the patient) was 14.38, and 3.81 minutes for PET/MRI and PET/CT, respectively. When the normalization by the number of PET/CT studies was applied, we found no statistical difference for effective and equivalent dose values. Our study encourages future investigations on the nursing staff, which is a critical population that might be exposed to ionizing radiation, mainly on dynamic studies, due to the synchronized injection must be with the protocol starting.

KEYWORDS: PET/MRI, PET/CT, Nuclear Medicine, dosimetry, medical physics, radiation protection.

1 INTRODUCTION

The Positron Emission Tomography (PET) evaluates the metabolism of structures of interest such as bones [1], muscles [2], brain [3], lungs [4] and liver [5], among other organs. The advent of PET/MRI (PET/magnetic resonance imaging) provided new horizons in the study of hybrid imaging in Nuclear Medicine. The new equipment provided physiological and anatomical images unparalleled quality images, as the PET detectors are digital and provide functional images with great spatial resolution, that could be related to the anatomical MR images with high contrast resolution [6].

The PET/CT (PET/Computed Tomography), is more widespread among Nuclear Medicine services in Brazil and worldwide. This hybrid technology also allows to fuse metabolic and anatomical images but it is rather affordable, compared to the PET/MRI [7]. In this sense, the PET/CT is suggested for several pathologies and, especially in oncology, is used in detecting and staging tumors and metastasis that could be correlated with the structural information from CT [8]. Such synergy provides for details than both examinations performed separately. The post-processing allows the identification and differentiation between benign and malign nodules through the radiotracer uptake. Thus, PET/CT studies are shown to be more sensitive to very small lesion detection, which most of the times are not seen by any other image modality [9].

The radiopharmaceutical is necessary to perform the PET studies, i.e., ^{18}F-FDG, ^{18}F-NaF, among other β-emitters to show the tissue-of-interest's uptake. In the so-called pair annihilation process, two high-

energy photon (511 keV's) s are emitted from the patient's tissue-of-interest in opposite direction, reaching the PET detectors. During this period, the patient is under care of the clinic workers, i.e., the occupationally exposed individuals (OEI): nurses and biomedical staff and nuclear medicine physicians, which are exposed to the emitted radiation.

The concern about the absorbed radiation by the OEI always encouraged studies and specialists in radioprotection [10] as the low amounts of radiation that might harm the worker's health in the future still are not quite determined. The field of physics that provides advances in the frontier of knowledge regarding the absorbed radiation from both patient and OEI is dosimetry [11]. In the scope of this study, we were interested in the specific dosimetry of the biomedical staff as, in general, they have a higher amount of time dealing with the injected patient during the exam's explanation and their positioning in the scanners. The motivation of our study relied on the fact that PET/MRI scanners need to place coils over the patient to perform the MRI sequences. This step takes more exposure time by the OEI to the injected patient, lied in the bed scanner. Such step is absent in the PET/CT as there is no need to place scanner devices over the patients.

The aim of this study was to evaluate the OEI's dosimetry, i.e., the biomedical staff that work on PET/MRI and PET/CT in a Nuclear Medicine facility in São Paulo, Brazil.

2 MATERIAL AND METHODS

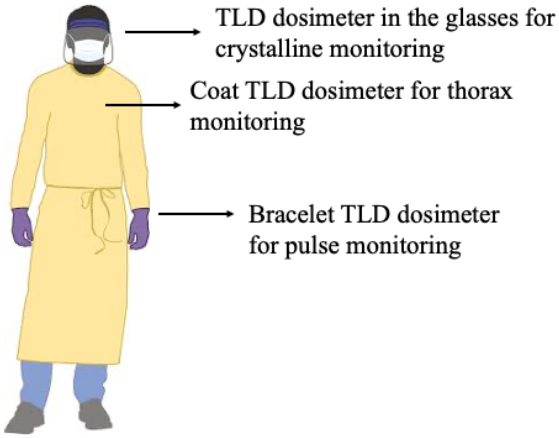
2.1 Ethical Committee

This study was approved by the institutional board of the Institute of Radiology of the Hospital das Clínicas de São Paulo (process number: 19491919.9.0000.0068).

2.2 Dosimetry measurement and reading

The dosimetry of two OEIs (biomedical staff) was measured during a period of five months. Both of them used two sets of TLD (thermoluminescent) dosimeters for pulse, thorax and crystalline: one set for PET/MRI, and the other set for PET/CT studies, respectively (see **Figure *1***). The set of dosimeters were monthly renewed and the TLD reading was performed at the Institute of Physics of the University of São Paulo. The dose values for each TLD dosimeter were showed in mSv.

Figure 1: crystalline, thorax and pulse TLD dosimeter monitoring



The time of patient management during the PET/MRI and PET/CT studies were recorded by the OEIs during the procedure, and it included only the time of positioning and removing the patient from each bed scanner.

2.3 Statistics

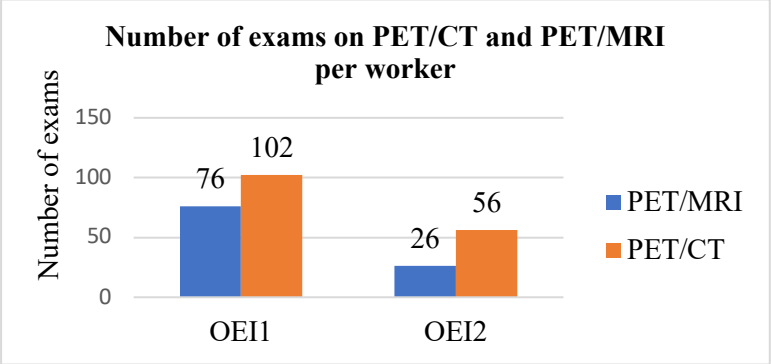
To evaluate the normality distribution of our data, we applied the Shapiro-Wilk test. Posteriorly, we used the One-way ANOVA to test the difference of effective and equivalent doses between the workers for both PET/MRI and PET/CT, and the difference of time management for placing and removing the patient from each bed scanner. Statistics calculation were performed using Microsoft® Excel. A significance level of $\alpha = 0.05$ was adopted.

3 RESULTS AND DISCUSSION

We evaluated the dosimetry of two OEIs through TLD dosimeters for pulse, thorax and crystalline for procedures on PET/CT and PET/MRI.

Several studies were performed on both scanners such as ^{18}F-FDG, ^{68}Ga-PSMA, ^{11}C-PIB, ^{11}C-PK11195. The most frequent study procedure on the PET/MRI was brain scans using ^{18}F and ^{11}C-labeled pharmaceuticals, and head-to-thighs standard oncologic procedure with ^{18}F-FDG on the PET/CT. Overall, one-hundred two studies were performed on the PET/MRI while one-hundred fifty-eight studies were performed on PET/CT during the period of this study. The **Figure *2*** show the number of examinations performed on the PET/MRI and PET/CT scanners by each worker.

Figure 2: studies performed on the scanners by each OEI



Because 511 keV positron annihilation radiation energy is much higher than the 140 keV from the conventional nuclear medicine, biomedical staff that deals with PET scanners my receive a higher equivalent dose than those working only with conventional nuclear medicine tracers do. Such scenario together with infrastructure matters, i.e., availability of shielding, radiopharmacy good practices, dedicated rooms to injected patients have posed an impact for radiation protection to the staff working in nuclear medicine, specifically PET scanners [12].

This study was performed before the pandemic. Therefore, these numbers of examinations for each scanner represent the common clinical routine in the Nuclear Medicine facility. Furthermore, the number of examinations on PET/CT represent the clinical demand, while almost all studies on PET/MRI was demanded by medical researches. This explains the higher number of PET/CT studies, compared to those of PET/MRI. The OEI2 performed a smaller number of examinations than OEI1 during our study because he had a schedule period on the conventional nuclear medicine as well.

The Table 1 show the mean values of effective and equivalent dose along the period of this study. There was no statistical difference of effective dose between PET/MRI and PET/CT, while we found evidences of difference in the mean values of equivalent doses for both scanners. The Table 2 show the

evaluation of equivalent dose, specifically for pulse and crystalline to track where was the relevant dose values (pulse or crystalline) that provided the aforementioned evidence. In such evaluation, we found no statistical difference neither for pulse or crystalline for PET/MRI and PET/CT.

Table 1: Mean values of effective and equivalent doses. CI: Confidence Interval.

	PET/MRI		PET/CT		*p*-value
	Mean (mSv)	**CI (95%)**	**Mean**	**CI (95%)**	
Effective dose	0.09	0.03 – 0.15	0.18	0.03 – 0.32	$p = 0.22$
Equivalent dose	0.09	0.07 – 0.11	0.26	0.13 – 0.40	$p < 0.05$

Table 2: Pulse and crystalline dose values between PET/MRI and PET/CT

	PET/MRI		PET/CT		*p*-value
	Mean (mSv)	**CI (95%)**	**Mean**	**CI (95%)**	
Pulse	0.10	0.06 – 0.13	0.28	0.06 – 0.51	$p = 0.08$
Crystalline	0.08	0.05 – 0.12	0.25	0.04 – 0.45	$p = 0.09$

The following Table 3 show the mean effective dose normalized by the number of exams performed on each scanner (102 PET/MRI and 158 PET/CT studies) over the whole period. As expected, the previous difference on the equivalent dose found for PET/CT was not relevant anymore when comparing to the normalized number of PET/MRI examinations.

Table 3: Mean dose values normalized by the number of PET/MRI and PET/CT studies. Values in the table are multiplied by 10^{-2}.

	PET/MRI		PET/CT		*p*-value
	Mean (mSv/exam)	**CI (95%)**	**Mean (mSv/exam)**	**CI (95%)**	
Effective dose	0.09	0.03 – 0.15	0.11	0.02 – 0.21	$p = 0.65$
Equivalent dose	0.09	0.06 – 0.11	0.17	0.08 – 0.26	$p = 0.42$

The effective dose value during the PET/MRI examinations ranged from (0.05 – 0.32 mSv), while the equivalent dose ranged from (0.05 – 0.19 mSv). For PET/CT examinations the effective dose, and the equivalent dose ranged from (0.05 – 0.66) and (0.05 – 0.93), respectively. These range values do not necessarily belong to the same worker, as they are the overall absolute maximum and minimum values reached during the period of this study.

Table 4: Mean time management on PET/MRI and PET/CT

	PET/MRI		PET/CT		*p*-value
	Mean (min)	**CI (95%)**	**Mean (min)**	**CI (95%)**	
Time management	14.38	11.92 – 16.85	3.81	3.48 – 4.13	$p < 0.001$

To regulate the exposure of workers and the public, two dose quantities are suggested by the International Commission on Radiological Protection (ICRP) [13]: the equivalent and effective doses, both expressed in sievert (*Sv*) to distinguish them from the absorbed dose in gray (*Gy*). We evaluated the effective and equivalent dose values of two workers on PET/MRI and PET/CT for clinical and research routine using TLD dosimeters for thorax, pulse and crystalline. As the Table 1 shows, both effective and equivalent dose values were higher for PET/CT examinations. However, the statistical difference was relevant only in the evaluation of the equivalent dose. As the pulse and crystalline TLD readings compose the equivalent dose, we also investigated which one could be relevant for such difference on the dosimetry of both workers on the PET scanners. Such evaluation is shown on Table 2, where the mean dose values are explicit for both TLD dosimeters, as well as the statistics. Despite the mean dose values were about 2-fold for PET/CT, we found no statistical difference. When normalizing the effective and equivalent dose values by the number of examinations for each scanner, we found no statistical difference anymore, as shown in the Table 3. Finally, we tracked the time spent on the patient management during their placement/adjustment and removal from the bed scanner by the workers. As expected, the PET/MRI procedures took longer than those from the PET/CT ($p < 0.001$) due to the positioning of the body coils over the patient. Also, a specific research protocol usually took about 30 to 40 minutes to correctly adjust a dedicated coil to the patient's kneel in the PET/MRI bed.

One limitation of our study was the lack of the dosimetry monitoring of the nursing staff. However, the high demand on the injected patient care that involves the exposure to the radioactive syringe, transportation would make the self-recording of exposure time by the nurse themselves unfeasible. It is our goal in the future to evaluate the nursing staff as the same as we performed in this study with the biomedical staff.

4 CONCLUSION

We found no difference on the effective dose between PET/MRI and PET/CT. Despite we found differences on the evaluation of equivalent dose values between both scanners, the stand-alone evaluation of pulse and crystalline did not show evidences of differences. Such differences were vanished when the normalization by the number of examinations on both PET scanners was applied. Also, none of the workers who contributed to the study have reached the investigation limit according to Brazilian recommendations for workers with ionizing radiation. Despite the longer period of patient management on the PET/MRI, our results showed the effect of the safety and good practice at our Nuclear Medicine facility. Our study encourages future investigations on the nursing staff, which is a critical population that is also exposed to ionizing radiation, mainly on dynamic studies due to the synchronized injection that must be performed in the exam room, aside from the injected patient.

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