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Radiation Safety for Anesthesiologists and Other Personnel on Simultaneous PET/MRI: Possible Radiation Exposure from Patients While Performing Prolonged Duration Scans

Chandana Nagaraj[1] Raman K. Joshi[1] Dinesh Kumar[1] Gopinath R.[1] Dhritiman Chakrabarti[2] Pardeep K. Singh[1] Sandhya Mangalore[1] Ramesh Venkatapura[2]

[1] Department of Neuro Imaging and Interventional Radiology, National Institute of Mental Health and Neuro Sciences, Bengaluru, Karnataka, India
[2] Department of Neuroanaesthesia and Neurocritical Care, National Institute of Mental Health and Neuro Sciences, Bengaluru, Karnataka, India

Address for correspondence Ramesh Venkatapura, MD, Department of Neuroanaesthesia and Neurocritical Care, National Institute of Mental Health and Neuro Sciences, Hosur Road, Bengaluru 560029, Karnataka, India (e-mail: drvjramesh@gmail.com).

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Abstract

This observational study was conducted owing to the challenges of the positron emission tomography/magnetic resonance imaging (PET/MRI) that requires longer duration scanning of radiopharmaceutical injected patient and added MRI environment. The aim of this study was to assess radiation dose at different distances from the patient and the radiation burden to anesthesiologist and other personnel in performing PET/MRI under general anesthesia or sedation. First, the pre- and postscan whole body radiation exposure (WBE) from the patient were obtained for 45 minutes ($n = 109$) after injection of the radiopharmaceutical. The WBE was obtained at specific distances from brain (10, 30, and 100 cm) and abdomen (10 and 30cm) of patients undergoing F18 fluorodeoxyglucose PET/MRI brain or whole body studies. Second, WBE of the anesthesiologist and other staff working was separately measured using pocket dosimeters during the whole procedure. In brain scans, the mean absorbed dose rates (ADR) of prescan (45 minutes) and postscan (45 minutes) were 44.4 and 31.1 μSv at 10 cm, 14.9 and 9.7μSv at 30 cm, and 3.5 and 2.8 μSv at 100 cm, respectively, from surface of head. Similarly, it was 54.8 and 30.3 μSv at 10 cm, 23 and 13.6μSv at 30 cm, respectively, from surface of abdomen. In WB scans, the mean ADR was higher than the brain scans. Anesthesiologist exposure overall was found to be 4.84 μSv/patient/scan (112 patients). The anesthesiologist receives a safe mean effective dose in PET/MRI scanning. With good training and adequate planning, it is possible to decrease the radiation exposure to all the concerned personnel including anesthesiologists.

Keywords
- anesthesiologists
- radiation safety
- simultaneous PET/MRI

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Introduction

With the growing edge in technology of hybrid imaging, simultaneous positron emission tomography with magnetic resonance imaging (PET/MRI) has steadily transitioned from a predominant research focus to a specialized clinical practice at several medical centers.[1] Its application in clinical practice has expanded for both oncological and nononcological indications with additional role in imaging for neurological and psychiatric disorders. Due to inherent clinical course of these disorders, additional clinical support of anesthesiologist is imperative for smooth and safe conduct of the study. Due to the ever-present risk of radiation, the conduct of such a study under anesthesia is a greater challenge. The underlying principle of working under hazard of radiation exposure is ALARA (as low as reasonably achievable), which is achieved by distancing from the radiation source, shielding, and spending least amount of time possible in vicinity of the radiation source. The aim of this study was to assess the exposure rate and whole-body (WB) radiation dose received by the anesthesiologist and other personnel conducting the procedure under sedation/general anesthesia (GA).

Materials and Methods

This study was conducted in patients who were referred for PET/MRI scans. The institute ethics committee told us to seek institute director permission for this study of radiation measurement as it involved faculty and staff of the institute as subjects; hence, the same was obtained. The study was conducted in two parts (►**Fig. 1**). Initially in phase I, radiation dose was measured at different distances from patients injected with the radiopharmaceutical. All patients with or without GA/sedation were included for this part of the study. The distances were at 10, 30, and 100 cm from the patient. These distance levels were adopted based on normal working distance of anesthesiologist with the patient. This was conducted to measure the exposure from the injected patient referred for PET/MRI scans. This was followed by phase II, actual radiation dose received by the personnel working in PET/MRI using the pocket dosimeter (PD) and the thermoluminescent dosimeter (TLD) badges was measured. This part of the study was done only in the patients in whom PET/MRI scan was performed under GA/sedation.

All the scans of F18 fluorodeoxyglucose (F18 FDG) PET/MRI were acquired using standard protocol as per guidelines.[2] All the scans (brain/WB) were performed on simultaneous PET/MRI scanner (SIEMENS Biograph mMRscanner Erlangen, Germany). Personal PD was used for measuring the exposure (Ludlum, Texas, United States).

Protocol Followed in All Patients Referred for PET/MRI

After the radiopharmaceutical injection, patients were made to wait in the postinjection waiting room for 45 minutes and later shifted to PET/MRI scanner. After the scan, patients were monitored in holding area for 45 minutes. The radiation dose was measured in the prescan waiting area (45 minutes) and postscan holding area (45 minute) at different distances. The measurements were taken at 10, 30, and 100 cm from surface of head and at 10 and 30 cm from surface of abdomen, respectively (►**Fig. 2**). This was recorded to obtain an estimate for the maximum possible exposure to anesthesiologists/staff during preanesthetic induction and postrecovery phase. The radiation dose during the scan within the gantry room was not feasible due to the limitation of strong magnetic field in the 3T MRI, which can lead to erroneous readings on the battery-operated PD/survey meter. Upon scan completion, patient was immediately transferred to postinjection waiting area. The postscan/recovery readings with PD were recorded during this time. Appropriate measures were taken to maintain strict adherence to ALARA principle for all the staff working in PET/MRI.

Protocol Followed in Patients Undergoing Scan under GA/Sedation

All consenting patients who were cleared in preanesthetic checkup done 2 to 3 days prior were scheduled for the F18 FDG PET/MRI under sedation/GA. On the day of the scan, patient was prepared as per standard guidelines and essential medications were administered with sips of water

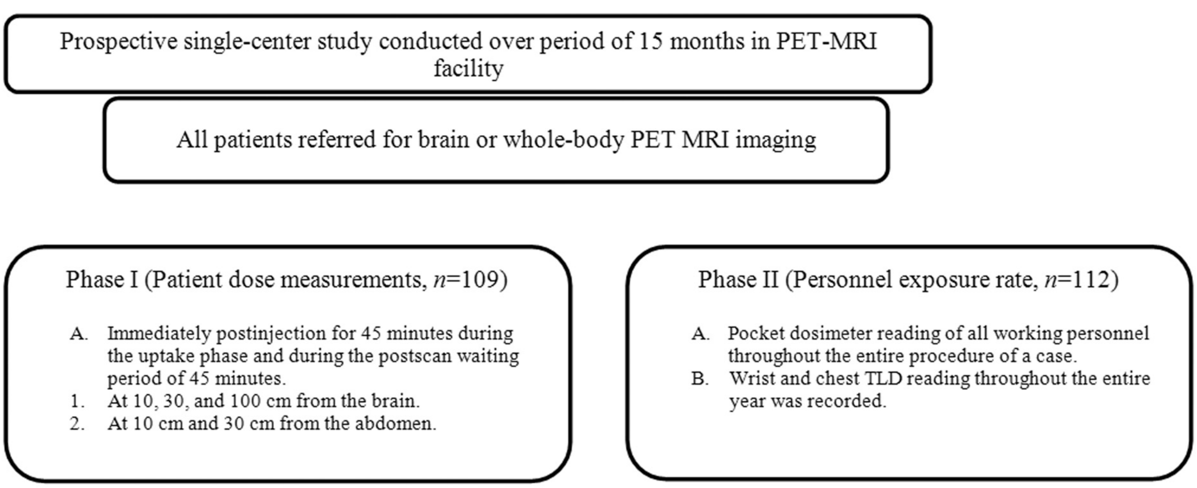

Fig. 1 Study design flowchart.

Fig. 2 Photograph showing position of the pocket dosimeter (white arrow) from the surface of the head at distance of 10, 30, and 100 cm from injected patients prescan in postinjection waiting room.

followed by 4 to 6 hours fasting (as per standard PET imaging protocol guidelines). Patients were asked to wait for 45 minutes in postinjection waiting room after intravenous (IV) injection of F18 FDG, under supervision of guardian in case of young children or under CCTV monitoring in other patients. After 45 minutes, postinjection patients were taken in PET/MRI gantry, induced, and positioned for scanning. Prior to induction for sedation or GA standard monitoring (electrocardiogram, pulse oximeter, noninvasive blood pressure, and end-tidal carbon dioxide) and oxygen by nasal prongs were applied. MRI-compatible infusion pump was used for controlled infusion of IV anesthetic drugs as per anesthesiologist choice. After patient was sedated, head coil (both brain and WB scans) and body coil (in case of WB scans) were placed in position. PET/MRI planning was done and acquisition of the scan was planned in a systematic manner and coordinated team work of technical staff, nursing personnel, and doctors. As far as possible, the anesthesiologist carrying the PD avoided venturing within the 20 millitesla MRI line during induction or intervention that would lead to erroneous recordings from PD. Vitals were monitored by the anesthesiologist via a slave monitor placed in the PET/MRI console. Lead apron or lead shields were not used as it would have hampered the easy movement of personnel. However, customized mobile lead barrier to ease the anesthetist workflow can be adapted to further enhance the radiation safety.

Results

The total number of scans performed during the study period of 15 months was 589 (brain, $n = 379$; WB, $n = 210$). Phase I of the study was done in 109 patients and phase II of the study was done in 112 patients. The approximate scan duration for acquisition brain PET/MRI was 26 ± 11 minutes and for WB PET/MRI was 75 ± 10 minutes. The mean injected activity for brain was 170.2 ± 55.5 megabecquerel (MBq) and for WB was 320.5 ± 43 MBq.

Phase I: Radiation Dose Measurement from Patients Undergoing PET/MRI (Pre/postscan exposure results)

The dose administered and the time lapse between the injection and imaging are presented in ►**Table 1**. The dose measurements that were measured at distances of 10, 30, and 100 cm from the brain and 10 and 30 cm from the abdomen are given in ►**Table 2**.

Table 1 Values of injected dose of radiotracer, time elapsed, and time taken for scan and postscan/recovery

F18 FDG PET/MRI	Mean ± SD			
	Injected dose MBq	Prescan (min)	Scan time (min)	Postscan (min)
Brain	165.02 ± 61.05	43.23 ± 11.22	57.30 ± 14.55	65.70 ± 16.63
Whole body	279.72 ± 85.84	45.21 ± 10.42	96.00 ± 14.63	68.30 ± 11.78

Abbreviations: F18 FDG PET/MRI, F18 fluorodeoxyglucose positron emission tomography/magnetic resonance imaging; MBq, megabecquerel; SD, standard deviation.

Table 2 Radiation dose measurements in μSv after injection

Type of scan		Brain			Abdomen	
Distance from patient		10 cm	30 cm	100 cm	10 cm	30 cm
Brain PET/MRI $n = 101$	Prescan	44.4 ± 16.61	14.91 ± 5.42	3.55 ± 1.96	54.83 ± 23.64	25.03 ± 12.01
	Postscan	31.1 ± 15.77	9.74 ± 5.27	2.77 ± 1.99	30.33 ± 16.07	13.59 ± 8.44
Whole-body PET/MRI $n = 8$	Prescan	90.35 ± 50.49	25.61 ± 10.1	6.58 ± 3.81	105.74 ± 55.26	42.23 ± 19.97
	Postscan	51 ± 27.77	14.97 ± 6.59	4 ± 2.65	48.59 ± 28.9	21.1 ± 12.61

Abbreviations: PET/MRI, positron emission tomography/magnetic resonance imaging; μSv, micro Sievert.

Phase II: Radiation Exposure of Personnel Conducting PET/MRI

In the normal course dose received by each anesthesiologist per patient while performing a single PET/MRI scan either WB or brain was around 3.6 ± 5.7 µSv/patient/scan unless there is a difficult case that can be up to 26.6 ± 10.22 µSv/patient/scan (►**Table 3**). The rest of working staff received an average calculated dose in micro Sievert (µSv) patient per scan was 5.66 ± 2.12 (NM physician), 7.43 ± 2.54 (physicist), 3.66 ± 2.12 (radiographer), and 6.66 ± 2.12 (staff nurse), respectively (►**Table 4**).

All the patients in this study underwent PET/MRI under sedation except six patients who underwent PET/MRI under full GA (►**Table 5**). The GA was administered directly as decided by the anesthesiologist or following failure of the initial deep sedation protocol. The maximum dose of exposure to the anesthesiologist ranged between 16 and 42 µSv (mean of 26.66 ± 10.22 µSv/patient/scan).

Discussion

Safety of all staff working in radiation facility is the main concern of any department. The radiation protection principles of time, distance, and shielding, as suggested by Atomic Energy Regulatory Board (AERB), are strictly adhered to. The recommended limit for radiation exposure to a radiation worker is 20 mSv per year (500 mSv per year for fingers) by the International Commission on Radiological Protection (ICRP Publication No. 103).[3] The Sievert is a measure of the health effect of low levels of ionizing radiation on the human body and is important in dosimetry and radiation protection. However, becquerel is defined as the activity of a quantity of radioactive material in which one nucleus decays per second. Exposure rate is the amount of ionizing radiation per hour in a person's vicinity (measured in milliRoentgen per hour, mR/h), whereas dose rate is the biological effect on the body from exposure to that radiation (measured in milliSieverts per hour, mSv/h).[3]

In a nuclear medicine setup, the injected patient itself is the source of radiation and if performed under sedation/GA, the risk of exposure is increased due to the increased amount of time spent near the patient. In such scenarios, radiation protection principles of time, distance, and shielding might get compromised. Time spent for initial assessment can be minimized but not when it requires emergency interventions like conversion of cases under sedation to GA owing to the compromise in the vital parameters. Patient assessment, anesthetic induction, and endotracheal intubation require close proximity. Routinely used lead aprons in a radiation environment are approximately 0.5 mm thick and used to stop X-rays. But in a nuclear medicine setting, it mainly deals with open-source radiation and as already explained injected patient is itself a source of radiation. The thickness of lead aprons or shield required to decrease the gamma radiation to half its original value would be 4.1 mm.[4] Hence, use of such heavy lead aprons or lead barrier is not feasible and hampers easy workflow. Anesthetic induction and endotracheal intubation whenever required are usually performed after radiopharmaceutical injections owing to decrease in glucose metabolism and erroneous imaging findings due to anesthetic drugs.[5] Induction prior to radiopharmaceutical injection was not feasible option because there is global 40 ± 9% reduction of WB glucose metabolism.[5] Monitoring exposure rates that is routinely done in any nuclear medicine setting also posed a challenge here because of the PET/MRI setup. In the strong magnetic field of 3Telsa MRI, the battery-operated PD gives erroneous reading within the 20 millitesla Gauss line. The study design had to be executed keeping all these shortcomings into consideration.

Many published literatures are available that have measured the radiation dose received by the working personnel in both positron emission tomography/computed tomography (PET/CT) and nuclear medicine department in both diagnostic and therapeutic setting.[6–8] However, we could not find any article of radiation dose measurement in the personnel especially anesthesiologist working in PET/MRI facility. The articles on radiation dose received in PET/CT[9,10] cannot be directly applied to PET/MRI facility due to prolonged time of imaging (PET/CT scan usually takes 10–15 minute for

Table 3 Radiation dose measurements of personnel working in PET/MRI facility during scanning of patients under GA or sedation total 112 patients

Mean dose in µSv/per scan/per procedure					
PET/MRI scan	Anesthesiologist	NM physician	Physicist	Radiographer	Staff nurse
Brain/whole body	4.84 ± 0.33	5.66 ± 2.12	7.43 ± 2.54	3.66 ± 2.12	6.66 ± 2.12

Abbreviations: GA, general anesthesia; PET/MRI, positron emission tomography/magnetic resonance imaging; µSv, micro Sievert.

Table 4 Cumulative TLD dose of nuclear medicine personnel working in PET/MRI mSv/year

Staff details	Anesthesiologist	NM physician	Physicist	Radiochemist	
Chest TLD	0.00	0.65	1.70	1.35	Staff involved in patient injection, dose dispensing in PET/MRI and also SPECT/CT, rest of the staff (nurse and radiographer) the chest TLD readings was 0.00 mSv/year
Wrist TLD	0.00	0.05	3.75	9.90	

Abbreviations: mSv, milliSievert; PET/MRI, positron emission tomography/magnetic resonance imaging; SPECT, single photon emission computed tomography; TLD, thermoluminescent dosimeter.

Table 5 Conversion of sedation to GA

Cases	Reason for conversion	Radiation dose received by anesthesiologist (μSv)	Time spent by anesthesiologist with the patient during induction, postscan, and during recovery
Case 1	Failed deep sedation	22	10–15 minutes spent during conversion from deep sedation to full GA including endotracheal intubation. Post-scan extubation and monitoring
Case 2	Failed deep sedation	16	10–15 minutes spent during conversion from deep sedation to nasolargyngeal tube. Postscan extubation and monitoring
Case 3	Short neck with difficult intubation	42	20–25 minutes spent in inducing and endotracheal intubation. Patient developed arrythmias. Postscan extubation and monitoring
Case 4	Failed deep sedation	20	10–15 minutes spent during conversion from deep sedation to nasolargyngeal tube. Postscan extubation and monitoring
Case 5	Failed deep sedation	17	10–15 minutes spent during conversion from deep sedation to endotracheal intubation. Postscan extubation and monitoring
Case 6	Failed deep sedation	20	10 minutes spent during conversion from deep sedation to endotracheal intubation. Postscan extubation and monitoring

Abbreviations: GA, general anesthesia; μSv, micro Sievert.

brain imaging and 15–20 minutes for WB imaging), challenges of the MRI environment (battery operated PD does not work), and workflow pattern adopted to PET/MRI settings. Owing to the longer duration of the PET/MRI scan (3 times the duration of PET/CT scan), it is very essential to plan the workflow especially for cases performed under GA/sedation.

A recent study evaluated the effective WB dose rate of each staff during the PET/CT procedure with the help of dose rate meter and recorded the dose received per working day, time spend in contact with patient, and daily injected activity. In addition, they measured the instantaneous dose rates at 0.1, 0.5, 1.0, and 2.0 m from the mid-thorax from the patient.[11,12] Another study that looked into the radiation dose received by all staff working based on the daily workflow and design of the facility in a high-volume center clearly concluded that an increase in the number of cases does not necessarily mean an increase in radiation exposure to the staff. Judiciously designing the facility with optimal shielding, along with an efficient workflow to reduce unnecessary patient proximity to the staff, enables a reduction in professional radiation exposure.[13]

In our study, the mean radiation exposure received by an anesthesiologist per patient was 4.84 μSv that was slightly lesser compared with the dose received by a nuclear medicine physician (5.66 μSv) who routinely involved in radioactive tracer injections in both single photon emission computed tomography and PET and far less than the physicist (7.43 μSv) who was majority of time involved in dose dispensing, patient positioning, and assisting physicians. However, these recorded values were definitely more than the values measured by Pant and Senthamizhchelvan,[14] where in their mean dose measured at the chest level per PET/CT procedure was 3.24 and 0.62 μSv for the physicians and technologists, respectively. This definitely can be attributed to the longer duration of the scans and monitoring required in the PET/MRI.

The increased dose measurements in six patients who were converted from sedation to GA were due to the specific interventions required based on the clinical condition and difficulty during sedation/ postrecovery period. In such scenarios, keeping distance which is the most economical way of reducing our exposure to radioactive sources fails owing to the immediate medical care the patient needs. Though the exposures in such scenarios have found be at least seven times more than usual routine cases, the fact needs to be emphasized that it was only in 6/112 patients, that is, 5.3% of total cases were performed under GA.

There are no studies looking at the exposure of anesthesiologist in a nuclear medicine Imaging facility, since this is very occasionally used in PET/CT facility where the scan durations are short (15–20 minutes) for WB imaging and (10–15minutes) brain imaging. In one study, Siddiqui et al[15] not only noted the risk of radiation exposure during bedside radiologic procedures but also when intensive care unit (ICU) physicians accompanying patients to radiology suites. The aim of their study was to quantify levels of radiation exposure among medical professionals working in the ICU. And they found that if standard radiation safety precautions are followed, the cumulative radiation exposure to ICU resident doctors is well within permissible limits and is not a cause of concern. The only personal radiation dosimeter that works in MRI environment is TLD. Those readings of the anesthesiologist were also recorded.

In addition, good work practice is of paramount importance. Preprocedure detailed evaluation and anticipation of complications during initial evaluation are important. Planned workflow (preparation with preloading of drugs, use of MRI compatible infusion apparatus, slave monitor, induction beyond 20 millitesla line, team work and minimizing the time spent), preprocedure checklist, and division/rotation in work are required (coordinated team work with technical staff, nursing personnel, and doctors during induction). Proper training (to spend less time and maintain distance during induction, use of slave monitor, and CCTV for monitoring) and awareness (about dose limits and ALARA) can further reduce the exposure and procedure can be done without fear of radiation.

Limitations of this Study

There are few limitations in the study

1. The PD readings at 100 cm from abdomen could not be measured because of space constraints in the patient waiting area.
2. The staff (anesthesiologists, nurses, radiologists) are working in rotation shifts in PET/MRI facility. Therefore, their cumulative exposure as measured by the TLD will always be lower.
3. A mobile lead shield of an appropriate thickness could have been used and would be helpful in providing additional radiation safety.

Conclusions

Performing F18 FDG PET/MRI was found to be a safe procedure from radiation exposure point of view to all the working personnel. We conclude in this study the radiation exposure to the anesthesiologist and rest of the staff working in PET/MRI was within the safe limits as specified by the regulatory authorities.

Conflict of Interest
None declared.

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