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Reducing Radiation Exposure from PET Patients

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Abstract

Objective: This study measured the typical emitted radiation rate from the urinary bladder of PET patients after their scan and investigated simple methods for reducing the emitted radiation before discharge.

Methods: The study included 83 patients, 63 [^{18}F]FDG and 20 [^{18}F]NaF. Emitted radiation from the patients' urinary bladder was measured with an ionization survey meter at a 1-meter distance, presuming the urinary bladder to be the primary source of radiation. The measurements were taken at different time points after PET image acquisition: immediate (pre-void 1), voided (post-void 1), after waiting 30 min in the uptake room while drinking 500 mL of water (pre-void 2) and voided again (post-void 2).

Results: For [^{18}F]FDG patients, the reduction of emitted radiation due to drinking water and voiding alone from pre-void 1 to decay corrected post void 2 was an average of 22.49 ± 7.48% (13.65 ± 3.42 μSv/h to 10.48 ± 2.37 μSv/h, $p < 0.001$). As for [^{18}F]NaF patients, the reduction was an average of 25.80 ± 10.03% (9.83 ± 2.01 μSv/h to 7.23 ± 1.49 μSv/h, $p < 0.001$).

Conclusions: In addition to the physical decay of the radiotracers, utilizing the biological clearance properties have resulted in a significant decrease of the emitted radiation in this study. Implementing additional water consumption to facilitate voiding with 30 minutes of wait time before discharging certain [^{18}F]FDG and [^{18}F]NaF patients that need to be in close contact with others such as elderly, caregivers and inpatients, might facilitate lowering their emitted radiation by an average of 22-25% due to voiding, not counting in the physical decay which should add an additional 17% reduction.

Keywords: PET/CT, Public Safety, Radiation Exposure, ALARA

Introduction:

Positron emission tomography (PET) imaging procedures have increased in the past few decades. The increased use of PET is attributed to multiple factors, including awareness of referring physicians and the emergence of a variety of tracers with numerous clinical applications (1). Further, the clinical indications of PET have expanded beyond oncology to include infection, inflammation, cardiovascular, brain and skeletal imaging. The first approved PET radiotracers by US Food and Drug Administration (FDA) and most widely used were ^{18}F-fluorodeoxyglucose ([^{18}F]FDG) and ^{18}F-sodium fluoride ([^{18}F]NaF) (2). Recently, the FDA has approved more PET radiotracers that are being used in clinical practice: [^{13}N]ammonia in 2007, [^{18}F]florbetapir in 2012, [^{18}F]flutemetamol in 2013, [^{18}F]florbetaben in 2014, [^{18}F]fluciclovine in 2016, ^{68}Ga-DOTA-TATE in 2016, ^{68}Ga-DOTA-TOC in 2019, [^{18}F]fluorodopa in 2019, ^{64}Cu-DOTA-TATE in 2020, [^{18}F]fluoroestradiol in 2020 and ^{68}Ga-PSMA in 2020. Currently, there are additional PET radiotracers that are being evaluated in clinical trials and as investigational new drugs.

With the recent development of these PET radiotracers, there has been more attention to the radiation exposure from PET patients after being discharged. Although radiation from medical use and nuclear medicine is overall safe (3,4), lowering radiation exposure from the patients to their caregivers or contacts is desirable. This is particularly important in special patient groups such as inpatients, who immediately return to their wards after imaging, and also for patients who require special assistance from a caregiver. There are a couple of studies that measured the emitted radiation from patients undergoing ^{68}Ga-DOTA-TOC, [^{18}F]fluorodopa, [^{18}F]FDG and [^{18}F]fluciclovine scans (3,5).

Since the majority of diagnostic studies prior to PET popularity were performed using ^{99m}Tc-labeled radiotracers, the discharge criteria for these studies are well-defined because there is minimal radiation exposure from the patients due to the 140 keV gamma emission and a 6-hour half-life of ^{99m}Tc radionuclide. On the other hand, PET radionuclides emit two 511 keV photons simultaneously, which are capable of more ionizing damage to their surrounding in comparison to ^{99m}Tc radionuclide. Therefore, both types of radiotracers cannot be treated equally and separate guidelines should be implemented for PET radiotracers. To date, however, there are no mandated release criteria for discharge of PET patients after completion of their scan.

Published articles have stated that the majority of the patients who underwent an [^{18}F]FDG scan had emitted radiation exceeding or close to 20 μSv/h at the time of discharge (3-7). Muzzafar et al. stated that 97% of these patients had dropped the radiation exposure to below 20 μSv/h by using simple interventions such as waiting half an hour post-scan and voiding before being discharged (5). This was, however, not the case with [^{18}F]fluciclovine patients in which only 25% of the patients had a drop of radiation exposure below 20 μSv/h following the same interventions. This observation is mainly due to the facts that the imaging protocol and the biodistribution of [^{18}F]fluciclovine is significantly different than [^{18}F]FDG (5).

The objectives of this project were to determine the typical emitted radiation rate from the urinary bladder region of PET patients after the completion of [^{18}F]FDG or [^{18}F]NaF PET scans and to further investigate and validate the importance of simple interventions in an attempt to reduce the emitted radiation. These simple interventions may help in lowering the potential radiation exposure to close contact without compromising the quality of images and at no additional cost.

Materials and Methods:

Patients undergoing PET scans in the nuclear medicine department for various clinical indications were asked to volunteer for this study. The study protocol was approved by the Kuwait University, Faculty of Medicine Ethical Review Committee as well as the Ministry of Health Ethical Review Committee. All the subjects signed a written informed consent to participate in this study.

A total of 83 eligible patients consented to participate in the study. The study included patients undergoing PET scans using [^{18}F]FDG or [^{18}F]NaF. Patients who were bedridden, on kidney dialysis, with urine catheters, and under the age of 18 years were excluded from the study.

There were 63 patients (35 male and 28 female; mean age 54.27 ± 15.14 years) who received a weight-based [^{18}F]FDG dose of 5.18 MBq/kg (0.14 mCi/kg) which ranged from 185 to 352 MBq (5-9.5 mCi) (Table 1). Post injection, the patients had an approximately 60 min uptake time followed by a whole-body PET/CT acquisition of about 15-20 min duration (Philips Gemini TF 64 slice PET/CT). Each patient's equivalent dose rate was then measured with an ionization survey meter (GM detector, International Medcom, USA, model IA-V2) at 1 meter immediately after the completion of the PET scan. Based on institutional guidelines, the ionization survey meter is calibrated every six months. For distance consistency, two tape marks were placed on the floor of the uptake rooms at a 1-meter distance. Patients were asked to stand by one of the tape marks on the floor with the technologist on the other tape mark. Presuming the urinary bladder is the primary source of activity emitted from the patient, the radiation emission from the urinary bladder were recorded. The location of the bladder was determined anatomically. The survey meter was held by the technologist at the height of the patient's urinary bladder. The measurements were recorded after the radiation reading became steady on the ionization survey meter. After the initial radiation measurement (pre-void 1), the patients were then asked to void, and another measurement (post-void 1) was recorded. Then the patients were given 500 mL of water to drink while waiting for 30 minutes in the uptake room and instructed not to void during this period. As per the study protocol, the patients waited in their individual uptake rooms and did not come into contact with anyone during this time. Additional measurements were recorded after the 30 minutes wait (pre-void 2), and finally, the patients were asked to void again for one last measurement (post-void 2) before being discharged from the department. The average stay of the patients in the department during this study was 139 ± 16 min (range 86-177 min) from the time of [^{18}F]FDG administration till the time of post void 2 measurement.

As for [^{18}F]NaF, 20 patients (8 male and 12 female; mean age 57.55 ± 18.69 years) were eligible and agreed to participate in this study (Table 1). These patients received a weight-based dose of 5.18 MBq/kg (0.14 mCi/kg) that ranged from 186 to 376 MBq (5.02-10.17 mCi). The emitted radiation was measured in a similar manner to [^{18}F]FDG patients as previously described. The average stay of the patients in the department during this study was 168 ± 15 min (range 140-191 min) from the time of [^{18}F]NaF administration till the time of post void 2 measurement..

Statistical analysis

IBM Statistical Package for Social Sciences version 23 (SPSS-Inc., Chicago, US) was used to perform all statistical analyses. Group statistics, providing basic information about group comparisons, including the sample size (n), mean and standard deviation, were calculated and presented as mean ± SD. The independent samples t-test was conducted to compare the means between groups in order to determine statistical significance.

The data was analyzed based on different categories, including gender, body mass index (BMI) and age. In the gender category, there were 35 males and 28 females for the [^{18}F]FDG group and eight males and 12 females in the [^{18}F]NaF group. In the BMI category, the patients were grouped according to WHO classifications: a “normal” group from 18.5 to 24.9, an “overweight” group from 25 to 29.9 and an “obese” group with a BMI of 30.0 and higher (8). There were 13 normal, 22 overweight and 28 obese [^{18}F]FDG patients, and there were 5 normal, five overweight and ten obese [^{18}F]NaF patients. The age category included: a “youth” group of 18-24 years old, an “adult” group of 25-64 years old and a “senior” group of 65 years and older. For the [^{18}F]FDG patients, there were 2 in the youth group, 41 in the adult group and 20 in the senior group. For the [^{18}F]NaF patients, there were 2 in the youth group, 8 in the adult group and 10 in the senior group.

Results:

[^{18}F]FDG Patients:

For [^{18}F]FDG patients, the average decrease of emitted radiation rate from pre-void 1 to post-void 1 was 10.05 ± 6.54 % (13.69 ± 3.42 µSv/h to 12.16 ± 2.74 µSv/h, p = 0.008) as illustrated in Figure 1. The average decrease from pre-void 2 to post-void 2 was

12.08 ± 6.02 % (9.87 ± 2.18 μSv/h to 8.67 ± 1.96 μSv/h, $p = 0.001$). The average reduction of emitted radiation due to drinking water and voiding from pre-void 1 to decay corrected post void 2 was 22.49 ± 7.48% (13.65 ± 3.42 μSv/h to 10.48 ± 2.37 μSv/h, $p < 0.001$).

In the gender category, the difference in the overall reduction of the emitted radiation between the males and females was not statistically significant (Figure 2). In the BMI category, the difference in an overall reduction of the emitted radiation between the normal, overweight and obese patient groups was not statistically significant (Figure 2). As for the grouping based on age, the difference in overall reduction of the emitted radiation between the youth, adult and senior groups was not statistically significant (Figure 2).

[^{18}F]NaF Patients:

For [^{18}F]NaF patients, the average decrease of emitted radiation rate from pre-void 1 to post-void 1 was 13.33 ± 11.26 % (9.83 ± 2.01 μSv/h to 8.32 ± 1.63 μSv/h, $p = 0.011$) as illustrated in Figure 3. The average decrease from pre-void 2 to post-void 2 was 15.64 ± 8.17 % (7.08 ± 1.58 μSv/h to 5.98 ± 1.24 μSv/h, $p = 0.012$). The average reduction of emitted radiation rate due to drinking water and voiding from pre-void 1 to decay corrected post void 2 was 25.80 ± 10.03% (9.83 ± 2.01 μSv/h to 7.23 ± 1.49 μSv/h, $p < 0.001$).

In the gender category, the difference in the overall reduction of the emitted radiation between the males and females was not statistically significant (Figure 4). In the BMI category, the difference in an overall reduction of the emitted radiation between the normal, overweight and obese patient groups was not statistically significant (Figure 4). As for the category based on age, the overall reduction in the emitted radiation between the youth, adult and senior patient groups was not statistically significant (Figure 4).

Discussion:

Nuclear medicine departments routinely perform both diagnostic and therapeutic procedures using a variety of radionuclides with different types and energies of emitted radiations. The majority of performed procedures in nuclear medicine are diagnostic radionuclide imaging. Extensive work has been undertaken for the reduction of radiation exposure to patients and nuclear medicine staff (9-13). It has been well reported that patient radiation exposure from nuclear medicine is overall safe and might be beneficial in some cases (3,4). Consequently, nuclear medicine practice incorporates important principles for the reduction of the radiation dose, such as As Low As Reasonably Achievable (ALARA) principle. The nuclear medicine staff are trained to handle all types of radioactivity, keeping in view the time, distance and shielding principles in order to minimize radiation exposure. In addition, the radiation exposure of the nuclear medicine staff is continuously monitored to ensure that the allowed radiation dose limits are not exceeded.

Unlike the radiation exposure to patients and nuclear medicine staff, the radiation exposure from the PET patients at the time of discharge has not been extensively addressed. The goal of our study was to determine the typical emitted radiation rate from the urinary bladder region of patients after the completion of [^{18}F]FDG or [^{18}F]NaF PET scans and evaluate simple, non-invasive interventions aimed at reducing radiation exposure to close contacts and caregivers from the discharged PET patients utilizing both the physical half-life and biological half-life. The physical half-life is the time during which an initial activity of a radionuclide is reduced to one-half by physical decay (14). Biological half-life is the time by which one half of the administered dose is eliminated via biological processes such as urinary and faecal excretion (14). Effective half-life is calculated based on both the physical half-life and biological half-life for each radiotracer. It is defined as the time required for an initial administered dose to be reduced to one-half due to both the physical decay and biological elimination of the radiotracer (14).

The two PET tracers investigated in this study are eliminated via the kidneys, with the urinary bladder being the organ with the highest radiation absorbed dose (15-19). However, each radiotracer has a different biological half-life. About 21% of [^{18}F]FDG is cleared in urine approximately 2 hours post-administration (15). As for [^{18}F]NaF, about 20% is cleared in urine within the first 2 hours (16,17). Both [^{18}F]FDG and [^{18}F]NaF are labeled with the same radionuclide, i.e. F-18, which has a physical half-life of 110 minutes. The shorter physical and biological half-lives of PET radiotracers allow for faster elimination, and hence presumably implementing simple interventions based on these properties prior to patient discharge may be potentially advantageous. The whole concept of having the patient wait for a certain period of time prior to being discharged is based on the decay property of the radionuclide. As for voiding, the concept of biological half-life is important, and this is achieved by ensuring that the patient is well hydrated during the uptake time and prior to discharge.

Our data shows that a simple precautionary measure of making the patients void prior to discharge reduces the emitted radiation by a mean of about 10% for [^{18}F]FDG and 13% for [^{18}F]NaF. Waiting an additional 30 minutes while drinking water resulted in an additional reduction of the emitted radiation by 12% and 16% for [^{18}F]FDG and [^{18}F]NaF; respectively, due to re-voiding. From another perspective, a 30 min exposure dose at 1 m distance would be around 6.83 and 4.92 μSv from [^{18}F]FDG and [^{18}F]NaF patients; respectively, at the standard time of discharge. This radiation exposure dose would drop to 4.33 and 2.99 μSv from [^{18}F]FDG and [^{18}F]NaF patients; respectively, following the simple steps outlined in this study. This decrease might be of benefit in cases who need to be in close contact with a caregiver. These include elderly patients and young patients as well as their mothers, particularly mothers who are nursing or have young children who would not comply with the instruction to maintain a safe distance. Also, there are other patients who do not have the luxury of separate rooms/bathrooms in their homes, and they may perhaps benefit from the extra time in the department before discharge. This might also be beneficial for inpatients who will be returning back to the ward immediately after completing the scan and potentially exposing other patients and nursing staff to unnecessary radiation.

A previously published article by Muzaffar et al. aimed at introducing simple methods to reduce radiation exposure rates to the public from [^{18}F]FDG PET/CT patients (5). They used [^{18}F]FDG doses of 370-740 MBq (10-20 mCi), and our patients were injected with [^{18}F]FDG doses of 185-352 MBq (5-9.5 mCi). Muzaffar et al. reported that about 75% of their patients leave the imaging facility with emitted radiation exceeding 20 μSv/h (2 mR/h) (3). Only 3% of our patients would have left the department with emitted radiation exceeding 20 μSv/h because they were injected with lower doses compared to Muzaffar et al. patients. Our data also showed that the overall emitted radiation reduction from both [^{18}F]FDG and [^{18}F]NaF was not affected by the patients' gender, BMI or age as the p values showed no statistical significance.

Patient preparation prior to the scan may play an important role in decreasing the radiation dose. Good hydration and voiding have always been advised and recommended before, during and after the scan in the patients' instructions but are not usually re-enforced (20-23). This is mainly recommended to accelerate the clearance of the background blood pool activity in order to improve the image quality and decrease the radiation dose to the patient (20-23). In addition to these benefits, based on our decay corrected data, the biological clearance permitted the decrease of emitted radiation of an average of 22.49% for [^{18}F]FDG, which is equivalent to 40 minutes of F-18 decay time and 25.80% for [^{18}F]NaF which is equivalent to 47 minutes of F-18 decay time. Therefore, good hydration assisted in significantly decreasing the emitted radiation from the patients to their close contacts.

Adding the decay property of the radionuclide by asking the patients to wait 30 minutes while maintaining a good hydration state will always result in an overall reduction of 17% of the emitted radiation. However, the drop of radiation due to decay cannot be measured accurately from our collected data because the radiotracer is continuously circulating in the patients' body between post-void 1 and pre-void 2 measurements as accumulation of the radiotracer is taking place in the urinary bladder.   Therefore, this value wasn't calculated from our data as it isn't feasible.

During this study, none of the staff was exposed to additional radiation since the department has shielded uptake rooms in the PET suite. Each patient stayed comfortably in their individual uptake room without exposing any of the Nuclear Medicine staff to additional radiation. We can accommodate the use of these rooms even if there is a busy schedule. However, the logistics vary from one hospital to another and this is outside the scope of this manuscript.

The lower-than-expected number of patients was a limitation, as the majority of the eligible patients did not consent to be a part of this study. In addition, the renal function tests of most patients were not available due to logistical issues. Therefore, it was not feasible to study the relationship between renal function and its effect on emitted radiation rates. Also, utilizing a whole-body radiation counter would have provided a more accurate measurement, but unfortunately, this was not available in our institution. However, based on the collected data from the two different PET tracers, it was obvious that utilizing both physical decay and biological elimination properties had a significant impact on lowering the emitted radiation from the patients. There should not be major logistical issues to implement these steps at the nuclear medicine department since it will be based on individual cases.

Conclusion:

With the increasing use of PET in clinical practice and the approval of new PET radiotracers, the emitted radiation from the discharged PET patients has been of interest. Utilizing the biological half-life properties of radiotracers, demonstrated to have a significant impact on lowering the emitted radiation rate from PET patients. Requesting the patient to consume additional water after the completion of the scan will facilitate voiding with 30 minutes of wait time prior to being discharged will be of benefit to certain PET patients such as the elderly, caregivers and inpatients who need to be in close contact with others. In addition to the possible reduction of emitted radiation rates an average of 22-25% due to voiding, there is an additional 17% reduction due to decay of the radioactivity during this time.

KEY POINTS:

QUESTION: Will undertaking simple steps with the PET patients prior to their discharge from the department significantly reduce the emitted radiation to their close contacts?

PERTINENT FINDINGS: In a prospective study of patients undergoing PET scans, the emitted radiation from their urinary bladders were measured after completing the exam (pre-void 1), voiding (post-void 1), waiting 30 min while drinking water (pre-void 2) and voiding again (post-void 2). Overall voiding in this study resulted in an average decrease of emitted radiation rate of 22.49% for [^{18}F]FDG and 25.80% for [^{18}F]NaF, in addition to a fixed 17% decrease from the physical decay of ^{18}F-radiotracers after 30 min of wait time.

IMPLICATIONS FOR PATIENT CARE: Following simple steps after the completion of the PET scan, there will be a significant decrease of the emitted radiation from the PET patients to their close contacts.

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FIGURE 1. Exposure rates (µSv/h at 1 m) from [^{18}F]FDG patients (n=63) at different time points

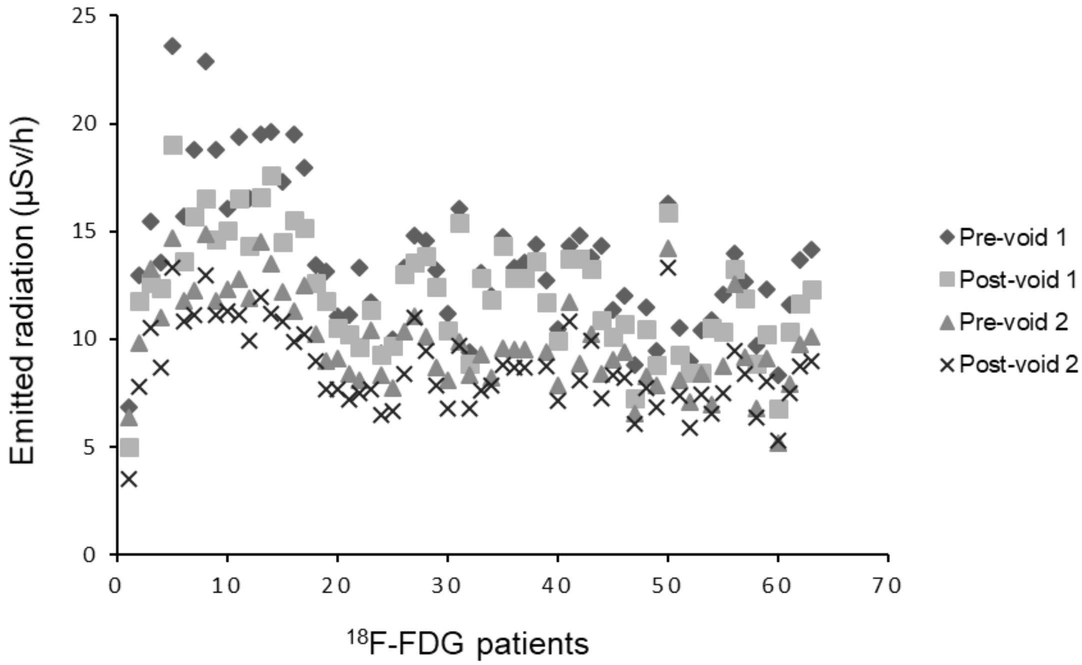
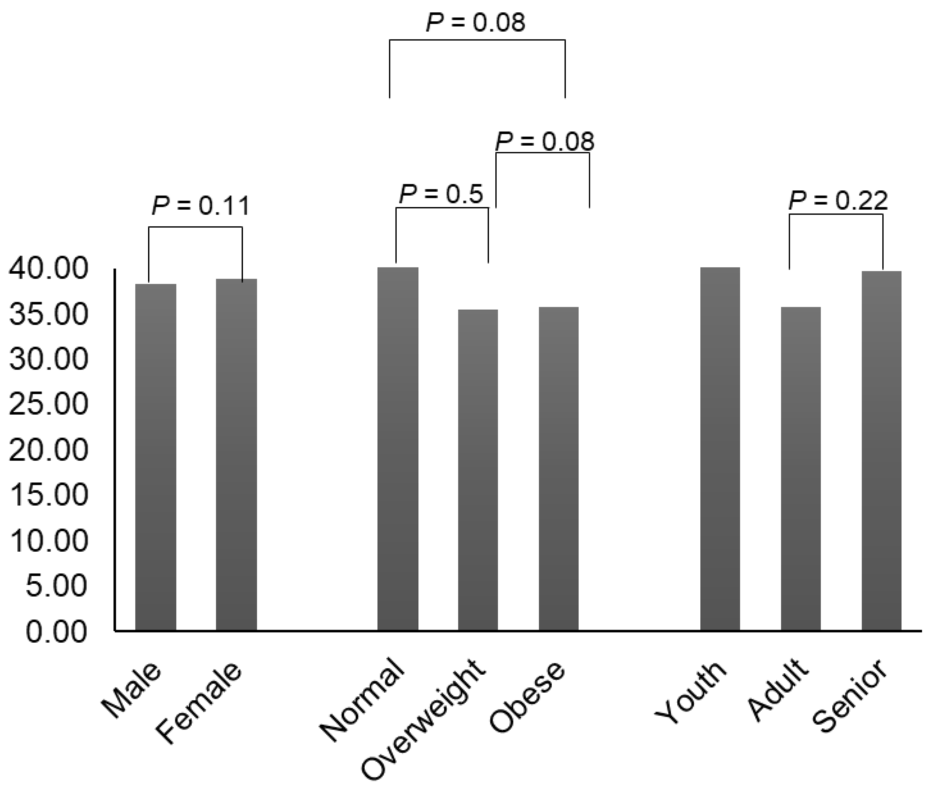


FIGURE 2. Comparison of the overall reduction of emitted radiation from voiding after decay correction of categorized [^{18}F]FDG patients with the corresponding P values



*The P values indicate no statistical significance between the different patient categories regarding the effect of decay corrected void.

**The youth group has only 2 patients therefore the P value of this group was not calculated.

FIGURE 3. Exposure rates (μSv/h at 1 m) from [^{18}F]NaF patients (n=20) at different time points

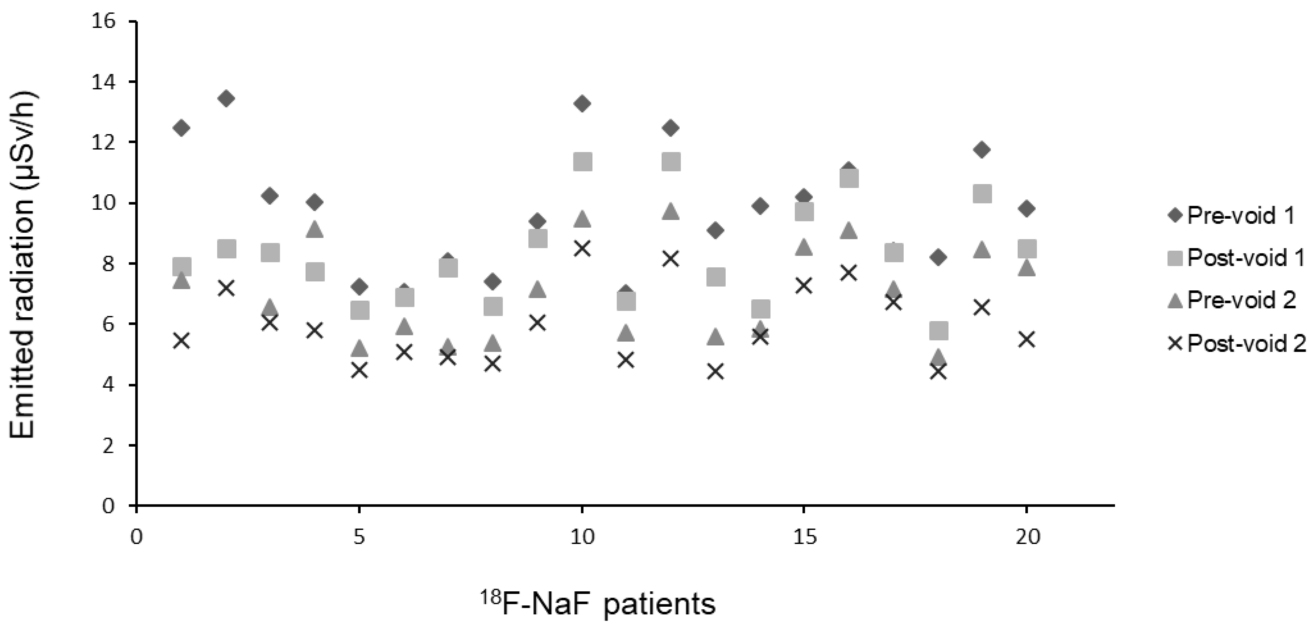
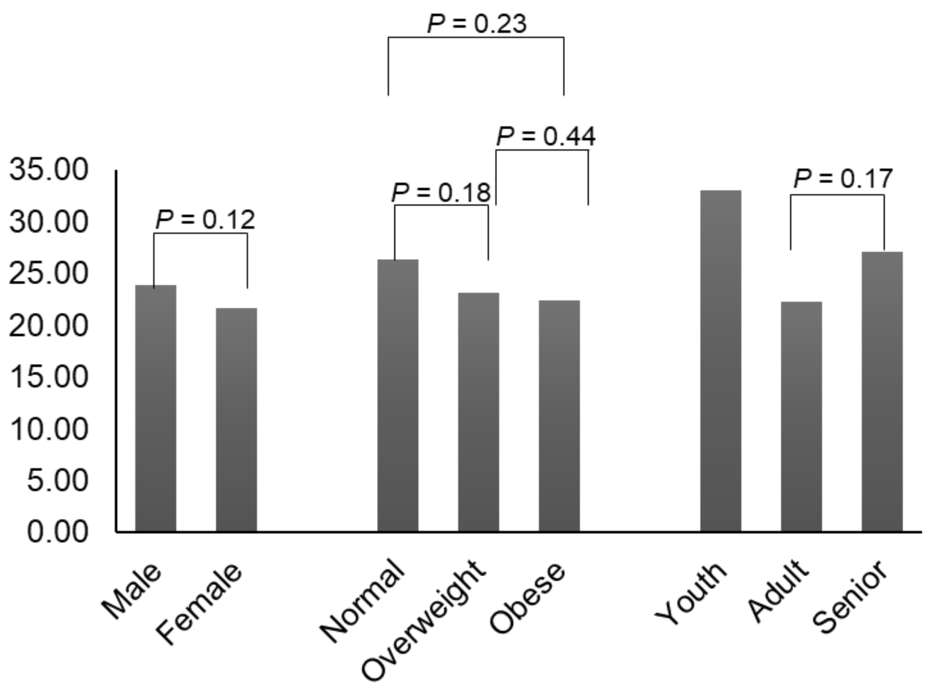


FIGURE 4 Comparison of the overall reduction of emitted radiation from voiding after decay correction of categorized [^{18}F]NaF patients with the corresponding P values



*The P values demonstrate that there was no statistical significance between the different categories regarding the effect of decay corrected void.

**The youth group has only 2 patients therefore the P value of this group was not calculated.

Table 1. Patient Demographic Data

Tracer	Study Group	#		Age (Yrs)	BMI	Dose (MBq)
[18F]FDG	Male	35	Range	27 - 77	19.31 - 43.04	188 - 337
			Mean	54.63 ± 14.95	28.99 ± 5.39	284 ± 35
	Female	28	Range	21 - 81	17.58 - 39.91	185 - 352
			Mean	53.82 ± 15.37	29.80 ± 4.86	278 ± 77
	All	63	Range	21 - 81	17.58 - 43.04	185 – 352
			Mean	54.27 ± 15.14	29.33 ± 5.19	281 ± 37
[18F]NaF	Male	8	Range	22 - 81	21.55 - 34.55	224 – 376
			Mean	63 ± 20.84	28.34 ± 4.87	289 ± 50
	Female	12	Range	23 - 78	20.09 - 39.84	186 – 369
			Mean	53.92 ± 16.11	29.66 ± 5.39	261 ± 51
	All	20	Range	22 - 81	20.09 - 39.84	186 - 376
			Mean	57.55 ± 18.69	29.25 ± 5.26	272 ± 53

Graphical Abstract