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Factors affecting radiation exposure dose in nursing staff during ^{18}F- fluorodeoxyglucose positron emission tomography/computed tomography

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Abstract: Factors affecting radiation exposure dose in nursing staff during ^{18}F- fluorodeoxyglucose positron emission tomography/computed tomography: Kimiteru Ito, *et al.* Department of Diagnostic Radiology, Tokyo Metropolitan Geriatric Hospital—Objectives: We evaluated factors associated with increased radiation exposure dose in nursing staff who assisted patients with ^{18}F-fluorodeoxyglucose (^{18}F-FDG) positron emission tomography (PET)/computed tomography (CT) examinations. **Methods:** The Barthel Index and Mini-Mental State Examination (MMSE) score were obtained before PET/CT examinations in 193 patients (mean age ± SD, 77.7 ± 8.0 yr). Three nurses self-measured their radiation exposure dose while assisting patients during each PET examination. Disturbance factors during PET examinations (use of a stretcher or wheelchair, use of lines or tubes connected to the patient, use of diapers or urethral catheterization, patient age), ^{18}F-FDG injection dose, and previous PET/CT experience in the patients and outpatient or inpatient status were evaluated as factors possibly associated with increased radiation exposure. Principle component analysis, univariate analysis, and multivariate regression analysis were used for assessing associations between radiation exposure dose and factors. **Results:** The mean radiation exposure dose of the nursing staff was 6.07 ± 5.71 μSv per examination. Statistically significant factors associated with increased radiation exposure (<8 or ≥8 μSv/case) in the univariate analysis were the Barthel Index (<75 or ≥75), MMSE score (<22 or ≥22) of the patients, numbers of lines or tubes to the patient, use of a stretcher or wheelchair, and ^{18}F-FDG injection dose. Multivariate logistic regression modeling showed that the Barthel Index (<75 or ≥75) and MMSE score (<22 or ≥22) of the patients were significant factors in the final model. **Conclusions:** Lower Barthel Indexes (lower ADL) and lower MMSE scores (lower cognitive function) were independent factors associated with increased radiation exposure dose in nursing staff assisting during ^{18}F-FDG PET/CT.
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Key words: Activity of daily living, Barthel index, Dementia, ^{18}F-fluorodeoxyglucose (^{18}F-FDG), Radiation exposure, Positron emission tomography (PET)/computed tomography (CT)

In Japan, 25% of the population is older than 65 years. Along with the increased age of the population, medical care and types of labor are different from those of a few decades ago[1, 2]. Increased age also has led to increases in the numbers of patients with neoplasia, vascular diseases, or dementia. The technique of ^{18}F-fluorodeoxyglucose (^{18}F-FDG) positron emission tomography (PET)/computed tomography (CT) is widely used in various clinical settings in oncology, neurology, and cardiology. In elderly patients with these diseases, ^{18}F-FDG PET/CT can be performed as a minimally invasive examination with high safety. Although the radiation exposure of patients is acceptable in PET/CT examinations, the radiation exposure of medical examination staff must be carefully controlled because of repeated exposure. The physical characteristics of positron emissions cause a higher radiation risk for staff. The penetrating ability of the high-energy 511 keV γ-rays produced by the annihilation reaction of a positron and an electron is greater than that of other single-positron emission computed tomography tracers[3, 4]. Along with the atten-

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tion given to the increasing elderly population and to the injection devices used during PET examinations, the role of nursing staff during PET examinations has also received greater attention[5]. The burdens of nursing care are increasing for patients who have low activities of daily living (ADL) indices or impaired cognitive function because ^{18}F-FDG PET/CT is increasingly used to examine them. Furthermore, the radiation exposure doses of nursing staff during PET examinations are increasing in Japan[6]. The principles of radiation protection, i.e., exposure time, distance, and shielding, are always adhered-to for any procedure involving radioactive administration. However, reducing radiation exposure for nursing staff during PET/CT examinations is difficult because their work involves care for patients with disabilities. Therefore, awareness of the radiation doses of nursing staff during PET/CT examinations is highly important. Several studies have reported the radiation exposure doses of PET technologists or nuclear medicine physicians[7–14]. However, few studies have evaluated the exposure doses of nursing staff and factors associated with increased radiation exposure doses.

The purpose of this study was to identify factors associated with increased radiation exposure doses in nursing staff during ^{18}F-FDG PET/CT examinations.

Subjects and Methods

This study was approved by our institutional ethics committee. One hundred and ninety-seven consecutive patients who underwent whole-body ^{18}F-FDG PET/CT to examine malignancies were recruited (Table 1). The exclusion criteria were patients who had previously undergone ^{18}F-FDG PET/CT examinations within 6 months and were <55 years of age because most of our patients (approximately 98%) were over 55 years of age. Written informed consent for the study was obtained from the patients or the legally authorized representatives of those who had diminished decision-making capacity. After obtaining informed consent, a medical doctor evaluated the patients' ADL by using the Barthel Index (Table 2), and cognitive function was assessed by using the Mini-Mental State Examination (MMSE), as shown in Table 3[15, 16]. Three experienced female nurses (with 15, 12, and 10 years of experience), who were blinded to the examination results, explained the procedures to be used during the ^{18}F-FDG PET/CT examination and assisted the patients. All of the nurses received education about basic radiation protection and radiology. The following procedures were used by the nurses during the ^{18}F-FDG PET/CT examinations: injection of ^{18}F-FDG, assisting the patients to the waiting rooms, helping to transfer the patients with low ADL, managing the lines or tubes connected to the patients (i.e., drip lines, chest drainage tubes, urinary tubes, cardiac monitors, nasal cannulas for oxygen therapy), changing the patients' diapers or disposing of urine from drainage bags, and assisting the patients when exiting the radiation controlled area after the ^{18}F-FDG PET/CT examination. The radiology technologists usually assisted the patients into and out of the PET/CT room and set the bed position for the patients. The nurses provided additional assistance to the technologists when necessary. The nurses self-measured their radiation exposure dose after each procedure and recorded their dose. They used a personal radiation exposure dosimeter with silicon semiconductor detector (PDM-122B-SHC, MYDOSE mini, Hitachi Aloka Medical Ltd., Tokyo, Japan). They wore the dosimeter on the front of their trunk. All of the staff followed the guidelines and regulations for radiation exposure protection: the recommended limit for radiation exposure for a staff member is 20 mSv per year averaged over 5 years or a maximum of 50 mSv in any single year[17].

Major factors that were possibly associated with increased radiation exposure were extracted as single variables and included the Barthel Index, MMSE score, ^{18}F-FDG injected dose, use of a stretcher or wheelchair, use of a line or tube, use of a diaper or urethral catheterization, patient age, previous PET/CT experience in the patients, and outpatient or inpatient status.

Table 1. Patient characteristics of the study population

Characteristics (n=193)	
Age (years)	77.4 ± 8.2
Sex (n)	
Male/female	98/95
Barthel Index (mean ± *SD)	82.64 ± 27.47
MMSE (mean ± *SD)	24.8 ± 4.99
Use of a stretcher or wheelchair (n)	
Yes/no	44/149
Previous PET experience in the patients (n)	
Yes/no	49/144
Inpatient or outpatient (n)	
Inpatient/outpatient	39/154
Injected FDG dose (mean ± SD)	205 ± 29.67
Use of a diaper or urethral catheterization	
Yes/no	21/172
Use of lines or tubes	
Yes/no	22/171

SD: standard deviation. MMSE: Mini-Mental State Examination. PET: positron emission tomography. FDG: fluorodeoxyglucose.

Table 2. The Barthel Index

Feeding
0 = Unable
5 = needs help cutting, spreading butter, etc.
10 = independent (food provided within reach)

Transfer
0 = unable - no siting balance
5 = major help (one or two people, physical), can sit
10 = minor help (verbal or physical)
15 = independent

Grooming
0 = needs help with personal care
5 = independent face/hair/tooth/shaving (implements provided)

Toilet use
0 = dependent
5 = needs some help, but can do something alone
10 = independent (on and off, dressing, wiping)

Dressing
0 = dependent
5 = needs help, but can do about half unaided
10 = independent up and down

Mobility
0 = immobile
5 = wheelchair independent, including corners, etc.
10 = walks with help of one person (verbal or physical)
15 = independent (but may use any aid, e.g., stick)

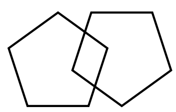
Bathing
0 = dependent
5 = independent (or in shower)

Stairs
0 = unable
5 = needs help (verbal, physical, carrying aid)
10 = independent up and down

Bladder
0 = incontinent, or catheterized and unable to manage
5 = occasional accident (max, once per 24 hours)
10 = continent (for over 7 days)

Bowels
0 = incontinent (or needs tube given enemata)
5 = occasional accident (once/weeks)
10 = continent

Table 3. The Mini-Mental State Exam

Temporal orientation (5 points)	What is the approximate season? What day of the week is it? What is the date today? What is the month? What is the year?
Spatial orientation (5 points)	Where are we now? What is this place? In what direction are we or what is the address here? In what town are we? In what state are we?
Registration (3 points)	Repeat the following words: (cherry blossom, cat, train)
Attention and calculation (5 points)	Subtract: 100−7=93, 93−7=86, 86−7=79, 79−7=72, 72−7=65
Remote memory (3 points)	Can you remember the 3 words you have just said?
Naming 2 objects (2 points)	Key and Pen
Repeat (1 point)	“MINNADE CHIKARAOAWASETE TSUNAO HIKIMASU” (We match power together and pull a rope.)
Three-stage command (3 points)	“Take this piece of paper with your right hand, fold it in half, and put it on the floor.”
Reading and obeying (1 point)	Close your eyes
Writing a complete sentence (1 point)	Write a sentence that makes sense.
Copy the diagram (1 point)	Copy two intersecting pentagons. 

Background radiation dose in the controlled area

The average daily background dose in the controlled area ranged from 0.3 to 0.5 μSv/h, and 5 h out of each 8-h work period were spent by the nurses in the area. Monitors were placed on the walls of the controlled area at a height of at least 2.5 m. The monitoring system did not show abnormal radiation doses during the study period. Thus, the background dose that the nursing staff received while working in the controlled area did not strongly affect the measured radiation doses received during the ^{18}F-FDG PET/CT examinations.

Measurement of injected activity

The nursing staff administered ^{18}F-FDG by using an automatic injection system (AI300; Sumitomo Heavy Industries, Ltd., Tokyo, Japan). Radioactivity was automatically counted by the system. The radioactivity dose (standard dose, from 4 to 5 MBq/kg), radiation density (standard range, from 200 to 800 MBq/m*l*), injection liquid volume (standard range, from 0.5 to 1.0 m*l*), and injection speed (standard, 0.5 m*l*/sec) were controlled within ±5%. The injected ^{18}F-FDG doses were automatically printed on paper and recorded in an electronic medical records system.

Technical parameters for ^{18}F-FDG PET/CT

After the patients had fasted for >4 hours, their blood glucose levels were measured before ^{18}F-FDG administration. A dose of 3.7 MBq/kg of ^{18}F-FDG was subsequently injected intravenously 60 minutes before the start of a whole-body PET/CT scan. Patients who weighed <50 kg received a fixed injection dose of 180 MBq. Imaging of all patients was performed using a combined 64-slice PET/CT scanner (Discovery PET/CT 710; GE Healthcare, Waukesha, WI, USA). At 60 minutes after the ^{18}F-FDG injection, a PET/CT acquisition protocol was initiated to acquire data from the vertex to the mid-thigh region. For this examination, CT was performed according to a body-image protocol without the use of intravenous iodinated or oral contrast media. For the emission scans (3 min/bed position; 128 × 128 matrix) of the whole-body PET/CT protocol, the patients were imaged by using a standard PET/CT bed with a built-in head holder, and the patients' upper limbs were positioned by their sides.

Statistical analysis

A software package, IBM SPSS Statistics (Version 21.0, IBM, Tokyo, Japan), was used to perform statistical analysis. Clinical data were expressed as means ± standard deviations (SDs) unless otherwise specified. A principal component analysis (PCA) was performed to explore abstractive patterns among the following variables: patient age (continuous), sex (nominal), injected ^{18}F-FDG dose (continuous), Barthel Index (continuous), MMSE score (continuous), use of a stretcher or wheelchair (nominal), use of lines or tubes (nominal), use of a diaper or urethral catheterization (nominal), previous PET/CT experience in the patients (nominal), personal attribute of the nursing staff (nominal), and outpatient or inpatient (nominal) status. The variables were selected on the basis of a prior clinical judgment and the existing literature[15, 16]. The Kaiser–Guttman rule was used to determine the number of components to be included. These components had eigenvalues >1. No rotation was used. The Kaiser–Meyer–Olkin measure of sampling adequacy and the Bartlett test of sphericity were performed to evaluate the correlation among the independent variables.

To calculate the risk ratios and 95% confidence intervals (CIs), univariate and multivariate logistic regression analysis were used to explain radiation exposure doses >8 μSv. In univariate analysis for the risk ratio, we used dummy variables of 1 for the following factors: age ≥75 yr, female, no previous PET experience in the patients, MMSE<22, use of a stretcher or wheelchair, Barthel Index <75, use of lines or tubes, use of a diaper or urethral catheterization, and inpatient. Multicollinearity was assessed using Spearman's correlation for continuous variables and the phi coefficient for nominal variables. Correlation coefficients >0.9 (absolute value) were regarded as indicating serious multicollinearity, and values >0.7 (absolute value) were judged to be a cause for concern. After controlling for potential confounders, we analyzed the explanatory variables, including at least one variable from each component. The statistical level of significance determined by the log-likelihood ratio test was set at p<0.10. For reliable analysis, we required that the analyses use the primary outcome measures of ≥10 patients per variable. Conformity to the linear gradient indexes was graphically checked, and logarithmic transformations were performed by category (<75 or ≥75 Barthel Index, <22 or ≥22 MMSE scores, and <75 years or ≥75 years of age). The Hosmer–Lemeshow test and chi-square test for models were used to evaluate the goodness of fit of the logistic regression modeling.

Differences in the radiation exposures among the 3 nurses were explored using one-way analysis of variance. The chi-square test or Fisher's exact test were used to compare nominal variables. Two-tailed p values of <0.05 were used to indicate statistical significance.

Results

Patient characteristics and variables

The patient characteristics are shown in Table 1.

One patient with deafness and 3 patients who refused interviews were excluded. The average ^{18}F-FDG dose was 205.43 ± 29.67 MBq. The average radiation exposure dose received by the nurses was 6.27 ± 5.95 μSv/case. The radiation exposure doses and injected ^{18}F-FDG doses among the 3 nurses showed no statistically significant differences (p=0.709). The total exposure dose in each nurse was acceptable.

Major components from PCA

The contribution rates of each component are shown in Table 4, and the cumulative contribution rate was 61.58%. The Kaiser–Meyer–Olkin measure of sampling adequacy and result of the Bartlett test of sphericity were 0.784 and p<0.001, respectively. The major variables in the first component, which was named "ADL" and reflected 37.59% of all components, were the Barthel Index, use of a stretcher or wheelchair, use of diapers or urethral catheterization, MMSE score, use of lines or tubes, and outpatient or inpatient status. The major variables in the second component, which was named "basic physique" and reflected 13.00% of all components, were age, injection dose, and sex. The major variables in the third component, which was named "experience" and reflected 10.98% of all components, were previous PET/CT experience in the patients and personal attribute of the nursing staff.

Explanatory variables and multiple logistic regression analysis

In univariate analysis for the risk ratio, Barthel Index (<75 or ≥75), MMSE score (<22 or ≥22) of the patients, use of a stretcher or wheelchair, use of lines or tubes, use of a diaper or urethral catheterization, and outpatient or inpatient status were found to be significant explanatory variables for differences in radiation exposure dose in nurses (<8 or ≥8 μSv/case), as shown in Table 5. Among the explanatory variables, use of a stretcher or wheelchair and use of a diaper or urethral catheterization were associated with a high risk ratio for the radiation exposure dose. However, we removed these variables because multicollinearities were confirmed between the Barthel Index (<75 or ≥ 75), and the variables in the phi coefficient (p<0.001). The other variables did not show multicollinearity and were used in the logistic regression modeling.

Multivariate logistic regression modeling using a forward stepwise (likelihood ratio) procedure was performed to examine the associations between radiation exposure dose (<8 or ≥8 μSv/case) and the potential explanatory variables. The groups of explanatory variables were sequentially introduced into the model. In the final logistic regression model, the Barthel

Table 4. Principal component analysis

	Components		
	1	2	3
Barthel Index	**–0.932**	–0.023	–0.051
Use of a diaper or urethral catheterization	**0.852**	0.145	0.096
Use of a stretcher or wheelchair	**0.851**	–0.003	0.097
Inpatients or outpatient	**0.771**	0.041	0.190
MMSE	**–0.726**	0.104	0.237
Use of lines or tubes	**0.714**	0.123	0.152
FDG injection dose	0.013	**0.828**	0.020
Sex	0.052	**–0.711**	0.351
Age	0.390	**–0.422**	–0.418
Personal attribute of the nursing staff	–0.106	0.070	**0.625**
Previous PET experience in the patients	–0.136	–0.086	**0.618**
Contribution rate (%)	37.59	13.00	10.98

Bold characters indicate the primary factors of each component.
A principal component analysis (PCA) was performed to explore abstractive patterns among the above variables. The major variables in the first component reflected 37.59% of all components: the Barthel Index, use of a stretcher or wheelchair, use of diapers or urethral catheterization, MMSE score, use of lines or tubes, and outpatient or inpatient status. The major variables in the second component reflected 13.00% of all components: age, injection dose, and sex. The major variables in the third component reflected 10.98% of all components: previous PET/CT experience in the patients and personal attribute of the nursing staff.
MMSE: Mini-Mental State Examination. FDG: fluorodeoxyglucose. PET: positron emission tomography.

Table 5. Univariate analyses

Variables	Risk ratio (95% CI)	*p* value
Age		
55–74 yr	1 (reference)	—
≥75 yr	1.84 (0.97–3.48)	<0.05
Sex		
Male	1 (reference)	—
Female	1.24 (0.87–1.76)	0.25
Previous PET experience in the patients		
Yes	1 (reference)	—
No	1.40 (0.76–2.60)	0.35
MMSE		
≥22	1 (reference)	—
<22	1.91 (1.44–2.54)	<0.001
Barthel Index		
≥75	1 (reference)	—
<75	3.84 (2.40–6.14)	<0.001
Use of a stretcher or wheelchair		
No	1 (reference)	—
Yes	4.10 (2.50–6.73)	<0.001
Use of a diaper or urethral catheterization		
No	1 (reference)	—
Yes	1.76 (1.39–2.23)	<0.001
Use of lines or tubes		
No	1 (reference)	—
Yes	1.46 (1.20–1.77)	<0.001
Patient status		
Outpatient	1 (reference)	—
Inpatient	1.95 (1.45–2.61)	<0.001

Univariate analyses for the risk ratio were performed to examine the associations between radiation exposure dose (<8 or ≥8 μSv/case) and the potential explanatory variables. We used dummy variables of 1 for the following factors: age ≥75yr, female, no previous PET experience in the patients, MMSE<22, use of a stretcher or wheelchair, Barthel Index <75, use of lines or tubes, use of a diaper or urethral catheterization, and inpatient.

Table 6. Multivariate logistic regression analyses

	Risk ratios for radiation exposure(8 μSv/case)					
Variables	Model 1			Model 2		
	Partial regression coefficient	Adjusted risk ratio (95% CI)	*p* value	Partial regression coefficient	Adjusted risk ratio (95% CI)	*p* value
Barthel Index	4.91	135.47 (36.70–499.77)	<0.001	4.45	85.92 (22.62–326.31)	<0.001
MMSE	—	—	—	1.47	4.37 (1.18–16.08)	0.027
Constant	−2.55	—	<0.001	−2.55	—	<0.001
Model chi-square	*p*<0.001			*p*<0.001		
Model accuracy	91.70%			91.70%		

Multivariate logistic regression modeling using a forward stepwise (likelihood ratio) procedure was performed to examine the associations between radiation exposure dose (<8 or ≥8 μSv/case) and the potential explanatory variables. The groups of explanatory variables were sequentially introduced into the model. In the final logistic regression model, the Barthel Index (<75 or ≥75) and MMSE score (<22 or ≥22) of patients remained significant for risk ratios. Multivariate logistic regression modeling using a backward stepwise (likelihood ratio) procedure also showed the same variables.

Index (<75 or ≥75) and MMSE score (<22 or ≥22) of the patients remained significant for risk ratios (Table 6). The chi-square test for the model was statistically significant (p<0.001), and the overall percentage of model accuracy was 91.7%. The Hosmer–Lemeshow test yielded p=0.95. There were no outliers >3 SDs for predicted values compared with actual measurements. Multivariate logistic regression modeling using a backward stepwise (likelihood ratio) procedure also showed that the Barthel Index (<75 or ≥75) and MMSE score (<22 or ≥22) of the patients were statistically significant explanatory factors in the final logistic regression model.

Discussion

To the best of our knowledge, this is the first study that has attempted to identify factors associated with increased radiation doses in nursing staff who provide assistance during ^{18}F-FDG PET examinations to patients with lower MMSE score and lower Barthel Indexes. Multivariate logistic regression modeling showed that low MMSE scores (dementia) and low Barthel indexes (low ADL) were independent factors associated with increased radiation exposure.

The variables in this study were grouped into 3 major components in PCA. However, the ADL component was the only one associated with increased radiation exposure dose in nursing staff. Other components, such as "basic physique" and "experience," were not associated with increased radiation exposure dose (<8 or ≥8 μSv/case) in logistic regression analysis. One of the reasons for this is that low ADL directly affects the time and distance principles of radiation protection, because nursing staff have to assist the patients, which can take a long time; for example, transfer of bed position or toilet support can increase the care time. In a previous study, the Barthel Index, which is one of the most reliable indexes for evaluating general ADL, showed the highest risk ratio for increased radiation exposure dose and was the most important independent variable[16]. This finding simply shows that the patients with lower ADL indices needed medical support from the nursing staff during PET/CT examinations. The MMSE is one of the most common tests for evaluating cognitive abilities and a low MMSE was also a secondary independent risk factor. This finding is important because patients with dementia are common in the elderly population[18]. This suggests that nursing staff may have to use greater care when assisting patients with dementia in the radiation controlled area. To reduce radiation exposure in nursing staff, it may be useful to review patient information regarding ADL and dementia before ^{18}F-FDG PET/CT.

Previous studies reported that the average radiation dose was approximately 24 μSv/day or approximately 0.1 mSv/month in nursing staff[6, 10]; however, these reports did not describe the physical and mental conditions of the patients. In the present study, the average ± SD for radiation dose per case was slightly higher (6.07 ± 5.71 μSv/case) than those in the previous reports. Our institution specializes in gerontology, and the average age in the patient population was approximately 78 years. Although age was not a significant factor in this study, the staff naturally spends extra time with elderly patients and spontaneously provides assistance, even for patients with high ADL. We speculate that the component of "basic physique" could become a risk factor for increased radiation exposure dose. However, the factors included in the component "basic physique" were not significantly associated with increased exposure. These findings are important for nuclear medicine staff, as they can be used to reduce the radiation exposure dose they receive when providing care to elderly patients.

This study had some limitations. First, the study was conducted in a single hospital and may include biases in the patient population (e.g., our patients were older than those in the wider population). However, the age of people in our society has been increasing, so the findings of our study may be generally applicable in the near future and should contribute to improved radiation protection for nursing staff. Second, the Barthel Index is not a completely objective test because it utilizes self-assessments of caregivers or patients. However, it is one of the most common tests used in clinical trials[19]. We thought that a Barthel Index of <75 was a good cutoff level to help medical staff identify patients with significant disabilities, who may require longer duration of assistance times during examinations and thus contribute to greater radiation exposure of nursing staff. Our findings can be applied to common clinical practice in various PET centers, and skillful staff can evaluate the patient ADL level without having to measure the Barthel Index.

Conclusions

Lower Barthel Indexes (lower ADL) and lower MMSE scores of the patients (lower cognitive function) were independent risk factors for increased radiation exposure dose in nursing staff who assist patients with ^{18}F-FDG PET/CT examinations. However, patient age did not increase the occupational radiation exposure dose. To reduce the radiation exposure dose in nursing staff, extra attention should be given to the ADL status and cognitive function of patients who will receive examination assistance.

Conflict of interest: None.

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