THE FACTORS WHICH AFFECT THE EXTERNAL RADIATION DOSE RATE OF PET-CT PATIENTS

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Received November 27, 2012 / 1st Revised December 16, 2012 / Accepted for Publication December 17, 2012

This study derived measures to reduce exposure doses by identifying factors which affect the external radiation dose rate of patients treated with radiopharmaceuticals for PET-CT tests. The external radiation dose rates were measured on three parts of head, thorax and abdomen at a distance of 50cm from the surface of 60 PET-CT patients. It showed there are changes in factors affecting the external radiation dose rate over time after the administration of F-18 FDG. The external radiation dose rate was lower in the patients with more water intake than those with less water intake before the injection of radiopharmaceuticals at all three points: right after the injection of radiopharmaceuticals (average 4.17 mins), after the pre-PEET-CT urination step (average 77.47 mins), and right after the PET-CT test (average 114.15 mins). The study also found there is a need to increase the amount of water intake before the injection of radiopharmaceuticals in order to maintain a low external radiation dose rate in patients. This strategy is only possible under the assumption that the quality of the video has not changed after conducting this study on the relations between the image and quality. This study also found a need to use radiopharmaceuticals with the minimum amount needed for each patient because F-FDG doses affects the external radiation dose rate at the point right after the injection of radiopharmaceuticals. Urination frequency was the most significant factor to affect the external radiation dose rates at the point right after the PET-CT test and the point after the pre-PET-CT urination step. There is a need to realize the strategy to increase the urination frequency of patients to maintain the external radiation dose rate low (average 77.47 mins) before and after the injection of radiopharmaceuticals. In addition, at this point, there is a need to take advantage of personal strategies because the external radiation dose rate is lower if the fasting time is shorter, the contrast medium is used, and the amount of water intake is increased after the administration of radiopharmaceuticals. Finally this study found the need to be able to generalize these findings through an in-depth research on the factors affecting the external radiation dose rate, which includes radiopharmaceutical dose, urination frequency, the amount of water intake, fasting time and the use of contrast medium.

Key words: PET-CT, Patient, External radiation Dose rate, Influence factor

1. INTRODUCTION

The UNSCEAR 2000 report shows there are differences in exposures to radiation doses, up to 10 to 20 times, between medical institutions even though patients receive the same radiologic examination. Medical exposure to radiation is the largest source of exposure to artificial radiation [1]. PET-CT radiation exposure is second to only radiation therapy when it comes to exposing patients to radiological testing [2]. This has important implications to achieving optimization of medical exposures considering the total dose people receive from medical radiation is very high [3]. Multifaceted efforts are needed to reduce radiation exposure because there are no limitations to the total dose of medical exposure to individuals based on the principle of justification [4], according to ICRP.

The Nuclear Safety and Security Commission states in its regulations, patients who receive F-18 FDG for PET-CT should be quarantined to reduce the possibility of exposing other people in the case of exceeding 5 mSv due to the radioactive isotope treatment. It also states in its regulations guidelines to be followed while discharging patients to reduce the amount of radiation exposure to other people as low as reasonably achievable if there is a possibility that the effective dose exceeds 1 mSv [5]. These guidelines are needed to perform a variety of studies and to derive various measures to keep the radiation exposure by the use of PET-CT as low as reasonably achievable, in addition to these regulations.

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The development of PET-CT imaging equipment has contributed a lot in the advances of basic science and medical research by organically connecting studies [6]. In addition, the basic research has been designed to properly evaluate the performance of PET and CT by the American College of Radiology, the American Association of Physicist in Medicine and the European Nuclear Medicine. Proposals from these institutions have been steadily progressing and have studied to evaluate the regular performance and equipment installation of PET and PET-CT in Korea, together with the Korean Society of Nuclear Medicine center [7]. Results from the analysis of 65 domestic researches on PET-CT over the last 2 years shows that there are plenty of clinical studies related to diseases with 46 studies (70.7%), and 7 studies (10.7%) related to the standardized uptake values and SUV, and only a few studies related to other examination facilities or PET-CT equipment. Studies related to the reduction of radiation exposure are especially low with only about 5 studies, such as the radiopharmaceutical excretion characteristics, radiopharmaceutical optimal dose, PET-CT safety management guidelines, PET-CT exposure-related factors, etc. Therefore, this study aims to derive measures to reduce radiation exposure doses by identifying the factors which affect the external radiation dose rate of patients with radiopharmaceutical treatments.

2. MATERIALS AND METHODS

The external radiation dose rate was measured in 60 PET-CT patients in a University Hospital in the Yeongnam region for a period of 20 days starting on August, 11, 2011. The measurement tools used for the external radiation dose rate were the spatial dose rate meter, the RadEye G-10, and the energy compensation GM tube.

The meter is suitable for measurement of the external radiation dose rate of F-18 FDG because the measuring range of the meter was set from 0.05 μSv h^{-1} to 100 μ Sv/h, and the energy ranged from 50 keV to 1.3 MeV. In addition, the meter which is compact, easy to carry and shock-resistant was selected because measurement was carried out in real time. For the measurement method, it was measured in four points at a distance of 10 cm, 50 cm, 100 cm, 200 cm from the surface of the patients' bodies, and in three parts of head, thorax, and abdomen. For the analysis of the measured values, the measured values at the point of 50 cm were analyzed where the feature of the external dose rate is most obvious and the average values of the external radiation dose rate of each head, chest and abdomen were used for the analysis.

The measurement time of the external radiation dose rate was divided into three parts: right after the injection of radiopharmaceuticals(average 4.17±4.622 mins), after urination which is preparation step for PET-CT (average 77.47±17.740 mins), and right after the PET-CT test (average 114.15±18.461 mins).

The minimum dose of F-18 FDG was 8 mCi, the average was 11.89 mCi, and the maximum was 15 mCi according to the patients. In this hospital, injections were set to 13 mCi for average adults. The frequency, percentage, t-test, ANOVA, and regression analysis were used for the analysis of the measured values by using the SPSS statistical program.

3. RESULTS AND DISCUSSION

3.1. The Characteristics of the Subjects

The study consisted of 18 males (30%) and 42 females (70%) of whom 27 were in their 40's or younger (45%) and 33 were in their 50's (55%) or older; 29 (48.3%) measured under 160 cm, while 31 (51.7%) measured 160 cm or taller; 27 (45%) weighed less than 60 kg while 33 (55%) weighed 60 kg or heavier. In regards to obesity: 2 patients (3.3%) were underweight, 41 (68.3%) were average, 16 (26.7%) were overweight, and 1 (1.7%) was obese; 9 patients (15%) patients were diabetic while 51 (85%) were not diabetic. For the fasting times, 33 (55%) patients fasted under 10 hours while 27 (45%) fasted for 10 hours or longer. The amount of water intake prior to the injection of radiopharmaceuticals, 40 (66.7%) patients drank less than 250 ml while 20 (33.3%) drank 250 ml or more. The amount of water intake after the injection of radiopharmaceuticals, 20 (33.3%) patients drank some water while 40 (66.7%) did not drink any water. For the urination frequency immediately after the injection of radiopharmaceuticals before the PET-CT, 45 (75%) patients urinated once, 14 (23.3%) urinated twice, and 1 (1.7%) urinated three times or more. For the use of the contrast medium, 46 (76.7%) patients use it and 14 (23.3%) did not use it (Table 1).

3.2. The differences in the External Radiation Dose according to General Characteristics

The results of comparing the average of the external radiation dose rate has statistically significant differences in the body mass index and fasting times at the point right after the injection of radiopharmaceuticals (average 4.17 mins). The external radiation dose rate is high in the lower obesity group than in the higher obesity group. It may be concluded that the radiation penetration is higher for the lighter-weighting patients because this hospital injected the same amount of radiopharmaceuticals to adults according to the standards of the hospital. The results also showed that the external radiation dose is higher in the patients for the group who fasted less than 10 hours compared to the group who fasted 10 hours or longer.

Table 1. The Characteristics of the Subjects.

Items	Classification	n(%)
Gender	Male	18(30.0)
	Female	42(70.0)
	Total	60(100.0)
Age	In their 40's or younger	27(45.0)
	In their 50's or older	33(55.0)
	Total	60(100.0)
Height	160cm or shorter	29(48.3)
	160cm or taller	31(51.7)
	Total	60(100.0)
Weight	60kg or lighter	27(45.0)
	60kg or heavier	33(55.0)
	Total	60(100.0)
Body Mass Index(BMI)	Underweight	2(3.3)
	Average	41(68.3)
	Overweight	16(26.7)
	Obese	1(1.7)
	Total	60(100.0)
Diabetes	Yes	9(15.0)
	No	51(85.0)
	Total	60(100.0)
Fasting Time	10 hrs or less	33(55.0)
	10 hrs or More	27(45.0)
	Total	60(100.0)
Amount of Water Intake before the Injection of F-18 FDG	250ml or Less	40(66.7)
	250ml or More	20(33.3)
	Total	60(100.0)
Water intake after the Injection of F-18 FDG	Yes	20(33.3)
	No	40(66.7)
	Total	60(100.0)
Urination Frequency after the Injection of F-18 FDG	Once	45(75.0)
	Two Times	14(23.3)
	Three Times or More	1(1.7)
	Total	60(100.0)
Use of Contrast Medium	Yes	46(76.7)
	No	14(23.3)
	Total	60(100.0)

The results of comparing the average external radiation dose rate at the point after the urination (average 77.47 mins) which is a preparation step for the PET-CT test showed a statistically significant difference in the water intake before the injection of radiopharmaceuticals. The external radiation dose rate was higher in patients with water intake of less than 250 ml than those with of 250 ml or more. This is evidence to keep the external radiation dose rate low if water intake is increased prior to the injection of radiopharmaceuticals.

The results of comparing the average of the external radiation dose rate at the point right after the PET-CT test (average 114.15 mins) showed statistically significant differences in gender and water intake prior to the injection of radiopharmaceuticals. The external radiation dose rate is higher in the male patients than in female patients and in patients with water intake of less than 250ml than in patients with 250ml or more prior to the injection of radiopharmaceuticals (Table 2).

3.3. The Factors Affecting the External Radiation Dose Rate

The multiple linear regression analysis was done by taking the external radiation dose at three points: right after the injection of radiopharmaceuticals(average 4.17 mins), after the pre-PET-CT (average 77.47 mins) urination step, and right after PET-CT (average 114.15 mins) as the dependent variables, while age, height, weight, F-18 FDG administered does, fasting time, the amount of water intake before the injection of radiopharmaceuticals, the amount of water intake after injection of radiopharmaceuticals, the use of contrast medium, the urination frequency were taken as the independent variables.

As a result, the F-FDG dose and height in order affect the external radiation dose rate at the point of right after the injection of radiopharmaceuticals. A strategy of

Table 2. The Differences of the External Radiation Dose Rate According to the General Characteristics.

Classification	Item	Right after Injection of Radiopharmaceuticals (Average 4.17mins)		After the pre-PET-CT Urination Step (Average 77.47mins)		Right after PET-CT (Average 114.15 mins)	
		mean±sd (μSv/h)	t, F (p)	mean±sd (μSv/h)	t, F (p)	mean±sd (μSv/h)	t, F (p)
Gender	Male	106.26±23.244	0.637 (0.525)	61.06±18.983	1.465 (0.147)	48.37±12.702	2.022 (0.045)
	Female	103.79±24.125		56.80±14.970		44.54±11.158	
Age	40's or younger	102.17±19.728	-1.206 (0.230)	56.92±15.265	-0.860 (0.391)	45.18±9.651	-0.537 (0.592)
	50's or older	106.46±26.661		59.02±17.190		46.10±13.240	
Height	160cm or shorter	106.62±26.170	1.138 (0.257)	59.79±16.104	1.369 (0.173)	47.36±13.044	1.857 (0.065)
	160cm or taller	102.58±21.363		56.47±16.484		44.13±10.198	
Weight	60kg or lighter	104.23±23.997	-0.153 (0.879)	58.64±16.665	0.416 (0.678)	46.37±12.593	0.707 (0.480)
	60kg or heavier	104.78±23.805		57.62±16.142		45.13±11.025	
BMI	Underweight a	122.28±36.969	3.504 (0.017)	63.03±21.953	0.788 (0.502)	53.27±15.687	1.916 (0.129)
	Average a b	101.38±22.171		57.69±17.290		44.66±12.123	
	Overweight a b	111.18±24.808		59.16±13.154		47.74±10.018	
	Obese b	91.77±8.997		46.37±8.605		39.77±2.401	
BMI	Yes	111.17±27.764	1.577 0(.117)	58.92±20.399	0.290 (0.772)	46.38±16.329	0.250 (0.804)
	No	103.36±22.967		57.93±15.593		45.57±10.797	
Fasting time	Less than 10 hrs	108.47±23.974	2.486 (0.014)	59.28±16.760	1.093 (0.276)	46.54±11.979	1.075 (0.284)
	More than 10 hrs	99.72±22.881		56.60±15.791		44.65±11.428	
Amount of Water Intake before Injection of F-18 FDG	250ml or Less	108.95±24.918	3.994 (0.000)	60.82±15.597	3.277 (0.001)	47.65±10.552	3.249 (0.001)
	250ml or More	95.69±18.730		52.58±16.534		41.77±13.043	
Water Intake after Injection of F-18 FDG	Yes	106.13±26.632	0.634 (0.527)	58.85±18.761	0.449 (0.654)	45.37±15.012	-0.225 (0.822)
	No	103.73±22.368		57.69±15.057		45.85±9.771	
Urination Frequency	Once a	101.73±20.998	5.255 (0.006)	57.20±14.792	0.771 (0.464)	45.82±10.944	0.047 (0.954)
	Two Times a	111.39±29.286		60.69±20.962		45.36±14.464	
	Three Times or More b	134.33±28.919		60.83±4.827		44.27±3.656	
	Total	104.53±23.826		58.08±16.341		45.69±11.739	
Use of Contrast Medium	Yes	104.60±24.799	0.07 (0.944)	57.56±15.406	-0.768 (0.444)	45.56±11.118	-0.266 (0.791)
	No	104.30±20.579		59.77±19.207		46.11±13.726	

minimal use of radiopharmaceuticals is needed because the external radiation dose rate is high if radiopharmaceuticals are used in high doses in the early stage of treatment.

At the point after the pre-PET-CT urination step the external radiation dose rate was affected by the urination frequency, the fasting time, the use of contrast medium, and the amount of water intake after the injection of radiopharmaceuticals in this order. These ordered steps maintained a low level of external radiation dose rate (average 77.47 mins) before and after the injection of radiopharmaceuticals by increasing the frequency of urination and shortening the fasting time before the test. The use of the contrast medium also helped to lower the external radiation dose rate. In addition, the strategy to increase the amount of water intake after the injection of radiopharmaceuticals should be used to lower the external radiation dose rate.

At the point right after the PET-CT test, the external radiation dose rate was affected by urination frequency, the use of contrast medium, the radiopharmaceuticals dose, and fasting time in this order. It was helpful to induce urination in order to reduce the amount of the radiation exposure to other people when the patients have left the hospital after the test (Table 3).

4. CONCLUSION

This study identified the factors affecting the external radiation dose rate of PET-CT patients based on the time lines in order to derive grounds to reduce the external radiation dose rate in PET-CT patients. The factors affecting the external radiation dose rate are derived by classifying the personal variables which patients have essentially, which includes: gender, age, height, weight, body mass index, diabetes, and adjustable variables, which include: fasting time, the amount of water intake before and after the injection of radiopharmaceuticals, urination frequency after the injection of radiopharmaceuticals, and the use of contrast medium. There is a significantly greater chance of contributing to the reduction of the external radiation exposure at the adjustable variable level as there are lim-

Table 3. Factors Which Affect the External Radiation Dose Rate.

Classification	Right after Injection of Radiopharmaceuticals (Average 4.17mins)					After the Pre-PET-CT Urination Step (Average 77.47mins)					Right after PET-CT (Average 114.15mins)				
Model	Non-standardized Coefficients		Standardized coefficients	t	Significant Probability	Non-standardized Coefficients		Standardized coefficients	t	Significant Probability	Non-standardized Coefficients		Standardized coefficients	t	Significant Probability
	B	Standard Error	beta			B	Standard Error	beta			B	Standard Error	beta		
(a constant)	178.622	90.656		1.970	0.055	51.865	64.418		0.805	0.425	55.345	44.860		1.234	0.223
Age	-2.545	3.670	-0.092	-0.694	0.491	3.619	2.608	0.184	1.388	0.172	0.971	1.816	0.063	0.535	0.595
Height	-1.359	0.603	-0.291	-2.253	0.029	-0.022	0.429	-0.007	-0.051	0.960	-0.129	0.299	-0.050	-0.432	0.668
Weight	0.745	0.664	0.177	1.122	0.267	0.120	0.472	0.040	0.254	0.801	-0.353	0.329	-0.151	-1.075	0.288
F-FDG Usage	8.422	2.942	0.486	2.863	0.006	2.731	2.090	0.222	1.307	0.198	4.821	1.456	0.501	3.312	0.002
Fasting Time	-2.439	1.350	-0.318	-1.807	0.077	-3.403	0.959	-0.625	-3.547	0.001	-1.689	0.668	-0.396	-2.527	0.015
Amount of Water Intake before Injection of Radiopharmaceuticals	0.025	0.019	0.172	1.339	0.187	0.013	0.013	0.129	1.003	0.321	0.017	0.009	0.211	1.845	0.071
Amount of Water Intake after Injection of Radiopharmaceuticals	0.112	0.124	0.150	0.909	0.368	0.126	0.088	0.237	1.432	0.159	-0.007	0.061	-0.017	-0.114	0.910
Contrast Medium Usage	0.137	0.069	0.305	1.987	0.053	0.123	0.049	0.384	2.500	0.016	0.115	0.034	0.460	3.370	0.002
Urination Frequency	-2.859	7.652	-0.051	-0.374	0.710	-21.402	5.437	-0.541	-3.936	0.000	-16.944	3.787	-0.547	-4.475	0.000

ited chances on the personal variable level.

As a result, there are changes in the factors affecting the external radiation dose rate depending on the flow of time after the administration of F-18 FDG radiopharmaceuticals. There are changes in the external radiation dose rate depending on the body mass index but there are no statistically significant differences over time from the point immediately after the administration of radiopharmaceuticals. For gender, the external radiation dose rate is higher in men than women at the point immediately after PET-CT. In this regard, variables for strategic intervention are not possible because they are personal aspects which do not allow for intervention. However, when it comes to adjustable aspects, the external radiation dose rate is lower in patients with larger amounts of water intake before the injection of radiopharmaceuticals at all three points: right after the injection of radiopharmaceuticals (average 4.17 mins), after the urination which is the previous step of the PET-CT test (average 77.47 mins), and immediately after PET-CT test (average 114.15 mins). This indicates there is a need to increase the amount of water intake before the injection of radiopharmaceuticals in order to maintain a low external radiation dose rate in patients. This strategy is only possible under the assumption that the quality of the video has not changed after conducting the study on the relations between the image and quality.

As a result of regression analysis to identify the factors affecting the external radiation dose rate, it seems necessary to use the minimum amount of radiopharmaceuticals in a range that does not affect the test because the external radiation dose rate was higher if the radiopharmaceutical dose was higher at the point right after the injection of the radiopharmaceuticals. The result of random queries to each medical institution after this research showed that only some medical institutions determine the dose of radiopharmaceuticals considering the patients' body weight, and a large number of institutions inject the same amount for convenience. A strategy is needed to use radiopharmaceuticals with adjusted amounts needed for each patient to maintain a low external radiation dose rate in patients. Urination frequency was the most significant factor at the point immediately after the PET-CT test and the point after the pre-PET-CT urination step. There is a need to realize a strategy to increase urination frequency in patients to maintain a low external radiation

dose rate (average 77.47 mins) before and after the injection of radiopharmaceuticals. In addition, at this point, there is a need to take advantage of personal strategies because the external radiation dose rate is lower if the fasting time is shorter, the contrast medium is used, and the amount of water intake is higher after the administration of radiopharmaceuticals.

Although it is not possible to generalize these findings in this study because the target sample size is small, it is, however, necessary to be able to generalize the findings through an in-depth research on the factors affecting the external radiation dose rate, including radiopharmaceutical dose, urination frequency, the amount of water intake, fasting time and the use of contrast medium. In addition there is also a need to derive strategies to reduce the number of high exposure doses nationwide with various researches for reducing the amount of radiation exposure to the patients' guardians as well as to patients with the increasing use of PET-CT tests.

ACKNOWLEDGEMENTS

본 연구는 2011년도 교육과학기술부의 재원으로 한국연구재단의 지원을 받아 수행된 연구(원자력기반확충사업 중 인력양성분야, No. 2011-0021280)이며 대한방사선방어학회 제37권제2호의 PET-CT검사 환자의 외부 방사선량률 변화에 대한 연속선상의 분석이다.

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