Original Article

PET/CT 에서 표준섭취계수(SUV)의 신뢰성 확보를 위한 초기연구

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An Initial Study on the Reliability Assurance in PET/CT Standardized Uptake Values

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Purpose: As the number of domestic medical institutions installing PET/CT is increasing rapidly, the transfer of PET/CT images among medical institutions is also increasing. Thus, it is necessary to collect the comparative SUV data from several medical institutions' PET/CT systems through a phantom study which semi-quantitatively compares the SUV on one bed, the change scale of the SUV on the slices, and the time of measuring. The phantom study to find differences among the SUVs from various PET/CT offers the opportunity to obtain the reliability of the SUV in PET/CT images. **Materials and Methods:** Ten PET/CT systems from medical institutions in Korea were used. To obtain the accurate data, the study has been using the radiation detector of Korea Research Institute of Standards and Science to verify. The internal structures of NEMA PET phantom ™ were removed and Six thousand milliliters of distilled water which has 1mCi of ^{18}F-FDG put into the phantom. The water was properly integrated with ^{18}F-FDG using magnetic stirrer. The images were acquired at 60, 70, 80, 90, 100, 110 and 120-minutes for 3 minute each. Two hundred square centimeters of region of interests were placed and analyzed. To confirm the usefulness, the correction-table came out from patients' data. **Results:** The coefficient of variability of the SUV from -11.0 to 9.90 % fell into the range of international standards(±10%) along with the SUV on a bed, the change scale of the SUV on the slices, and the time of measuring, except one PET/CT system. Using the data of the differences among the SUVs, we came to withdraw the correction-table ranging from 0.803 to 1.246. The correction-table was confirmed its usefulness through Linear Regression Analysis which was applied to normal cases. **Conclusions:** Although studies have been made on the variation of the SUV, there is little attention on the standardization of the SUV. Based on this study of the quantitatively comparable data about the SUV accommodating the correction-table, it would help to have more corrective diagnosis. **(Korean J Nucl Med Technol 2009;13(3):31-42)**

Key Words: Nuclear medicine image, PET/CT, Quantization, Standardized uptake value

INTRODUCTION

Positron emission tomography (PET) is a nuclear medicine imaging technique which produces a three-dimensional image or picture of functional processes in the body. The system detects pairs of gamma rays which has 511 KeV as the energy emitted indirectly on the 180 degrees by a positron-emitting radionuclide.PET scans are increasingly read alongside CT scan,

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the combination could give both anatomic and metabolic information. The demand of PET/CT is increasing.[1,5] Modern PET scanners are now available with reduced scan time by the extending the field of view. It is possible to increase the accuracy of image reconstruction with shortened resolving time, measuring the both of flying time of gamma ray. Besides, PET/CT combined with independent PET and CT systems. CT was scanned ahead of then PET scan, with the patient not changing position between both scans. Two sets of images are more-precisely registered, so that areas of abnormality on the PET imaging can be more perfectly correlated with anatomy on the CT images. CT images also could give correct data to PET images[6,8]. Therefore, these facts are useful in showing detailed views of abnormal uptake on the region so that it could increase the diagnosability and could assess the correct location of the region. For this reason, PET/CT provides with superior information for determining tissue characterizations and classifications, staging of cancers, restaging of cancers, diagnosis of recurrence, detection of remote metastasis and lymphogenous metastasis, patient prognosis and monitoring the effectiveness of cancer therapies. For this feasibility, PET/CT has spread recently. There are many medical institutes which have several PET/CT systems. It is necessary to carry out proper performance assessment and quality control on PET/CT systems.

Therefore, the opinion comparing PET/CT images between medical institutes or between the systems was presented.[9-11]. There are many approaches to confirm the stage of cancer and determining tissue characterizations using in ^{18}F-FDG. Standardized uptake value which is calculated as a ratio of tissue radioactivity concentration at time, and injected dose at the time of injection divided by body weight, SUV is a widely used as a simple PET quantifier. Difference of SUV between the PET/CT systems is important factor but in the case of comparison, it depends on interpreters' individual experience. Therefore, it would be necessary to have the reliability of SUV between PET/CT images for correct and objective comparison.

The difference between SUVs from PET/CT systems were taken through the phantom study. The correction-table of SUV providing accurate SUV values were calculated from the data of several PET/CT systems. The phantom study to find differences among the SUVs from various PET/CT systems offers the opportunity to obtain the reliability of the SUV in PET/CT images.

MATERIALS AND METHODS

1. PET/CT systems for measuring the Standardized Uptake Values

Ten PET/CT systems from medical institutions in Korea were used {2 Discovery STE (General Electric Healthcare, Wisconsin, MI, USA), 1 Discovery ST (General Electric Healthcare, Wisconsin, MI, USA), 1 Biograph Truepoint 40 (Siemens Medical Systems, CTI, Konxville, TN, USA), 2 Biograph Duo (Siemens Medical Systems, CTI, Konxville, TN, USA), 1 Gemini GXL 6 (Philips Medical System, Cleveland, OH, USA), 2 Gemini 16 (Philips Medical System, Cleveland, OH, USA), and 1 Gemini 2 (Philips Medical System, Cleveland, OH, USA)}.

2. Relative measurement of Dose Calibrator using ^{18}F-FDG

For an accurate calculation from the radiation of ^{18}F-FDG which goes into Phantom, we compared the Dose Calibrators normally used for PET/CT systems were compared by measuring the accuracy and precision, and corrected the radiation. ^{18}F-FDG was produced from the Cyclotron HM-18 (Sumitomo Heavy industries, Ltd. Tokyo, Japan). The double-coincidence counting rate and triple-counting rate were measured with TDCR detector in Korea Research Institute of Standards and Science with priority given to a vial. Radiation per mass unit of ^{18}F-FDG was 20.11 MBq/g (2008 September 2, 12:00:00, uncertainty of measurement±2 %). The Dose Calibrators placed in different institutes were measured with following certain time intervals over 4 times between 12 a.m. and 5 p.m. in 2008 September 2nd. We designated the Korea Research Institute of Standards which has traceability of national standards as the radiation measurement institute to compare the dose of radiation from each hospital. The accuracy and precision were calculated. The reliability assured by correcting an amount of

radiation of phantom, and by using the accuracy.

3. Phantom for measurement of SUV in PET/CT

NEMA PET Phantom™(NU2-1994) was used (Table 1). One mCi of ^{18}F-FDG diluted with distilled water over 10 minutes in beaker on the magnetic stirrer. To put accurate amount of radiopharmaceutical to the phantom, a measuring flask were used and a funnel and syringes used for remove the air from the phantom.

4. The resent valuation basis of SUV

One or three mCi of ^{18}F-FDG diluted with distilled water put in NEMA PET Phantom™ (NU2-1994) or phantom each manufacturer provided. One or two bed image data were acquired. If the results were within ±10%, it was considered as an 'acceptable'.

$$\text{Standardized Uptake Value (SUV)} = \frac{\text{Measured dose(Bq)/Weight of Region of Interest (g)}}{\text{Injected dose(Bq)/ Weight of Phantom containing radiopharmaceutical solution(g)}} \times 100$$

The image reconstruction data was used in 30% from the center of 1 bed image. This area would be a 'Weight of Region of Interest (g)'. To have SUV, 'Measured dose (Bq)', 'Injected dose (Bq)', and 'Weight of Phantom containing radiopharmaceutical solution (g)' were calculated with 'Weight of Region of Interest (g)' (Fig. 2).

In the case of radiological monitoring, Region of Interest (expressed as Becquerel per milliliter) was drawn over 70% from the center of the image (Fig. 1). The reduction of radiation level was considered because the injected dose did radioactive decay.

$$\text{Coefficient of Variation} = e^{-\frac{0.693}{109.8}\times t}$$

t: delayed time (sec)

Predicted Dose was considered by multiplying the Injected Dose by Coefficient of Variation. Predicted Dose per milliliter was considered by the fluid volume of the Phantom.

$$\text{Predicted Dose/mL} = e^{-\frac{0.693}{109.8}\times t} \times \frac{Injeted\ Dose}{The\ Solution\ Volume\ of\ the}$$

SUV was from Measured Dose per gram was divided by Predicted Dose per milliliter.

$$\text{SUV} = \frac{\text{Measured Dose per gram}}{\text{Predicted Dose per milliliter}}$$

5. The deduction process of Measured Dose

The emission of the radiation was monitored on ROI that was drawn over 70% from the center of the image. SUV mean, SUV max and SUV standard deviation were measured (Fig. 1, 2).

6. Measurement of the reproducibility of SUV

The images were acquired at 60, 70, 80, 90, 100, 110 and

Table 1. Specifications of NEMA PET PhantomTM (NU2–1994)

Photograph	Specifications
	Cylinder outside diameter: 20.3 cm Cylinder insider diameter: 19.7 cm Wall thickness: 3 mm Delrin Insert diameter: 5 cm Fillable Insert inside diameter: 4.3 cm Fillable Insert height: 18.3 cm Fillable Insert volume:~260 mL Line Source diameter:~1 mm Line Source height: 1.4 cm

Fig. 1. Region of Interest was drawn over 70% from the center of the image, SUV mean and SUV max were measured on ROI.

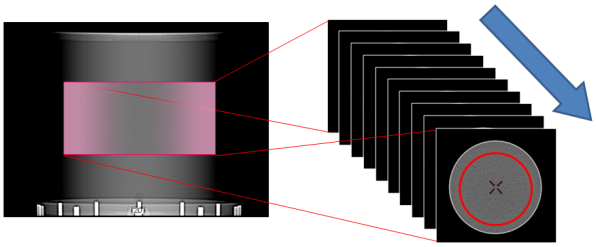


Fig. 2. Thirty percent from the central among the reconstructed image data in 1 bed acquisition set as 'Valid Image Range' and measured SUV.

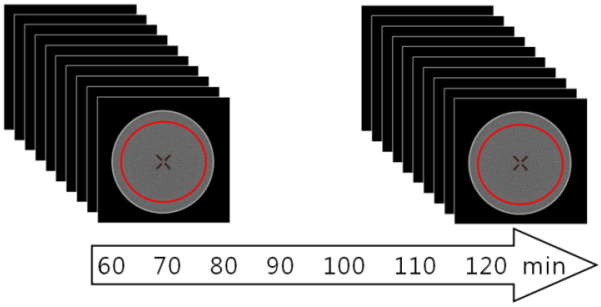


Fig. 3. To check the repeatability, the images were acquired at 60, 70, 80, 90, 100, 110 and 120-minutes. SUV were measured.

120-minutes from the beginning of the injection. Region of Interest was drawn over 70% from the center of the image, and 30% from the center among the reconstructed images in 1 bed acquisition. SUV mean, SUV max and standard deviation were measured and confirmed the reproducibility (Fig. 3).

7. SUV Correction-Table

BQML (Becquerel/milliliter) was used as pixel value units from GE Healthcare PET/CT and SIEMENS PET/CT systems. CNTS (counts) was used as pixel value units from PHILIPS PET/CT. Because of different units, the special correction-table was made for PHILIPS systems.

8. Confirmation of usefulness of SUV Correction-Table through clinical application

Thirty eight patients who do not have diabetes underwent the examination from September 2007 to October 2008 (male: 17, female: 21, Age: 18~77, mean age: 52.5). Whole patients fasted for 6 or 8 hours. SUV was measured after the whole body scan by drawing the circle ROIs at both lungs and liver. The size of ROIs was 1000 mm^2 and 2000 mm^2. The maximum and minimum SUV were measured.

The usefulness was confirmed as comparing between the correction-table of SUV differences and the correction-table of phantom SUV drawing in both lung and 3 areas of the liver. In terms of having the statistical confidence level of usefulness, a coefficient of correlation was taken through a linear regression analysis (Fig. 4).

RESULTS

1. Comparison of Dose Calibrator using ^{18}F-FDG

The dose calibrators were measured over 4 times at regular intervals on September 2nd 2008, between 12 PM and 5 PM. The accuracy of resuLt.of comparing data was in -5% to +4.5% (Table 2).

$$A_i = \frac{\overline{H}_i - H_i}{H_i} \times 100(\%)$$

Ai: Accuracy Percentage, Hi-: Measured Dose, Hi: Standard

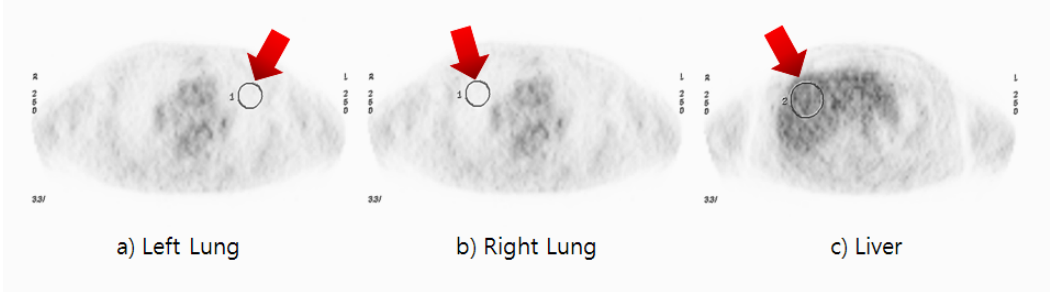


Fig. 4. SUV was measured after the whole body scan by drawing the circle ROIs at the left and right of lung, and liver. The size of ROIs was 1000 mm2 and 2000 mm2. The maximum and minimum SUV were measured.

Table 2. Comparison of Dose Calibrators; using F-18 FDG

No	Manufacturing Company (Model)	Dose Calibrator	2008.09.03 09:00:00 (kBq) KRISS	Medical Institute 2008.09.02 Time	Measured Dose (kBq)	2008.09.03 09:00:00 (kBq) Converted Dose	Accuracy (%)	Precision (%)	recovery coefficient
1	GE (Discovery STE)	CRC-15 PET	29.410	11:51	84,360	27.869	-5.00	0.35	1.0527
				11:51	84,360	27.869			
				11:51	84,360	27.869			
				11:52	84,360	28.045			
				11:52	84,360	28.045			
2	GE (Discovery STE)	CRC-15 PET	28.921	14:03	37,703	28.671	-0.91	0.05	1.0092
				14:04	37,444	28.655			
				14:05	37,185	28.637			
				14:06	37,000	28.675			
				14:07	36,741	28.655			
3	GE (DiscoveryST)	CRC-71 2MH	29.236	16:53	13,764	30.630	+4.50	0.17	0.9569
				16:54	13,616	30.493			
				16:55	13,542	30.519			
				16:56	13,468	30.545			
				16:57	13,394	30.569			
4	SIEMENS (Biograph TruePoint 40)	CRC-15 PET	29.410	11:51	84,360	27.869	-5.00	0.35	1.0527
				11:51	84,360	27.869			
				11:51	84,360	27.869			
				11:52	84,360	28.045			
				11:52	84,360	28.045			
5	SIEMENS (Biograph Duo)	CRC-15 PET	28.851	15:05	25,419	28.596	-1.01	0.13	1.0102
				15:10	24,568	28.525			
				15:15	23,828	28.554			
				15:20	23,125	28.601			
				15:25	22,348	28.526			
6	SIEMENS (Biograph Duo)	CRC-15 PET	28.641	14:52	27,158	28.144	-1.87	0.13	1.0191
				14:53	26,973	28.129			
				14:54	26,751	28.074			
				14:55	26,566	28.057			
				14:56	26,455	28.117			
7	PHILIPS (GEMINI GXL6)	CRC-15 PET	29.061	15:18	23,384	28.558	-1.89	0.31	1.0193
				15:19	23,236	28.377			
				15:20	23,088	28.555			
				15:21	22,940	28.552			
8	PHILIPS (GEMINI16)	CRC-15 PET	29.061	13:31	46,731	29.033	+0.26	0.20	0.9974
				13:32	46,620	29.148			
				13:33	46,361	29.170			
				13:34	46,065	29.167			
				13:35	45,769	29.163			
9	PHILIPS (GEMINI16)	CRC-15 PET	28.711	14:46	27,750	27.688	-3.81	0.40	1.0396
				14:59	25,530	27.653			
				15:32	20,720	27.644			
				15:49	18,500	27.480			
10	PHILIPS (GEMINI2)	CRC-15 Beta	29.410	11:57	85,470	29.326	-0.21	0.11	1.0021
				11:57	85,470	29.326			
				11:57	85,470	29.326			
				11:58	85,100	29.384			
				11:58	85,100	29.384			

Radiation

$$\overline{A} = (1/n)\sum_{i=1}^{n} A_i$$

A- : Accuracy Percentage

A correction constant which was calculated from the results of comparison data was from 0.9569 to 1.0527.

$$\text{Correction constant} = \frac{1}{1 + \text{Average Accuracy}}$$

If the accuracy value was a negative number, it means the measured radiation was underestimated than the actual radiation. On the contrary, if the accuracy value was a positive number, it means the measured radiation was overestimated than the actual radiation.

Precision was calculated from RMSE (Root Mean Square Error).

$$P = \left[\sum_{i=1}^{n} (A_i - \overline{A})^2/(n-1)\right]^{1/2}$$

Percent Precision calculation as follows:

$$\text{Percent Precision} = \frac{P}{\bar{A}} \times 100\ (\%)$$

In the results of the measurement of 9 Dose calibrators, 6 were less than 2% and 3 were more than 5%. The largest fluctuation of the numerical value was 9% (-5% and +4.5%) (Fig. 5).

2. Comparison of SUV using Circle Phantom

Region of Interest was drawn on valid area from the center of the image. SUV_{mean} and SUV_{max} were measured on ROI. Thirty percent from the central among the reconstructed image data in 1 bed acquisition set as 'Valid Image Range' and measured SUV. Because of different unit systems, BQML (Becquerels/milliliter) and CNTS(counts/pixel) were shown, followed by each PET/CT systems.

1) GE Discovery STe (Year Installed: 2006, G1), GE Discovery STe(Year Installed: 2007, G2), GE Discovery ST (Year Installed: 2004, G3), SIEMENS Biograph TruePoint 40 (Year Installed: 2007, S1), SIEMENS Biograph Duo (Year Installed: 2006, S2), and SIEMENS Biograph Duo (Year Installed: 2004, S3) are using BQML(Becquerels/milliliter) unit as a Pixel value units.

In 60 minutes delayed images, The averages and standard deviations of G1, G2, G3, S1, S2, and S3 about SUV_{mean} of ROI in one slice of the image and SUV_{mean} of the valid area in one bed image are 0.934±0.072, 1.045±0.091, 1.065±0.185, 0.951±0.046, 1.098±0.079, and 0.884±0.059, respectively (Fig. 6).

In 60 minutes delayed images, the averages and standard deviations of G1, G2, G3, S1, S2, and S3 about SUV_{max} of ROI in one slice of the image and SUV_{max} of the valid area in one bed image are 1.210±0.048, 1.409±0.064, 1.780±0.099, 1.115±

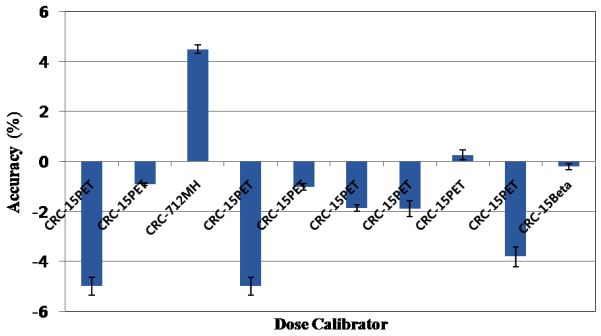


Fig. 5. The results of the comparison of Dose Calibrators using ^{18}F-FDG.

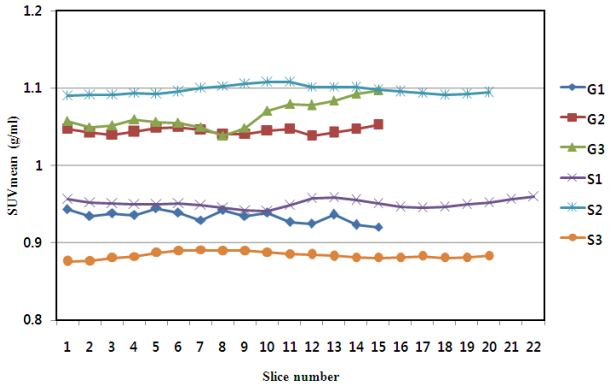


Fig. 6. SUV_{mean} of each slice in one bed images (BQML, 60 minutes delayed images).

0.020, 1.372±0.049, and 1.098±0.02, respectively (Fig. 7).

The SUV Coefficient of Variability(%) which shows the proportions of SUV_{mean} and standard deviations of G1, G2, G3, S1, S2, and S3 are 8.078%, 9.092%, 18.121%, 5.124%, 7.4787%, and 6.904%, respectively (Fig. 8).

2) PHILIPS GEMINI GXL 6(Year Installed: 2007, P1), PHILIPS GEMINI 16(Year Installed: 2006, P2), PHILIPS GEMINI 16(Year Installed: 2003, P3), PHILIPS GEMINI 2(Year Installed: 2003, P4) are using CTNS (counts/pixel) unit as a Pixel value units. In 60 minutes delayed images, the averages and standard deviations of P1, P2, P3, and P4 about the average kilo counts per pixel of ROI in one slice of the image and the average kilo counts per pixel of the valid area in one bed images are 4.171±0.062, 2.014±0.060, 1.829±0.022, and 1.961±0.010, respectively (Fig. 9).

In 60 minutes delayed images, the averages and standard deviations of P1, P2, P3, and P4 about the maximum kilo counts per pixel of ROI in one slice of the image and the maximum kilo counts per pixel of the valid area in one bed images are 4.171±0.062, 2.014±0.060, 1.829±0.022, and 1.961±0.010, respectively (Fig. 10).

The Counts Coefficient of Variability(%) which shows the proportions of Kilo Counts per Pixel mean and standard deviations of P1, P2, P3, and P4 are 8.935%, 9.748%, 10.264%, and 9.780%, respectively (Fig. 11).

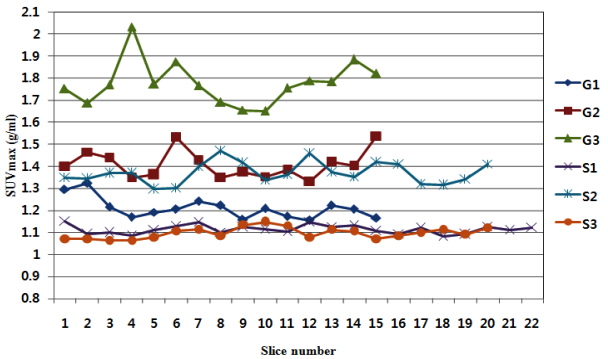


Fig. 7. SUV_{max} of each slice in one bed images (BQML).

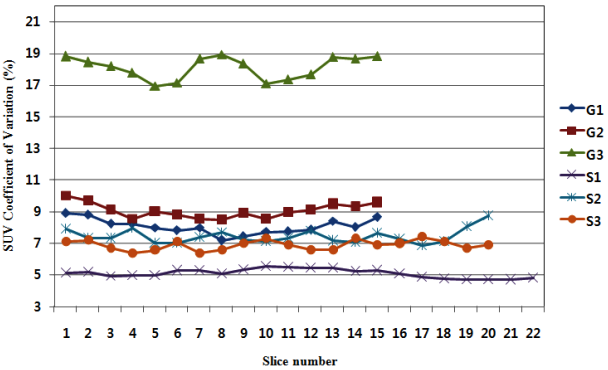


Fig. 8. SUV Coefficient of Variability of each slice in one bed images (BQML).

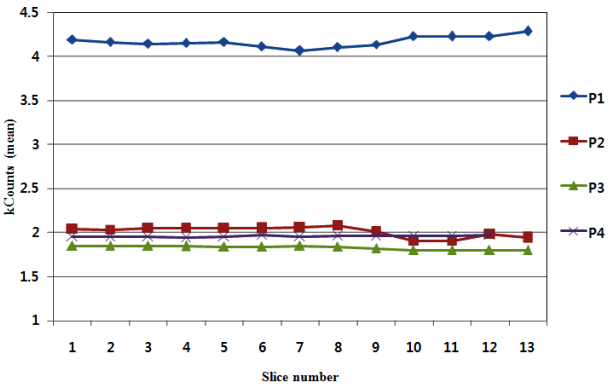


Fig. 9. The average kilo counts mean in one bed images (CNTS).

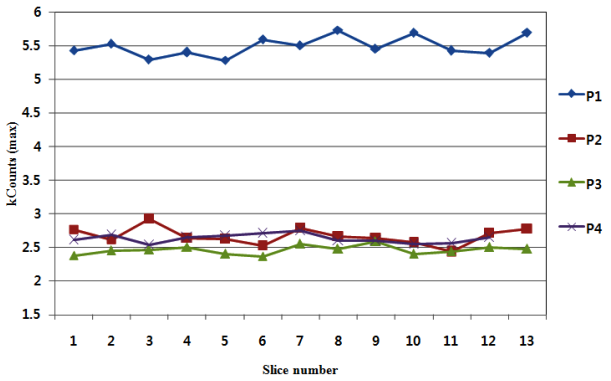


Fig. 10. The maximum kilo counts mean in one bed images (CNTS).

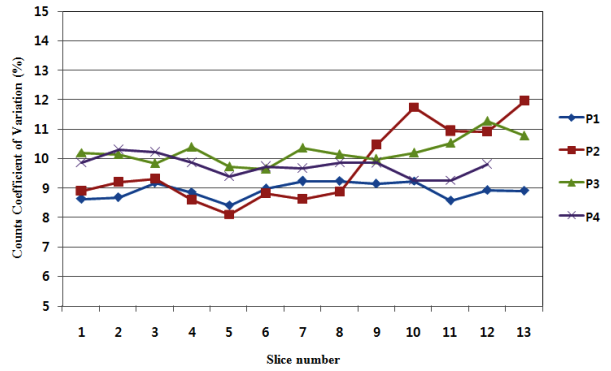


Fig. 11. Kilo Counts Coefficient of Variability in one bed images (CNTS).

Table 3. Repeatability of SUV_{mean}

PET/CT	60 min	70 min	80 min	90 min	100 min	110 min	120 min
G1	0.934	0.930	0.931	0.933	0.931	0.932	0.929
G2	1.045	1.047	1.043	1.044	1.047	1.047	1.047
G3	1.065	1.062	1.058	1.061	1.061	1.062	1.057
S1	0.951	0.947	0.944	0.945	0.942	0.946	0.947
S2	1.098	1.099	1.100	1.101	1.100	1.103	1.102
S3	0.884	0.880	0.882	0.880	0.880	0.885	0.878

Table 4. Repeatability of SUV_{max}

PET/CT	60 min	70 min	80 min	90 min	100 min	110 min	120 min
G1	1.210	1.209	1.208	1.215	1.237	1.260	1.242
G2	1.409	1.425	1.432	1.428	1.479	1.483	1.515
G3	1.780	1.817	1.854	1.876	1.888	1.837	1.909
S1	1.115	1.112	1.115	1.134	1.144	1.135	1.134
S2	1.372	1.393	1.406	1.413	1.424	1.434	1.487
S3	1.098	1.090	1.101	1.124	1.141	1.151	1.139

3. Repeatability of SUV mean

On the Region of Interest of images acquired at 60, 70, 80, 90, 100, 110 and 120-minutes from the beginning of the injection, Coefficient of Variability of Repeatability of SUV mean for G1, G2, G3, S1, S2, and S3 are 0.19%, 0.18%, 0.24%, 0.30%, 0.16%, and 0.27%, respectively (Table 3.).

On the Region of Interest of images acquired at 60, 70, 80, 90, 100, 110 and 120-minutes from the beginning of the injection, Coefficient of Variability of Repeatability of SUV max for G1, G2, G3, S1, S2, and S3 are 0.19%, 0.18%, 0.24%, 0.30%, 0.16%, and 0.27%, respectively (Table 4.).

4. Calculating SUV Correction–Table

In 6 PET/CT systems using BQML (Becquerels/milliliter) unit as a Pixel Value Units. The measured SUV from the averaged 60 and 70 minutes delayed image data for G1, G2, G3, S1, S2, and S3 are 0.932, 1.046, 1.063, 0.949, 1.099, and 0.882, respectively. The differences from the measured SUV and the predicted SUV for 1, 2, 3, 4, 5, and 6 are -6.80%, +4.60%, +6.30%, -5.10%, +9.90%, and -11.80%, respectively (Table 5.).

$$\text{Difference of SUVsystem (\%)} = \frac{\text{SUVmeasured}-1}{1} \times 100\ (\%)$$

Table 5. SUVsystem and the differences from SUVmeasured and SUVpredicted

PET/CT	SUVmeasured	SUVpredicted	Difference of SUVsystem (%)
G1	0.932	1.209	-6.80
G2	1.046	1.417	4.60
G3	1.063	1.798	6.30
S1	0.949	1.114	-5.10
S2	1.099	1.383	9.90
S3	0.882	1.094	-11.80

If the Difference of SUVsystem (%) is negative number, it means that SUVmeasured was underestimated than the calculated true SUV from the actual radiation. On the contrary, if the Difference of SUVsystem (%) if the accuracy value was a positive number, it means that SUVmeasured was overestimated than the calculated true SUV from the actual radiation. The correction constant of the different PET/CT systems were calculated from the numerical data of PET/CT system. The correction constant of SUVsystem-mean was obtained from the calculation of the ratio of both SUVpre-transfer of G1, G2, G3, S1, S2, and S3, and SUVpost-transfer of G1, G2, G3, S1, S2, and S3 (Table 6).

$$\text{The correction constant of SUVsystem-mean} = \frac{\text{SUVpre-transfer-mean}}{\text{SUVpost-transfer-mean}}$$

Table 6. The correction-table of SUVsystem-mean (BQML)

pre-transfer \ post-transfer	G1	G2	G3	S1	S2	S3
G1	1.000	1.122	1.141	1.018	1.179	0.946
G2	0.891	1.000	1.016	0.907	1.051	0.843
G3	0.877	0.984	1.000	0.893	1.034	0.830
S1	0.982	1.102	1.120	1.000	1.158	0.929
S2	0.848	0.952	0.967	0.864	1.000	0.803
S3	1.057	1.186	1.205	1.076	1.246	1.000

Table 7. Clinical data of SUV

			G1	S1	S2	S3
Person			9 (Male 5, Female 4)	10 (Male 3, Female 7)	10 (Male 5, Female 5)	9 (Male 4, Female 5)
Age(Year)			58.4±10.1	46.3±15.3	56.8±7.0	48.6±8.4
Weight(kg)			60.1±9.5	57.7±12.3	64.1±9.8	59.7±7.8
Left Lung	SUV mean	All	0.389±0.127	0.378±0.120	0.450±0.071	0.344±0.053
		Male	0.400±0.141	0.333±0.103	0.450±0.084	0.350±0.058
		Female	0.367±0.115	0.467±0.115	0.450±0.058	0.340±0.055
	SUV max	All	0.633±0.206	0.556±0.151	0.680±0.114	0.511±0.105
		Male	0.667±0.242	0.517±0.147	0.700±0.141	0.475±0.096
		Female	0.567±0.115	0.663±0.153	0.650±0.058	0.540±0.114
Right Lung	SUV mean	All	0.367±0.112	0.322±0.067	0.450±0.071	0.333±0.050
		Male	0.383±0.133	0.317±0.075	0.450±0.084	0.325±0.050
		Female	0.333±0.058	0.333±0.058	0.450±0.058	0.340±0.055
	SUV max	All	0.522±0.156	0.478±0.109	0.650±0.127	0.433±0.071
		Male	0.550±0.187	0.467±0.121	0.683±0.147	0.450±0.058
		Female	0.467±0.058	0.500±0.100	0.600±0.082	0.420±0.084
Liver	SUV mean	All	2.133±0.332	2.178±0.499	2.350±0.172	1.778±0.164
		Male	2.100±0.329	2.200±0.544	2.350±0.187	1.725±0.050
		Female	2.200±0.400	2.133±0.503	2.350±0.173	1.820±0.217
	SUV max	All	2.878±0.406	2.667±0.534	2.930±0.279	2.333±0.250
		Male	2.750±0.288	2.683±0.578	3.017±0.264	2.400±0.183
		Female	3.133±0.511	2.633±2.633	2.800±0.283	2.280±0.303

5. Confirmation of the clinical application using the correction-table

The SUVsystem-mean and SUV_{max} were calculated from the different PET/CT systems of G1, G2, G3, S1, S2, and S3 (Table 7).

The correction constant of Clinical SUVsystem-mean from the different PET/CT systems was calculated from SUVpre-transfer of G1, G2, G3, S1, S2, and S3, and SUVpost-transfer of G1, S1, S2, and S3 (Table 8.).

$$\text{The correction constant of Clinical SUVsystem-mean} = \frac{\text{SUVpre-transfer-mean}}{\text{SUVpost-transfer-mean}}$$

Table 8. Correction-table of Clinical SUVmean

	SUV_{mean}	G1	S1	S2	S3
G1	Phantom	1.000	1.018	1.179	0.946
	Lt.Lung	1.000	0.972	1.157	0.884
	Rt. Lung	1.000	0.877	1.226	0.907
	Liver	1.000	1.021	1.102	0.834
S1	Phantom	0.982	1.000	1.158	0.929
	Lt.Lung	1.029	1.000	1.190	0.910
	Rt. Lung	1.140	1.000	1.398	1.034
	Liver	0.979	1.000	1.079	0.816
S2	Phantom	0.848	0.864	1.000	0.803
	Lt.Lung	0.864	0.840	1.000	0.764
	Rt. Lung	0.816	0.716	1.000	0.740
	Liver	0.908	0.927	1.000	0.757
S3	Phantom	1.057	1.076	1.246	1.000
	Lt.Lung	1.131	1.099	1.308	1.000
	Rt. Lung	1.102	0.967	1.351	1.000
	Liver	1.200	1.225	1.322	1.000

Table 9. Correction-table of Clinical SUVmax

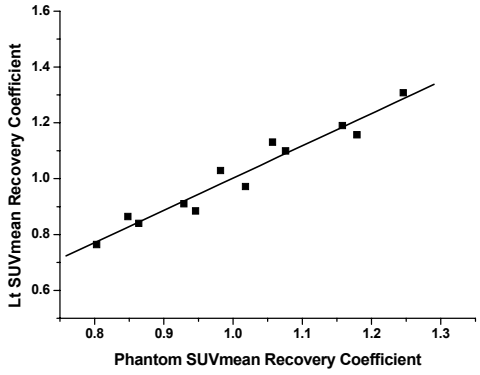
	SUV_{max}	G1	S1	S2	S3
G1	Phantom	1.000	0.921	1.144	0.905
	Lt.Lung	1.000	0.878	1.074	0.807
	Rt. Lung	1.000	0.916	1.245	0.830
	Liver	1.000	0.927	1.018	0.811
S1	Phantom	1.085	1.000	1.241	0.982
	Lt.Lung	1.138	1.000	1.223	0.919
	Rt. Lung	1.092	1.000	1.360	0.906
	Liver	1.079	1.000	1.099	0.875
S2	Phantom	0.874	0.805	1.000	0.791
	Lt.Lung	0.931	0.818	1.000	0.751
	Rt. Lung	0.803	0.735	1.000	0.666
	Liver	0.982	0.910	1.000	0.796
S3	Phantom	1.105	1.018	1.264	1.000
	Lt.Lung	1.239	1.088	1.331	1.000
	Rt. Lung	1.206	1.104	1.501	1.000
	Liver	1.234	1.143	1.256	1.000

The correction constant of Clinical SUVsystem-max from the different PET/CT systems was calculated from SUVpre-transfer of G1, G2, G3, S1, S2, and S3, and SUVpost-transfer of G1, S1, S2, and S3(Table 9.).

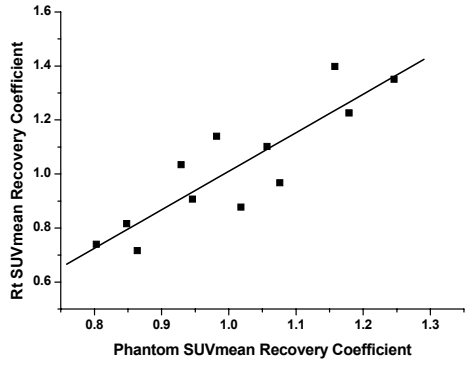
$$\text{The correction constant of SUVsystem-max} = \frac{\text{SUVpre-transfer-max}}{\text{SUVpost-transfer-max}}$$

The correlation coefficient from the linear regression analysis which was compared the correction-table of the difference of SUVtotal-mean from PET/CT systems in the region of both lung and liver with the correction-table of SUV_{mean} of the phantom were 0.97184 (p<0.0001), 0.87981 (p=1.60898E-4), 0.85245 (p=4.27671E-4), 0.88938 (p<0.0001), respectively (Fig. 12).

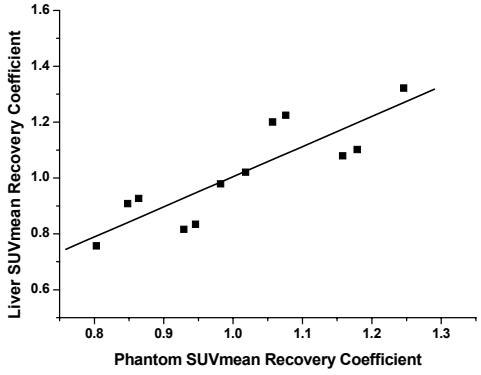
The correlation coefficient from the linear regression analysis which was compared the correction-table of the difference of SUVtotal-max from PET/CT systems in the region of both lung and liver with the correction-table of SUV_{max} of the



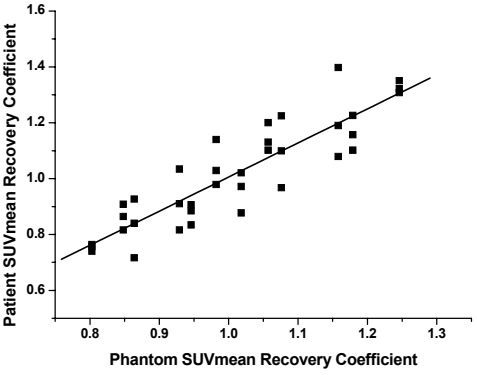
a) Correlation between Phantom SUV_{mean} and Left lung SUV_{mean}



b) Correlation between Phantom SUV_{mean} and Right lung SUV_{mean}

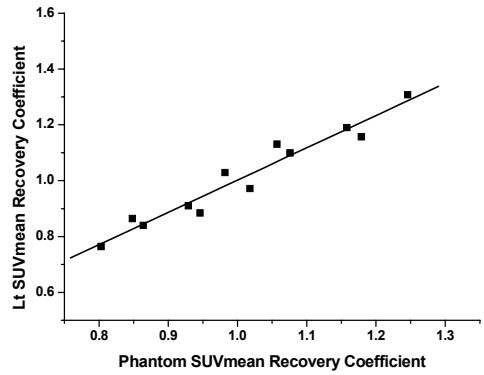


c) Correlation between Phantom SUV_{mean} and Liver SUV_{mean}

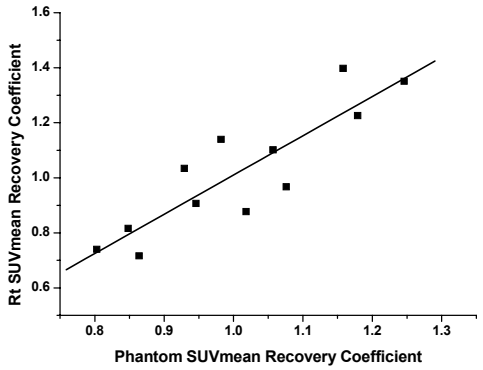


d) Correlation between Phantom SUV_{mean} and Patient SUV_{mean}

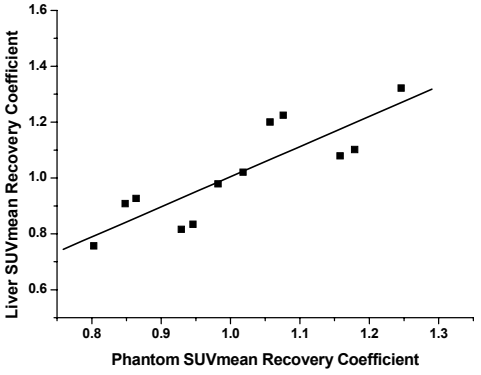
Fig. 12. The correlation between the Phantom and Clinical SUV_{mean}



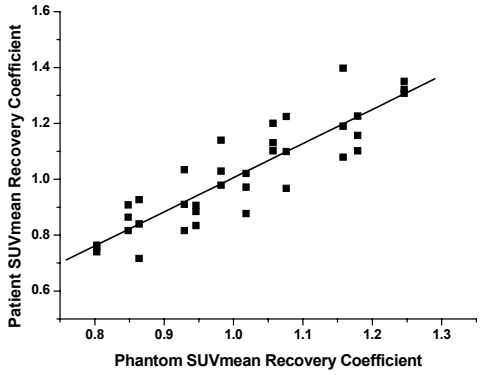
a) Correlation between Phantom SUV_{max} and Left lung SUV_{max}



b) Correlation between Phantom SUV_{max} and Right lung SUV_{max}



c) Correlation between Phantom SUV_{max} and Liver SUV_{max}



d) Correlation between Phantom SUV_{max} and Patient SUV_{max}

Fig. 13. The correlation between the Phantom and Clinical SUV_{max}.

phantom were 0.93458 (p<0.0001), 0.98488 (p<0.0001), 0.79443 (p=0.00202), 0.89832 (p<0.0001), respectively (Fig. 13).

CONCLUSIONS

The accuracy and precision of Dose Calibrators were obtained and corrected to have quantitative analysis and to calculate the accurate level of radiation. The usefulness was confirmed as the correction-table about the differences of SUV of PET/CT systems applied for clinical data. Through this study, the quantitative basis was presented by using the correction-table in terms of distinguishes to Fig. out the differences of SUV, not for the clinical doctor. This could be the bottom support for not only the accurate diagnosis but also having international standard.

요 약

최근 PET/CT가 급격하게 증가하면서 의료기관 사이에 영상의 이동도 증가하고 있다. 이에 서로 다른 의료기관 간의 시스템 별 표준섭취계수 차이를 반영하기 위하여 1 Bed에서 표준섭취계수, 슬라이스 내의 표준섭취계수 변화율과 측정시간에 따른 표준섭취계수를 정량적으로 비교할 수 있는 팬텀을 이용한 비교측정이 필요하다. 본 연구에서는 임상에서 사용하는 다양한 PET/CT 시스템의 표준섭취계수 차이에 대한 연구를 통하여, PET/CT 영상의 표준화섭취계수의 신뢰성을 확보하고자 하였다. 대한민국 전국에 분포되어 의료기관에 설치된 PET/CT 장비 10대를 대상으로 하였으므로, 정확한 방사능 산출을 위하여, 한국표준과학원의 검출기로 검증을 통하여 실험하였다. NEMA PET Phantom^{TM}의 내부구조물을 제거하고 ^{18}F-FDG 1 mCi를 6,000 mL 증류수에 균일하고 분포하도록 마그네틱 스터러와 마그네틱 바의 회전력으로 희석하여, 팬텀에 주입하였다. 주입 후 60분, 70분, 80분, 90분, 100분, 110분, 120분에 3분간 영상을 획득하고, 관심영역 200 cm^2에 대하여 분석하였으며, 유용성 확인을 위하여 임상환자

를 대상으로 교정표를 산출하였다. 1 Bed에서 표준섭취계수, 슬라이스 내의 표준섭취계수 변화율, 측정시간에 따른 표준섭취계수 변화율과 함께 표준섭취계수의 변이계수가 -11.0~9.90%로 국제적으로 통용되는 기준인 ±10%를 1개의 장비를 제외하고 모두 만족하였다. 또한, 시스템 별 평균 표준섭쉬계수 차이를 이용하여 0.803~1.246으로 이루어진 교정표를 도출하였고, 정상인을 통한 임상 적용에서 선형회귀분석을 통하여 유의함을 확인하였다. 본 연구를 통하여 PET/CT 장비간의 표준섭취계수 차이를 교정표를 이용하여 정량적으로 비교할 있는 근거를 제시한다면 정확한 진단에 도움이 되며, 아울러 이에 대한 세계적 기준이 명확하지 않기에 유사 연구에 도움이 되리라 사료된다.

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