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<원저>

The Study of Radiation Exposure Reduction by Developing Corpus Striatum Phantom

- 두개골-선조체 팬텀을 이용한 선량 저감화 방안 연구 -

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— Abstract —

The study is to produced a brain phantom simulating corpus striatum, which can evaluate the progression of parkinson's disease, to investigate possibility of reducing the brain exposure dose to CT while maintaining optimal image quality during PET-CT examinations. CT scans were performed by varying tube voltage (100, 120 kVp) and tube current (80, 140, 200 mAs) with ^{18}F FP-CIT injected into the phantom's hot sphere and background (radioactivity ratio 3:1)(reference condition; 120 kVp, 140 mAs). Estimated effective dose was calculated by using conversion factor according to each condition, and image quality was evaluated by setting SNR and CRChot image evaluation factors. Experimental results showed that the predicted effective dose below the CT imaging reference condition was reduced by at least 10% and by up to 60%, and the predicted effective dose beyond the reference condition was increased by 40%. In addition, there was no significant difference between SNR and CRChot of PET images, and it was confirmed that brain dose decreased with decrease of tube voltage and tube current. At the same time, there was no significant change in the quality of the image in terms of SNR and CRChot despite the change in scan conditions. This fact suggests that the quality of the images acquired under the existing dose conditions can be obtained even at low dose conditions and it is expected that it will be possible to use the brain PET-CT scan as a basic data for the research on reduction of dose and improvement of image quality.

Key Words : PET-CT, ^{18}F FP-CIT, Brain phantom, Effective dose, Dose reduction

Ⅰ. INTRODUCTION

Parkinson's disease is a chronic degenerative disease caused by abnormalities of dopaminergic neurons[1]. According to related studies, the prevalence of parkinson's disease is reported to be between 150 and 200 per 100,000 people and between 1 and 1.6 percent over the age of 65 and is increasing with aging[2]. Currently, parkinson's disease is reported to be caused by the loss of a part of dopaminergic cells and the degeneration of the dopaminergic neuronal circuit of corpus striatum, resulting in dopamine deficiency in dopaminergic neuron junctions[3]. Radiologic diagnoses such as computed tomography (CT) and magnetic resonance imaging (MRI) are only useful for differential diagnosis of diseases such

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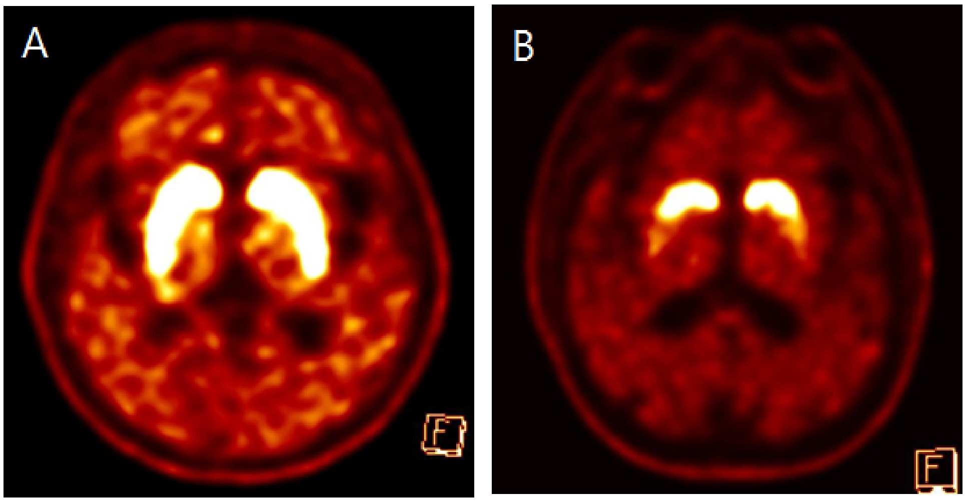

Fig. 1 ^{18}F FP-CIT corpus striatum (A) normal transverse image, (B) abnormal transverse image. FP-CIT is a synthesis of a fluoroalkyl group on the nitrogen atom of the tropane ring of β-CIT. It is a radioactive drug commonly used in parkinson's disease because it exhibits relatively fast pharmacokinetics in the body.

as cerebral vascular disorders, hydrocephalus, calcification, and there is much limitation in diagnosis[4,5]. Conversely, positron emission tomography (PET) scan can diagnose parkinson's disease using ligands involved in dopamine transport and have an advantage of detecting disease progression (Fig. 1)[6].

As a representative nuclear medicine scan to diagnose parkinson's disease, there is PET–CT scan using ^{18}F FP–CIT as a radioactive tracer and according to results of studies, it has been reported that the diagnostic accuracy using PET is superior to that of MRI by 15%[7]. This test identifies the extent of disease progression, how to diagnose and how to treat it according to the extent to which the radiopharmaceuticals are consumed in the corpus striatum. Recently, nuclear medicine equipment has been able to combine the existing single PET with equipment such as CT and MRI to obtain the correction effect through lack of anatomical information and attenuation mapping in PET images, and because of these advantages, PET–CT equipment is increasingly used in domestic hospitals and is already widely used[8]. On the other hand, while PET–CT has the advantage of obtaining information about the physiological function and anatomical position of the human body by using PET and CT simultaneously, the radiation dose received by the patient with the PET and CT examinations can not be overlooked[9]. There is software suggested by the equipment company for dose reduction, but it is not applied because it is inefficient in the brain which is composed of relatively simple structure compared to abdomen[10]. In addition, although studies have been actively conducted on the improvement of radiological exposure to PET and the improvement of image quality in the situation where the hazard of medical radiation exposure is a social issue, data on dose results for dual exposures of PET and CT in patients utilizes reference data from equipment companies[11]. Therefore the purpose of the study is to produce a brain phantom simulating corpus striatum, which can evaluate the progression of parkinson's disease, and investigate plans to reduce the brain exposure dose to CT while maintaining optimal image quality during PET–CT examinations.

II. Materials and Methods

1. Production for brain phantom

The brain is enclosed in the cerebrospinal fluid of the skull and is contained in the cerebrospinal fluid, mainly composed of soft tissues such as nerve cells and nerve fibers[12]. The effective atomic number according to the composition of human body is about 7.41 in soft tissue, 7.64 in air, and 20 in bone. Due to this difference, photons, such as gamma rays, attenuate as they interact with the material, for example, absorption through the photoelectric effect and scattering through the compton scattering and the higher the effective atomic number of a substance, the stronger this phenomenon becomes[13]. The principle of acquisition of nuclear medicine images is to reconstruct the signals of the photons emitted from the human body by collecting them with a detector and for examination of the brain, it is necessary to correct the degree of attenuation in the skull[14]. Thus, in brain phantom production, it is important to simulate each organ with a material that is as close as possible to the effective atomic number of each human tissue[15]. In this background, the brain phantom was made by measuring the head size of 10 adults based on CT data after PET-CT, and was constructed to inject radioactive isotopes into the corpus striatum. The phantom was divided into upper part and lower part and the upper part was inserted with two inserts of 2 ㎝ in diameter and 5 ㎝ in height indicating a corpus striatum as a disk having a diameter of 18 ㎝. The lower part was a cylinder with a diameter of 18 ㎝ and a height of 25 ㎝ and it was filled with water and represented as background (Fig. 2).

As a method for simulating the skull, high density (2.20E+00 g/㎤) teflon (polytetrafluoroethylene, PTFE, mean excitation energy=99.10 eV) was used and teflon is composed only of carbon with atom number 6 and fluorine with 9 and the weight ratios of each are 0.240183 and 0.759817. Teflon suitable for use as a phantom material using nuclear medical radiopharmaceuticals since it is not infringed by molten alkali metal and all other chemicals except fluorine gas at high temperature. Therefore, the surface of the brain phantom was fabricated using teflon as a material (Fig. 3).

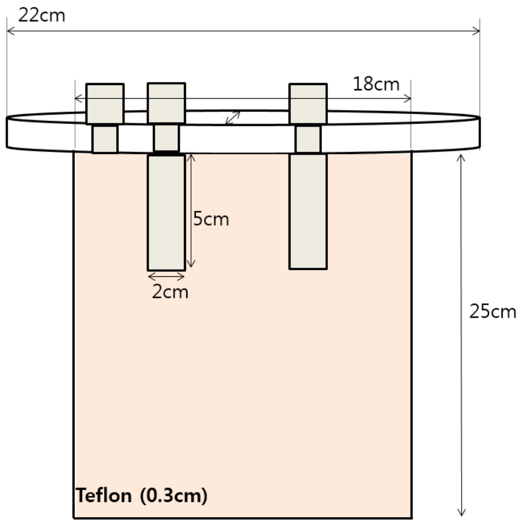

Fig. 2 Corpus striatum was made based on normal adult brain. The phantom was divided into an upper part and a lower part, and the upper part was inserted into two discs each having a diameter of 2 ㎝ and a height of 5 ㎝ representing a corpus striatum as a disk having a diameter of 18 ㎝. The lower part was a cylinder with a diameter of 18 ㎝ and a height of 25 ㎝ and it was filled with water and represented as background.

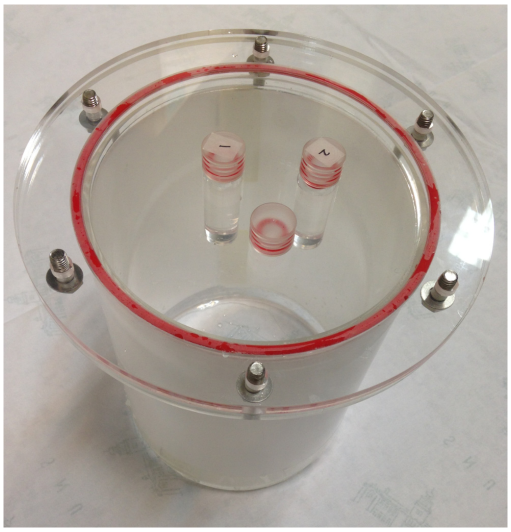

Fig. 3 Teflon is a trademark of polytetrafluoroethylene and is suitable for use as a phantom material using nuclear medical radiopharmaceuticals since it is not infringed by molten alkali metal and all other chemicals except fluorine gas at high temperature.

2. Image acquisition

1) PET acquisition

Biograph mCT40 (Siemens, Germany) and the brain phantom produced by the study was used to conduct the experiment. ^{18}F radioisotope was maintained at 3:1 radioactivity with a hot sphere (background ratio of 59:19 kBq/㏄), dedicated brain holder was equipped and data was acquired for 5 minutes. The obtained image was reconstructed by applying True X (iterations: 6,

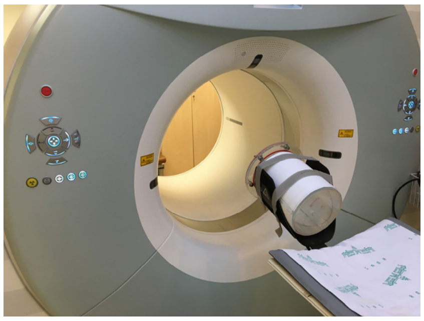

Fig. 4 PET and CT data were acquired by PECT-CT (Biograph mCT40, Siemens, Germany) scaner using the brain phantom. ^{18}F radioisotope was maintained at 3:1 radioactivity with a hot sphere ; Background ratio of 59: 19 kBq/cc, and a dedicated brain holder was equipped and data was acquired for 5 minutes.

subsets: 24) and gaussian filter (Fig. 4).

2) CT acquisition

CT images were obtained by varying tube voltage (100, 120 kVp) and tube current (80, 140 and 200 mAs). At this time, the CT imaging reference condition was set to tube voltage of 120 kVp and tube current of 140 mAs and was compared with other conditions.

3. Image analysis and evaluation parameter

1) SNR

SNR (signal to noise ratio), which is one of the methods of physical evaluation of image, is used to measure the intensity of the signal versus noise, and the signal intensity of the region of interest can be calculated by the standard deviation of the background noise[16]. The ROI (region of interest) was set in the same way for the ±1 slice based on the 10th slice (Fig. 5). Using the average counts and standard deviations of the ROI regions, the images were evaluated with the average SNR values of three slices using equation (1).

$$SNR = \frac{Average\ Count}{Standard\ Deviation} \quad (1)$$

2) CRC_{hot}

CRC_{hot} used equation (2)[17]. 1 hot sphere ROI and 10 backgrounds were set equal (Fig. 6). C_{hot} is the average

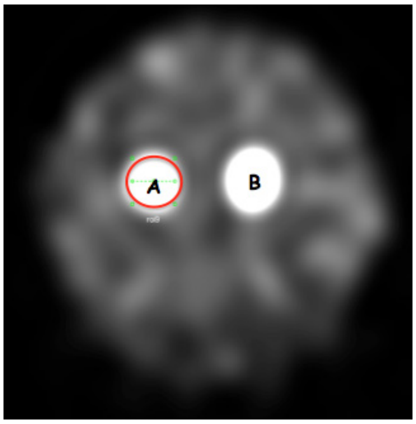

Fig. 5 Pet image correcting attenuation by the CT data was drawn by ROI to evaluate SNR. The image was evaluated with the average SNR value of three slices using the average count and standard deviation of the ROI region.

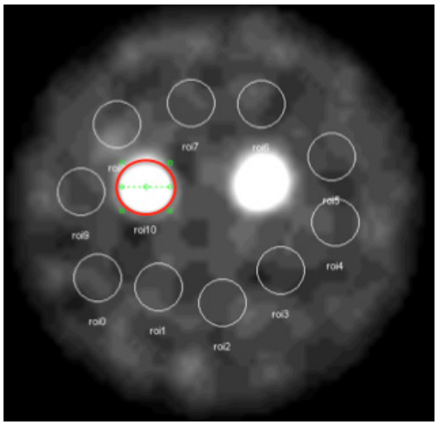

Fig. 6 Pet image correcting attenuation by the CT data was drawn by ROI with 1 hot insert and 10 background. Chot is the average count of the hot sphere, Cbkgd is the average count of the background, and ahot and abkgd are the ratio of the radioactivity of the hot sphere and background.

count of the hot sphere, C_{bkgd} is the average count of the background, and a_{hot} and a_{bkgd} are the ratio of the radioactivity of the hot sphere and background[18]. To make the true discovery that help medical team deliver the best outcome to the patient, or potentially impact the standard of care for all patients, It need the accuracy and consistency of absolute quantitation. Obtained images were analyzed using functional imaging Xeleris workstation ver. 3.0 (GE healthcare, USA).

$$CRC_{hot} = \frac{C_{hot}/C_{bkgd} - 1}{a_{hot}/a_{bkgd} - 1} \quad (2)$$

3) Effective dose

The values of DLP (dose length product) (mGy·㎝) according to each condition and the conversion factor k ($mSv·mGy^{-1}㎝^{-1}$) of head were applied based on tube voltage (120 kVp) and tube current (140 mAs) and estimated effective dose (E) was calculated using equation (3) and the dose was evaluated for each condition (Table 1)[19].

$$E\ (mSv) = DLP \times k \quad (3)$$

Ⅲ. Results

The tube voltage (100 kVp), tube current (80, 140, 200 mAs), tube voltage (120 kVp) and tube current (80 mAs) showed average SNR value of 6.11 and was 1.61% lower than the reference condition tube voltage (120 kVp) and tube current (140 mAs). The condition of tube voltage (120 kVp) and tube current (200 mAs) showed the same SNR value as the reference condition, and the SNR value according to the condition did not show much difference (Table 2).

Difference between CRC_{hot} values and reference conditions for tube voltage (100, 120 kVp) and tube current (80, 140, 200 mAs). A CRC_{hot} value similar to the reference condition (120 kVp, 140 mAs) was obtained under all conditions (Table 3).

While on the basis of tube voltage (120 kVp) and tube current (140 mAs) there was reduction in exposure dose 66.6%, 41.6%, 16.6%, and 41.6% respectively, under the conditions of tube voltage (100 kVp) and tube current (80, 140, 200 mAs), tube voltage (120 kVp) and tube current (80 mAs), exposure dose was increased by 29.4% under conditions of tube voltage (120 kVp) and tube current (200 mAs), (Table 4), (Fig. 7).

Ⅳ. Discussion

In this study, a brain phantom to evaluate the corpus striatum was created and evaluated for image quality and exposure reduction measures. The patient's head circumference was measured and high-density Teflon material was placed on the phantom surface to simulate the skull. To investigate the exposure dose according

Table 1 All other conversion factor (k)

Region of Body	k($mSv \cdot mGy^{-1}cm^{-1}$)
Head and neck	0.0031
Head	0.0021
Neck	0.0059
Chest	0.0140
Abdomen-pelvis	0.0150
Trunk	0.0150

Table 2 Average SNR in 3 slices

kVp	mAs	SNR			average	Difference (%)
		Slice 1	Slice 2	Slice 3		
100	80	6.11	6.17	6.05	6.11	-1.61
	140	6.10	6.08	6.15	6.11	-1.61
	200	6.19	6.10	6.04	6.11	-1.61
120	80	6.06	6.07	6.20	6.11	-1.61
	140	6.14	6.34	6.14	6.21	0.00
	200	6.18	6.24	6.14	6.19	-0.32

Table 3 Average CRChot in 3 slices

kVp	mAs	CRChot			average	Difference (%)
		Slice 1	Slice 2	Slice 3		
100	80	98.30	98.60	98.20	98.37	-0.14
	140	98.20	98.50	99.10	98.60	+0.10
	200	98.40	98.10	98.60	98.37	-0.14
120	80	100.00	101.10	100.20	100.43	+1.92
	140	98.50	99.10	97.90	98.50	0.00
	200	94.80	94.50	93.50	94.27	-4.30

Table 4 Effective dose according to CT conditions adjusting DLP and conversion factor

kVp	mAs	DLP (mGy · cm)	K ($mSv \cdot mGy^{-1}cm^{-1}$)	Effective Dose (mSv)	Difference (%)
100	80	191.50	0.0021	0.40	-65.51
	140	335.20		0.70	-39.66
	200	478.80		1.01	-12.93
120	80	315.90	0.0021	0.66	-43.10
	140	552.90		1.16	0.00
	200	789.80		1.66	+30.12

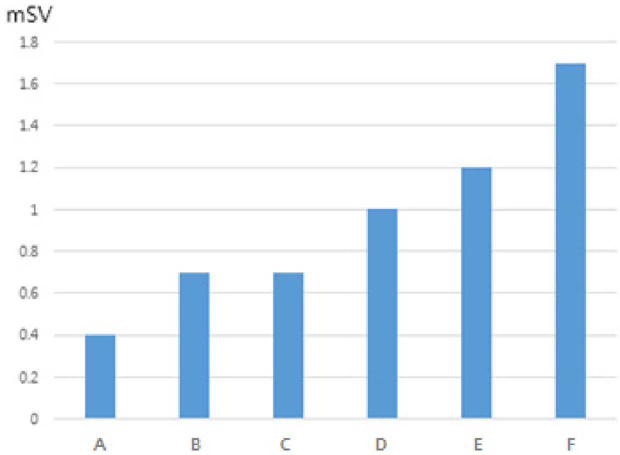

Fig. 7 Effective Dose (A) 100 kVp 80 mAs (B) 100 kVp 140 mAs (C) 100 kVp 200 mAs (D) 120 kVp 80 mAs (E) 120 kVp 140 mAs (F) 120 kVp 200 mAs

to CT condition, after injecting a certain amount of radiopharmaceuticals, image quality was evaluated as a factor of SNR and CRC_{hot} while changing 6 CT conditions of tube voltage (100, 120 kVp) and tube current (80, 140, 200 mAs), and the effective dose according to the condition was calculated and compared with the results obtained through the evaluation factors. The result values of SNR and CRC_{hot} according to the change of CT condition were not significantly changed. However, it can be seen that under the low condition, the dose to the DLP and the brain is reduced by changing the condition of the CT, and as the tube voltage and tube current were increased, the corresponding dose was also changed. According to previous studies, dose changes of CT for attenuation correction in PET–CT did not significantly affect image quality. Therefore, the dose of CT for attenuation correction other than diagnosis should be lowered at a level that does not change the image quality[20]. In addition, in the CT dose and phantom image evaluation studies for attenuation correction in pediatric PET-CT images, attenuation corrected PET images according to CT conditions did not affect SNR[21].

Since this study has limitations in conducting experiments with actual patients, only experiments with phantoms were conducted. In addition, it is not a phantom conforming to international standards such as NEMA (national electrial manufactures association) and IEC (international electrotechnical commission), but a phantom manufactured by measuring actual head circumference, thus it is problematic to apply it directly to human body. At present, the brain phantom mainly used globally is the hoffman brain phantom[22]. However, the hoffman brain phantom has limitations in evaluating other parts of the head, such as the corpus striatum, and many studies use anthropomorphic alderson RSD (radiology support devices) phantom for the evaluation of corpus striatum[23]. The phantom test to improve the quality of nuclear medicine images is mainly imported from foreign countries and the purchase price is very expensive, so there are several limitations. Therefore, in the reality that phantom production in domestic experiment is difficult, it is considered that it will be helpful in improving the performance of the equipment and image quality through the production of a phantom. Also, it is expected that the proportion of phantom experiments to corpus striatum will increase gradually, and based on the present phantom production, it is considered that a better phantom will be produced in domestic experiment and the quality of images will be greatly improved.

Ⅴ. Conclusion

As a result of comparing the quality of the image by setting the SNR of the PET-CT image and the image evaluation factor of the CRC_{hot} using the phantom simulating the skull-corpus striatum produced in the study, no specific quality change of the image was found according to the set CT condition. This fact suggests that the quality of the images acquired under the existing dose conditions can be obtained even at low dose conditions, and it is expected that it will be possible to use the brain PET-CT scan as a basic data for the research on reduction of dose and improvement of image quality.

REFERENCES

[1] Robeson W, Dhawan V, Belakhlef A, Ma Y, Pillai V, Chaly T, et al. Dosimetry of the dopamine transporter radioligand ^{18}F FP-CIT in human subjects. J Nucl Med. 2003;44(6):961-966.

[2] Hong SK, Park KW, Cha JK, Kim SH, Chun DY, Yang CK, et al. Quality of life in patients with parkinson's disease. J Korean Neurol Assoc. 2002;20(3):227-233.

[3] Chun HJ, Kim YS, Yi HJ, Ko Y, Oh SH, Choi YY. Clinical significance of ^{123}I-IPT SPECT for the diag-nosis of the parkinson's disease. J Korean Neurosurg Soc. 2003;34:104-109.

[4] Kathleen R. Fink, James R, Fink. Imaging of brain metastases. Surg Neurol Int. 2013;4(4):209-219.

[5] Marc C Mabray, Ramon F Barajas, Cha SM. Modern brain tumor imaging. Brain Tumor Res Treat. 2015;3(1):8-23.

[6] Lee WY, Kim JY, Kim ST. Transcranial sonography in parkinsons's disease and parkinsonism. Journal of Movement Disorders. 2008;1(1):6-12.

[7] Lee WH, Chung YA. Clinical application of ^{18}F-FDG PET in parkinson's disease. Nucl Med Mol Imaging. 2008;42:177-180.

[8] Lee SG. Policy synchronization for high-tech medical devices in korea. J korean Med Assoc. 2012;55(10): 950-958.

[9] Pasha Razifar, Mattias Sandström, Harald Schnieder, Bengt Långström, Enn Maripuu, Ewert Bengtsson, et al. Noise correlation in PET, CT, SPECT and PET/CT data evaluated using autocorrelation function: a phantom study on data, reconstructed using FBP and OSEM. BMC Med Imaging. 2005;5(5):148-152.

[10] Marcus Soderberg, Mikael Gunnarsson. The effect of different adaptation strengths on image quality and radiation dose using siemens care dose 4D.

Radiation Protection Dosimetry. 2010;139(1-3): 173-179.

[11] W Mazrani, K McHugh, PJ Marsden. The radiation burden of radiological investigations. Arch Dis Child. 2007;92(12):1127-1131.

[12] Vigh Teichmann I, Vigh B. The system of cerebrospinal fluid-contacting neurons. Arch Histol Jpn.1983;46(4):427-468.

[13] Balajiranganathan Anupreethi, Shivaramu. Effective atomic numbers for photon energy absorption and energy dependence of some thermoluminescent dosimetric materials. IARP. 2016;39(2):62-67.

[14] Hidehiro Iida, Yuki Hori, Kenji Ishida, Etsuko Imabayashi, Hiroshi Matsuda, Masaaki Takahashi. Three-dimensional brain phantom containing bone and grey matter structures with a realistic head contour. Ann Nucl Med. 2013;27(1):25-36.

[15] Abraham T, Feng J. Evolution of brain imaging instrumentation. Semin Nucl Med. 2011;41(3): 202-219.

[16] Qinan Bao, Arion F. Chatziioannou. Estimation of the minimum detectable activity of preclinical PET imaging systems with an analytical method. Med Phys. 2010;31(11):6070-6083.

[17] Daube-Witherspoon ME, Karp JS, Casey ME, DiFilippo FP, Hines H, Muehllehner G. PET performance measurements using the NEMA NU 2-2201 standard. J Nucl Med, 2002;43(10):1398-1409.

[18] Charles C. Watson, Michael E. Casey, Lars Eriksson, Tim Mulnix, Doug Adams, Bernard Bendriem. NEMA NU 2 performance tests for scanners with intrinsic radioactivity. J Nucl Med. 2004;45(5):822-826.

[19] AAPM Report 96, The measurement, reporting and management of radiation dose in CT. American Association of Physicists in Medicine. 2007.

[20] Ting Xia, Adam M. Alessio, Bruno De Man, Ravindra Manjeshwar, Evren Asma, Paul E. Kinahan. Ultra-low dose CT attenuation correction for PET/CT. Phys Med Biol. 2012;57(2):309-328.

[21] Xia T, Alessio AM, Kinahan PE. Dual energy CT for attenuation correction with PET/CT. Med Phys. 2014;41(1):012501

[22] Joshi A, Koeppe RA, Fessler JA. Reducing between scanner differences in multi-center PET studies. NeuroImage. 2009;46(1):154-159.

[23] Calvini P, Rodriguez G, Inguglia F, Mignone A, Guerra UP, Nobili F. The basal ganglia matching tools package for striatal uptake semi-quantification : description and validation. Eur J Nucl Med Mol Imaging. 2007;34(8):1240-1253.

•국문초록

두개골-선조체 팬텀을 이용한 선량 저감화 방안 연구

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본 연구는 파킨슨질환의 진행 정도를 평가할 수 있는 선조체를 모사한 brain 팬텀을 직접 제작하여, PET-CT검사 시 최적의 영상의 질을 유지하면서 CT 스캔에 의한 brain 선량 저감을 위한 가능성을 평가하였다. 팬텀의 hot sphere와 background (radioactivity ratio 3:1)에 ^{18}F FP-CIT를 주입하고, 관전압(100, 120 kVp)과 관전류(80, 140, 200 mAs)의 조건을 변화시키며 CT 스캔을 실험하였다(기준조건; 120 kVp, 140 mAs). 각 조건에 따라 예상유효선량을 conversion factor를 적용해 계산하였고, SNR과 CRChot의 영상평가 인자를 설정하여 영상의 질을 평가하였다. 실험결과 CT 촬영 기준조건 이하에서의 예상유효선량은 최소 10%에서 최고 60% 정도 감소하였고, 기준조건 이상에서의 예상유효선량은 40% 증가하였다. 또한 PET 영상의 SNR과 CRChot의 유의한 차이는 없었으므로, 관전압과 관전류의 감소에 따라 brain 선량이 감소함을 확인하였다. 이와 동시에 스캔 조건의 변화에도 불구하고 SNR과 CRChot 측면에서의 영상의 질에는 유의한 변화가 없었다. 이러한 사실은 낮은 선량 조건으로도 기존의 선량 조건으로 획득한 영상의 질 수준을 얻을 수 있었으므로, 추후 brain PET-CT 스캔의 선량감소와 동시에 영상의 질 향상에 관한 연구의 기초자료로 활용이 가능할 것으로 사료된다.

중심 단어: PET-CT, ^{18}F FP-CIT, Brain 팬텀, 유효선량, 선량저감