Effective Radiation Dose of ^{11}C-Choline and ^{18}F-FDG in Patients undergoing PET/CT

Paramest Wongsa, MSc[1], Supaporn Kongthai, BSc[2], Saiphet Vanprom, RN[2],
Savitree Suratako, RN[2], Chetsadaporn Promteangtrong, MD[2], Chanisa Chotipanich, MD[2]

[1] School of Radiological Technology, Faculty of Health Science Technology, HRH Princess Chulabhorn College of Medical Science, Chulabhorn Royal Academy, Bangkok, Thailand
[2] National Cyclotron and PET Centre, Chulabhorn Hospital, HRH Princess Chulabhorn College of Medical Science, Chulabhorn Royal Academy, Bangkok, Thailand

Background: Positron emission tomography/computed tomography (PET/CT) has been used as a noninvasive imaging method to assess the disease extent in patients.

Objective: To assess the effective radiation dose in patients who underwent PET/CT.

Materials and Methods: The present study included 24 patients with cholangiocarcinoma (CCA) or hepatocellular carcinoma (HCC), aged 39 to 74 years, who underwent ^{11}C-choline and ^{18}F-FDG whole body PET/CT scans at National Cyclotron and PET Centre, Chulabhorn Hospital. The radiation absorbed doses to target organs and effective whole body doses were calculated from ICRP 106 publication for ^{18}F-FDG and the US FDA publication for ^{11}C-choline.

Results: The average whole body effective dose from the ^{18}F-FDG PET scan was 6.81±1.09 mSv and from the CT scan was 12.95±3.33 mSv. For ^{11}C-choline, the effective whole-body dose was 1.90±0.40 mSv from the PET scan and 14.20±3.14 mSv from the CT scan. Our results showed that ^{11}C-choline accumulates mainly in the liver, lungs and stomach, while the accumulation of ^{18}F-FDG is mainly in bladder, lungs and liver.

Conclusion: The results showed that the effective dose from CT modality between ^{18}F-FDG and ^{11}C-choline patients were not significantly different. However, the average effective dose for patients undergoing whole body ^{18}F-FDG PET was 3.6 times higher than with ^{11}C-choline PET.

Keywords: ^{11}C-Choline, ^{18}F-FDG, Effective dose, PET/CT

The positron emission tomography (PET) and computed tomography (CT) PET/CT imaging modalities are widely used to assess disease extent in patients. In Thailand, ^{11}C-choline and ^{18}F-FDG PET/CT have been used as noninvasive imaging to diagnose lesions in patients with cholangiocarcinoma (CCA) or hepatocellular carcinoma (HCC). However, PET/CT examination leads to patient exposure of administered PET radiopharmaceuticals and x-rays generated by the CT. Thus, it is one of the most challenging and interesting areas of radiation safety in diagnostic nuclear medicine. The patient doses received from PET/CT procedures have been reported by many investigators[1-3]. However, their studies calculated radiation doses, ^{11}C-choline and ^{18}F-FDG in different groups of patients and therefore the comparison of ^{11}C-choline and ^{18}F-FDG doses in patients was not accurate.

The present study assessed the effective radiation dose of ^{11}C-choline and ^{18}F-FDG in CCA and HCC patients who underwent PET/CT. To address limitations from previous studies, here we compared individual radiation doses of ^{11}C-choline and ^{18}F-FDG in the same patient.

Materials and Methods

All imaging was performed on a 16-slice PET/CT system (Biograph16, Siemens, Erlangen, German), with PET detectors lutetium oxyorthosilicate crystals, 16-slice CT detectors and the syngo multimodality computer system[4,5].

The protocol of this research was reviewed and approved by the Human Research Ethics Committee, Chulabhorn Research Institute No. 052/2560.

Subjects

A total of 24 patients were examined using ^{11}C-choline and ^{18}F-FDG PET/CT whole body studies. The mean patient age was 55.67±14.80 years (range, 39 to 74 years).

Correspondence to:

Wongsa P.

School of Radiological Technology, Faculty of Health Science Technology, HRH Princess Chulabhorn College of Medical Science, Chulabhorn Royal Academy, Bangkok 10210, Thailand.

Phone: +66-2-5766000

Email: paramest.won@pccms.ac.th

The study protocol for patient radiation dose was approved by the Chulabhorn Research Institute Ethical committee for Human Research and written informed consent was obtained from each subject.

Protocol for PET/CT scan

The scanning protocol for ^{18}F-FDG and ^{11}C-choline PET/CT examinations consisted of (i) a scout CT scan for positioning and scan range setting; (ii) a spiral care dose 4D CT scan to be performed; and (iii) a 3D PET scan over the same position range as the CT protocol. For the whole body PET/CT scan, patients were scanned from the vertex of skull to upper thigh. The total scan time was approximately 30 min depending on patient weight and height. For heavier patients, an increase of scanning time (time per bed position) was considered to improve image quality without increasing dose. If patients were very tall, the scan range was also increased.

Patient dose from CT scan

The effective dose (E) of CT scan was calculated from the dose-length product (DLP) multiplied by the region-specific normalized effective dose per DLP (E_{DLP})[6],

$$E\,(mSv) = E_{DLP}\,(mSv.mGy^{-1}.cm^{-1}) \times DLP\,(mGy.cm)$$

Where:

$$DLP\,(mGy.cm) = CTDI_{vol}\,(mGy) \times scan\ length\,(cm)$$

$CTDI_{vol}$ is the computed tomography dose index that represents the average dose over total volume scanned in sequential or helical sequence.

In the present study, DLP values were collected from PET/CT patient data shown in the scanner monitor at the end of the study. The E_{DLP} for adults representing the whole body regions was 0.015 mSv.mGy^{-1}.cm^{-1}[7,8].

Patient dose from PET scan

The quantity of PET radiopharmaceuticals injected to each patient was calculated by patient body weight at 0.04 and 0.05 MBq per kilogram for ^{18}F-FDG and ^{11}C-choline, respectively. Organs and effective whole body dose were calculated using the biokinetic model from ICRP 106 publication[9] and the US FDA publication[10]. The radiation absorbed dose to target provided the patient-specific effective dose conversion factors of 0.919 mSv/MBq for ^{18}F-FDG and 0.00435 mSv/MBq for ^{11}C-choline. The radiation dose to target organs was calculated from the injection dose multiplied by the organ-specific effective dose conversion factors and tissue weighting factor from the ICRP 103 publication[11].

Results

The effective doses of the CT component of PET/CT examination calculated from DLP and multiplied by E_{DLP} are presented in Table 1. The average whole body effective dose from the CT component in ^{18}F-FDG examination was 12.95±3.33 mSv, ranging from 6.22 to 18.55 mSv. The average whole body effective dose from the CT scan in

Table 1. The whole body effective dose from PET/CT scan

Patient No.	Effective dose (mSv)					
	CT		PET		Total	
	FDG scan	Choline scan	FDG scan	Choline scan	FDG scan	Choline scan
1	17.22	18.19	8.41	1.76	25.63	19.95
2	15.46	17.29	8.60	1.80	24.06	19.09
3	13.00	13.71	6.82	2.04	19.82	15.75
4	9.63	13.31	6.14	1.49	15.77	14.80
5	11.24	10.89	5.83	1.65	17.07	12.54
6	11.24	13.31	5.33	2.05	16.57	15.36
7	16.87	19.26	7.66	2.25	24.53	21.51
8	6.22	9.06	4.44	0.89	10.66	9.95
9	12.68	13.31	6.52	1.80	19.20	15.11
10	8.50	9.06	6.02	1.73	14.52	10.79
11	12.78	13.71	6.76	1.90	19.54	15.61
12	10.06	11.60	5.62	2.22	15.68	13.82
13	15.46	17.29	7.68	1.93	23.14	19.22
14	6.96	9.06	5.22	1.17	12.18	10.23
15	9.91	11.60	5.31	1.47	15.22	13.07
16	12.94	13.71	7.83	1.82	20.77	15.53
17	18.35	18.19	7.76	2.09	26.11	20.28
18	14.95	17.29	7.15	1.99	22.10	19.28
19	12.60	14.31	7.34	2.24	19.94	16.56
20	13.07	12.75	6.77	2.03	19.84	14.78
21	14.98	14.81	7.41	2.16	22.39	16.97
22	18.55	19.21	8.30	2.87	26.85	22.08
23	15.04	16.58	7.47	2.24	22.50	18.82
24	13.17	13.21	6.99	2.11	20.16	15.32
Ave	12.95	14.20	6.81	1.90	19.76	16.10
SD	3.33	3.14	1.12	0.40	4.36	3.41

^{11}C-choline examination was 14.20±3.14 mSv, ranging from 9.06 to 19.26 mSv.

The average ^{18}F-FDG and ^{11}C-choline injected activities were 358.27 and 439.38 MBq, respectively. The average whole body effective dose from injected radiotracers ^{18}F-FDG and ^{11}C-choline was 6.81±1.09 mSv, ranging from 4.44 to 8.60 mSv, and 1.90±0.40 mSv, ranging from 0.89 to 2.87 mSv, respectively.

The total effective dose of ^{18}F-FDG and ^{11}C-choline PET/CT scan was calculated by external radiation from CT scan and internal radiation from radiopharmaceutical administration. The total patient doses of ^{18}F-FDG and ^{11}C-choline PET/CT were 19.76 mSv and 16.10 mSv, respectively.

The average organ dose from PET/CT scan was

calculated from each target organ in 24 patients. The results showed that ^{11}C-choline and ^{18}F-FDG accumulated in red bone marrow, colon, lungs, stomach, breast, bladder, liver, thyroid, bone surface, brain, skin and gonad (Table 2).

Discussion

The development of dual-modality PET-CT systems improved the accurate anatomical localization of radiotracer uptake sites detected on PET. However, this came at the expense of increased radiation dose to patients, compared with either PET or CT alone. The radiation dose results from both the injected radiotracer and the external dose of the CT component. In the present study, ^{11}C-choline accumulated mainly in the liver, lungs and stomach. The accumulated doses were 0.353, 0.242, and 0.316 mSv, respectively. In comparison, Tolvanen et al[12] reported the highest absorbed doses in the kidneys, liver and the pancreas. The accumulated doses from ^{18}F-FDG were 1.86, 0.86, and 0.51 mSv in the bladder, lungs and gonad, respectively. The critical organ with ^{18}F-FDG administration was the bladder. The maximum dose from the ^{11}C-choline PET scan was in liver at 0.353±0.075 mSv. The maximum organ dose from ^{18}F-FDG was in bladder at 1.86±0.31 mSv. No statistical difference of effective radiation dose was found between ^{18}F-FDG and ^{11}C-choline CT scans. However, the effective radiation dose of ^{11}C-choline PET scan was 3.6 times lower than that of ^{18}F-FDG PET scan (p<0.05).

The total effective radiation doses of ^{11}C-choline and ^{18}F-FDG PET/CT were 16.10 mSv and 19.76 mSv, respectively. Slightly lower findings for ^{18}F-FDG PET/CT were reported by Willowson et al[13], who found total effective dose averages of 14.5 mSv, and Kaushik et al[1] who reported the total effective dose from a typical protocol of whole body ^{18}F-FDG PET/CT examination of 14.4 mSv for female patients and 11.8 mSv for male patients. Caused by our CT procedure was used as diagnostic CT protocol while in general PET/CT was used only low dose CT protocol to acquire the CT images for localized the PET lesions. Our study results showed that the whole body dose with ^{18}F-FDG PET was higher than ^{11}C-choline PET. This finding corresponds to the study from Marti-Climent et al[2], who reported total effective dose averages from ^{11}C-choline and ^{18}F-FDG PET/CT examinations of 13.5 mSv and 20.0 mSv, respectively. Another study by Alkhybari et al[3] reported the diagnostic reference levels for ^{18}F-FDG whole body PET/CT procedures in Australia and New Zealand, and found that the total effective doses of ^{18}F-FDG PET/CT in Australia and New Zealand were 10.44 mSv and 16.65, respectively, which are lower than the ^{18}F-FDG PET/CT total effective radiation dose from the present study.

Conclusion

The average effective radiation dose in patients undergoing whole-body ^{18}F-FDG PET was 3.6 times higher than that of ^{11}C-choline PET. The total effective radiation doses of ^{11}C-choline and ^{18}F-FDG PET/CT were 16.10 mSv and 19.76 mSv, respectively. The effective radiation dose from CT scan was more than 2.9 and 8.5 times greater than ^{18}F-FDG and ^{11}C-choline PET scans, respectively. The effective radiation dose could be further reduced by optimizing the protocol for PET/CT scans by modifying CT scan parameters as per the size and weight of patients.

What is already known on this topic?

The study of the patient radiation dose in the PET/CT imaging was estimated from the radiation activity of radiopharmaceutical and radiation exposure from CT modality that aimed to minimize the patient dose from the examination.

What this study adds?

In this study, the patient radiation dose was estimated and compared in the same patient who was examined with ^{11}C-choline and ^{18}F-FDG PET/CT, which is more reliable than previous studies.

Potential conflicts of interest

The authors declare no conflict of interest

References

1. Kaushik A, Jaimini A, Tripathi M, D'Souza M, Sharma

Table 2. The average organ dose from PET/CT scan

Critical organs	Organ dose average (mSv)			
	[18]F FDG study		[11]C choline study	
	Ave	SD	Ave	SD
Red bone marrow	0.473	0.078	0.100	0.021
Colon	0.559	0.092	0.095	0.020
Lungs	0.860	0.141	0.242	0.051
Stomach	0.473	0.078	0.316	0.067
Breast	0.378	0.062	0.073	0.016
Bladder	1.863	0.306	0.060	0.013
Liver	0.301	0.049	0.353	0.075
Thyroid	0.143	0.024	0.026	0.006
Bone surface	0.039	0.006	0.021	0.004
Brain	0.136	0.022	0.005	0.001
Skin	0.028	0.005	0.005	0.001
Gonad	0.516	0.085	0.069	0.015

R, Mishra AK, et al. Estimation of patient dose in (18)F-FDG and (18)F-FDOPA PET/CT examinations. J Cancer Res Ther 2013;9:477-83.

2. Marti-Climent JM, Prieto E, Moran V, Sancho L, Rodriguez-Fraile M, Arbizu J, et al. Effective dose estimation for oncological and neurological PET/CT procedures. EJNMMI Res 2017;7:37.

3. Alkhybari EM, McEntee MF, Brennan PC, Willowson KP, Kench PL. Diagnostic reference levels for (18) F-FDG whole body PET/CT procedures: Results from a survey of 12 centres in Australia and New Zealand. J Med Imaging Radiat Oncol 2019;63:291-9.

4. Christian PE, Waterstram-Rich KM. Nuclear medicine and PET/CT technology and techniques. 6th ed. St. Louis: Mosby Elsevier; 2007.

5. Mettler FA, Guiberteau MJ. Essentials of nuclear medicine imaging. 6th ed. Philadelphia, PA: W.B. Saunders; 2012.

6. Valentin J. International Commission on Radiological Protection. Managing patient dose in multi-detector computed tomography (MDCT). ICRP Publication 102. Ann ICRP 2007;37:1-79.

7. Bongartz GG, Golding SJ, Jurik AG, Leonardi M, Van Persijn Van Meerten E, Rodriguez R, et al. European guidelines for multislice computed tomography [Internet]. 2004 [cited 2004 Mar 4]. Available from: http://www.biophysicssite.com/Documents/MSCT2004b/Appendix_A_MSCT_Dosimetry.pdf.

8. Shrimpton PC, Hillier MC, Lewis MA, Dunn M. Doses from computed tomography (CT) examinations in the UK – 2003 Review [Internet]. 2005 [cited 2020 Nov 4]. Available from: http://www.biophysicssite.com/Documents/NRPB_W67/NRPB_W67.pdf.

9. International Commission on Radiological Protection. Radiation dose to patients from radiopharmaceuticals. Addendum 3 to ICRP Publication 53. ICRP Publication 106. Ann ICRP 2008;38:1-197.

10. Choline C 11 injection, for intravenous use. Initial U.S. Approval [Internet]. 2012 [cited 2020 Nov 4]. Available from: https://www.accessdata.fda.gov/drugsatfda_docs/label/2012/203155s000lbl.pdf.

11. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. Ann ICRP 2007;37:1-332

12. Tolvanen T, Yli-Kerttula T, Ujula T, Autio A, Lehikoinen P, Minn H, et al. Biodistribution and radiation dosimetry of [(11)C]choline: a comparison between rat and human data. Eur J Nucl Med Mol Imaging 2010;37:874-83.

13. Willowson KP, Bailey EA, Bailey DL. A retrospective evaluation of radiation dose associated with low dose FDG protocols in whole-body PET/CT. Australas Phys Eng Sci Med 2012;35:49-53.