Original Article

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

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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$\pm$1.09 mSv and from the CT scan was 12.95$\pm$3.33 mSv. For ^{11}C-choline, the effective whole-body dose was 1.90$\pm$0.40 mSv from the PET scan and 14.20$\pm$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

J Med Assoc Thai 2021;104(Suppl.2):
Website: http://www.jmatonline.com

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.

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How to cite this article:
Wongsa P, Kongthai S, Vanprom S, Suratako S, Promteangtrong C, Chotipanich C. Effective Radiation Dose of ^{11}C-Choline and ^{18}F-FDG in Patients undergoing PET/CT. J Med Assoc Thai 2021;104 (Suppl.2):
doi.org/10.35755/jmedassocthai.2021.S02.12554

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$\pm$14.80 years (range, 39 to 74 years).

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:

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

$CTDI_{vol}$ 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$\pm$3.33 mSv, ranging from 6.22 to 18.55 mSv. The average whole body effective dose from the CT scan in ^{11}C-choline examination was 14.20$\pm$3.14 mSv, ranging from 9.06 to 19.26 mSv.

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

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$\pm$1.09 mSv, ranging from 4.44 to 8.60 mSv, and 1.90$\pm$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 this 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$\pm$0.075 mSv. The maximum organ dose from ^{18}F-FDG was in bladder at 1.86$\pm$0.31 mSv. No statistical difference of effective radiation dose was found between ^{18}F-FDG and ^{11}C-choline CT scans. However, the effective radiation dose of ^{11}C-choline PET scan was 3.6 times lower than that of ^{18}F-FDG PET scan ($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 this study.

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

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.

Acknowledgements

I would like to thank Associate Professor Chanisa Chotipanich for giving me the opportunity to complete this research under her supervision and am grateful for the advice, ideas and moral support through this project. In addition, I would like to express my appreciation for the staff of the National Cyclotron and PET Centre who assisted me in collecting research data.

Potential conflicts of interest

The authors declare no conflict of interest

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ปริมาณรังสีที่ผู้ป่วยได้รับจากการตรวจเพทซีที ด้วยสาร ^{11}C-choline และ ^{18}F-fluorodeoxyglucose

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ภูมิหลัง: การถ่ายภาพทางรังสีด้วยเครื่องเพทซีที เป็นการตรวจที่ไม่มีการรุกล้ำทางร่างกาย ซึ่งถูกนำมาใช้ประโยชน์ในการหาการเกิดซ้ำของรอยโรคภายในตัวผู้ป่วย

วัตถุประสงค์: เพื่อประเมินค่าปริมาณรังสีที่ผู้ป่วยมะเร็งตับและมะเร็งท่อน้ำดีได้รับจากการเข้ารับการตรวจเพทซีที ด้วยสาร ^{11}C-choline และ ^{18}F-FDG

วัสดุและวิธีการ: การศึกษาโดยการประเมินค่าปริมาณรังสีผู้ป่วยมะเร็งตับและมะเร็งท่อน้ำดี จำนวน 24 คน ที่มีอายุอยู่ในช่วงระหว่าง 39 ถึง 74 ปี ซึ่งได้รับจากการเข้ารับการตรวจเพทซีที ด้วยสาร ^{11}C-choline และ ^{18}F-FDG ณ โรงพยาบาลจุฬาภรณ์ โดยค่าปริมาณรังสีดูดกลืนและค่าปริมาณรังสียังผลทั่วร่างกาย คำนวณโดยอ้างอิงจากเอกสารคณะกรรมการนานาชาติด้านการป้องกันอันตรายจากรังสี ฉบับที่ 106 และเอกสารกำกับของคณะกรรมการอาหารและยาของสหรัฐอเมริกา

ผลการศึกษา: จากการศึกษาพบว่าค่าปริมาณรังสียังผลทั่วร่างกายจากการบริหารสารรังสี ^{18}F-FDG มีค่าเท่ากับ 6.81±1.09 มิลลิซีเวิร์ตและจากการทำเอกเรย์คอมพิวเตอร์เท่ากับ 12.95±3.33 มิลลิซีเวิร์ต ในส่วนของ ^{11}C-choline ที่ถูกบริหารเข้าไปในร่างกายผู้ป่วยทำให้ได้รับรังสี 1.90±0.40 มิลลิซีเวิร์ตและได้รับรังสีจากการทำเอกเรย์คอมพิวเตอร์ 14.20±3.14 มิลลิซีเวิร์ต โดยค่าปริมาณรังสีสะสมของสาร ^{11}C-choline พบมากที่บริเวณ ตับ ปอดและกระเพาะอาหาร ขณะที่ค่าปริมาณรังสีสะสมของสาร ^{18}F-FDG พบมากที่บริเวณกระเพาะอาหาร ปอดและตับ

สรุป: จากผลการศึกษาดังกล่าวสรุปได้ว่าว่าไม่มีความแตกต่างทางสถิติของค่าปริมาณรังสีที่ผู้ป่วยได้รับจากการตรวจเอกเรย์คอมพิวเตอร์ในทั้งสองการตรวจ อย่างไรก็ตามพบว่าผู้ป่วยที่ถูกบริหารสารเภสัชรังสีด้วยสาร ^{18}F-FDG จะได้รับค่าปริมาณรังสีมากกว่าผู้ป่วยที่ถูกบริหารด้วยสาร ^{11}C-choline เป็นจำนวนถึง 3.6 เท่า