Estimation of patient radiation dose from whole body ^{18}F-FDG PET/CT examination in cancer imaging: a preliminary study

M H Mahmud[1,2], A J Nordin[2], F F Ahmad Saad[2] and A Z Fattah Azman[3]

[1] Faculty of Medicine and Health Sciences, Universiti Putra Malaysia 43400 UPM Serdang, Selangor, Malaysia
[2] Centre for Diagnostic Nuclear Imaging, Universiti Putra Malaysia 43400 UPM Serdang, Selangor, Malaysia
[3] Department of Community Health, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia 43400 UPM Serdang, Selangor, Malaysia

E-mail: hafizimahmud@yahoo.com

Abstract. This study aims to estimate the radiation effective dose resulting from whole body fluorine-18 flourodeoxyglucose Positron Emission Tomography (^{18}F-FDG PET) scanning as compared to conservative Computed Tomography (CT) techniques in evaluating oncology patients. We reviewed 19 oncology patients who underwent ^{18}F-FDG PET/CT at our centre for cancer staging. Internal and external doses were estimated using radioactivity of injected FDG and volume CT Dose Index ($CTDI_{vol}$), respectively with employment of the published and modified dose coefficients. The median differences of dose among the conservative CT and PET protocols were determined using Kruskal Wallis test with $p < 0.05$ considered as significant. The median (interquartile range, IQR) effective doses of non-contrasted CT, contrasted CT and PET scanning protocols were 7.50 (9.35) mSv, 9.76 (3.67) mSv and 6.30 (1.20) mSv, respectively, resulting in the total dose of 21.46 (8.58) mSv. Statistically significant difference was observed in the median effective dose between the three protocols ($p < 0.01$). The effective doses of whole body ^{18}F-FDG PET technique may be effective the lowest amongst the conventional CT imaging techniques.

1. Introduction

The integration of Positron Emission Tomography (PET) and Computed Tomography (CT) scanners or the PET/CT provides a co-registration of morphological and functional information in a single setting. The technology of CT-based attenuation correction for the PET acquisition data is preferred to the out-phased conventional gamma ray source (such as germanium-68) and has greatly reduced the scanning time in a PET/CT study [1] and improved the quality of the corrected PET scans [2-4]. This integrated modality is becoming an important tool nowadays for clinical investigation with increased clinical use, expanding from oncologic diagnosis to other clinical indications, including infection, inflammation, cardiac study and neurology. The PET/CT plays an important role in clinical applications and yields as much imaging information as possible to derive an accurate diagnosis and to indicate the most appropriate treatment that the patient can receive. However, concern over the total radiation dose to patients in the PET/CT study is a matter of great concern among the clinicians.

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

To the best of our knowledge, there is limited study addressing the radiation dose of patients undergoing whole body fluorine-18 fluorodeoxyglucose (^{18}F-FDG) PET/CT examinations in Malaysian population, in particular. Therefore, this study is aimed to estimate the radiation effective dose resulting from whole body ^{18}F-FDG PET scanning as compared to conservative CT techniques in evaluating oncology Malaysian patients.

2. Materials and methods

2.1 Patients

This retrospective study included the analysis of integrated ^{18}F-FDG PET/CT images from 19 patients (10 men and 9 women; mean age 53.2 ± 16.8 years; ranging between 20 and 75 years) who were referred for whole body ^{18}F-FDG PET/CT imaging for cancer staging at the Centre for Diagnostic Nuclear Imaging of Universiti Putra Malaysia, Malaysia. This study was granted ethical approval by the institutional review committee.

2.2 Patient preparation

All the patients fasted for at least 6 hours before the scanning session and only oral hydration with glucose-free water was allowed. The fasting blood glucose level was recorded for all patients. Oral gastrografin solution (sodium meglumine diatrizoate; BerliMed S.A., Madrid, Spain) was given to patients in a three part dilution before the intravenous (IV) administration of a radiopharmaceutical agent and immediately before scanning. Mean 341.3 MBq (within the range of 293.8 - 397.8 megabecquerels) of ^{18}F-FDG was injected intravenously. All the patients were put to rest in a special uptake room for an average of 80.4 min (within the range of 30 - 282 min) and emptied their bladder before undergoing the PET/CT examination.

2.3 PET/CT imaging protocol

Image acquisition was performed using an integrated Siemens Biograph 64 TruePoint PET/CT system (Siemens Medical Solutions, Erlangen, Germany) consisting of a PET scanner with lutetium oxyorthosilicate (LSO) crystals detector and a 64-multi detector CT scanner (MDCT). A scout view was performed in the cranio-caudal direction to plan the study, followed by a non-contrast enhanced CT (NECT) protocol in caudo-cranial direction for the purpose of anatomical localization and attenuation correction. Subsequently, a contrast-enhanced CT (CECT) or known as high dose CT protocol with IV injection of non-ionic contrast, iohexol (Omnipaque 350 mgI/mL, GE Healthcare, Shanghai, China) 84.1 mL (mean; within the range of 50 - 110 mL) was performed, using a dual head automatic pressure injector (Mallinckrodt, Missouri, USA) with a flow rate of 2.5 mL/s and was followed by a 20 mL saline flush. CECT acquisition started in the caudo-cranial direction. A PET scan was acquired consecutively at 3 min per bed position using a three-dimensional acquisition mode. The total duration of the PET/CT examination was about 20 min, with approximately 1 min to complete the CT scans and about 19 min to acquire the PET emission data. The latter was acquired in a caudo-cranial direction. The PET images were then reconstructed by using a TrueX reconstruction algorithm. The CT datasets were employed for attenuation correction with the same set of PET images.

2.4 Estimation of internal dose

Absorbed dose , D_T to a tissue or organ, T resulting from the IV administration of an activity, A of ^{18}F-FDG was computed by means of dose coefficients Γ_T^{FDG} as recommended by the International Commission on Radiological Protection (ICRP) in Publication 106 [5] for a variety of organs and tissues of the adult hermaphrodite MIRD phantom, which is $D_T = A \,.\, \Gamma_T^{FDG}$. Whole body effective dose coefficient values were calculated using the acquired data as reported by Brix et al. [6] and Huang et al. [7] with some modifications on these data through the use of a tissue weighting factor, W_T provided by ICRP Publication 103 [8].

Using the published and modified whole body effective dose coefficient values, the average effective dose for whole body FDG PET was estimated as follows [6] :

$$E = \sum_T w_T \,.\, D_T = A \,.\, \sum_T w_T \,.\, \Gamma_T^{FDG} = A \,.\, \Gamma_E^{FDG} \quad (1)$$

2.5 Estimation of external dose

To estimate the radiation exposure of patients resulting from the acquisition of CT scans, volume CT Dose Index ($CTDI_{vol}$) was used; it was directly obtained from the display screen of the operator console of the CT workstation. The organ specific dose coefficient Γ_T^{CT} values for organ dose calculation were also adapted from Brix and his co-workers [6]. With some modifications through the use of a tissue weighting factor, W_T provided by the ICRP Publication 103 [7], the whole body effective dose coefficients Γ_E^{CT} value was calculated using the following formula [6]:

$$\Gamma_E^{CT} = \sum_T w_T \,.\, \Gamma_T^{CT} \quad (2)$$

Using both whole body effective dose coefficients, as adapted from the study by Brix et al. [6] and the modification method, the average effective dose for whole body CT was estimated by equation [9]:

$$E = \Gamma_E^{CT} \,.\, CTDI_{vol} \quad (3)$$

2.6 Statistical analysis

The results were presented as a median (interquartile range, IQR). The Kruskal-Wallis test was carried out to determine the difference of the median effective dose between each of the stand-alone scan protocol, including NECT, CECT and PET. All the hypothesis tests were two-sided with a significant level of 0.05. The Statistical Package for the Social Sciences program for Windows 21.0 (SPSS 21) (IBM Corp, Somers, New York) was used for the statistical analysis.

3. Results and discussion

The median whole body effective doses for NECT and CECT scans were 7.50 (IQR 9.35) mSv (ranging from 0.61 to 43.80 mSv) and 9.76 (IQR 3.67) mSv (ranging from 7.01 to 27.56 mSv), respectively. The median whole body effective doses from the PET were 6.30 (IQR 1.20) mSv (ranging from 5.45 to 7.38 mSv) whereby 21.46 (IQR 8.58) mSv (ranging from 15.00 to 77.38 mSv) contributed to the total whole body effective dose for PET/CT scan. The data on the patient effective dose from the stand-alone scan and whole body PET/CT scan are shown in Table 1.

This study demonstrated that CT examination took the major role in contributing to the total effective dose of PET/CT imaging, corresponding to approximately 80.43%. This finding is in agreement with a study by Huang et al. [7], in which up to 81% of the total PET/CT effective dose was attributable to the CT doses. Huang and his colleagues specified that diagnostic CT scanning is a standard practice for PET/CT imaging in their institution, which is similar to the practice in the present study. In fact, their PET/CT system (64-detector CT system) and some CT scanning parameters (kVp and scanning coverage area) were also similar to those in the present study as well, making the data comparable.

In this particular study, the average FDG radioactivity of 341.3 ± 37.6 MBq was administered for the patients, this level of radioactivity being derived from their body weight. This amount is greater than the value in a study by Khamwan et al. [10], even though the physical characteristics of their Thai patients seem not to have been greatly different from those of the Malaysian patients in the present study. With this higher value, it was expected that the effective dose of PET scan from this study would be increased. Nevertheless, the effective dose of PET resulting from this study is still in accordance with the results in the study by Brix et al. [6] with a range of 5.7 to 7.0 mSv in the

effective dose of PET reported in their study. Moreover, the total PET/CT effective dose for the Thai patients seems to have been lower than the effective dose in the present study. The present NECT study was acquired with the mid range exposure which has given higher dose in comparison to low dose CT. A higher tube current exposure time product (mAs) is required to compensate the increase in density in the contrasted tissues as a result of contrast media administration. The additional CT dose contributing from CECT results to increase the total dose as compared to the NECT alone. In fact, only the NECT protocol was performed in all CT scans in the PET/CT practice of the Thai study; a much lower dose is expected from such CT scans than in the integrated protocols (NECT and CECT protocols) that the present study records. However, when comparing the effective dose of NECT with that given to the Thai patients, a much lower effective dose of 7.50 mSv was demonstrated in the present study than for the Thai patients (14.45 mSv).

Table 1. The effective dose of the stand-alone and integrated whole body PET/CT scanning protocols.

Patient no.	Effective dose (mSv)			
	Stand-alone			Integrated PET/CT scan
	NECT[a]	CECT[b]	PET[c]	NECT+CECT+PET
1	0.75	12.08	7.31	20.14
2	9.70	10.06	6.70	26.46
3	0.65	9.34	6.77	16.76
4	0.73	12.08	7.23	20.04
5	0.62	8.24	6.56	15.42
6	0.75	12.08	6.82	19.65
7	0.65	8.41	7.38	16.44
8	0.62	9.34	7.33	17.29
9	0.61	8.36	6.03	15.00
10	7.50	7.26	6.70	21.46
11	7.23	7.01	5.81	20.05
12	43.80	27.56	6.02	77.38
13	10.00	9.76	5.64	25.40
14	9.88	9.21	5.62	24.71
15	10.25	10.00	5.62	25.87
16	9.09	8.54	5.49	23.12
17	14.76	13.72	5.45	33.93
18	12.75	12.39	6.30	31.44
19	9.70	10.36	5.50	25.56

[a] Effective dose acquired from non-contrast enhanced CT scan
[b] Effective dose acquired from contrast-enhanced CT scan
[c] Effective dose acquired from PET scan

The median effective dose for patients undergoing whole body ^{18}F-FDG PET/CT imaging in our study was 21.46 (8.58) mSv, which is less than is specified in the previous reports by Brix et al. [6] of 25.0 mSv and by Chawla et al. [11] of 24.8 mSv. Indeed, this result is within the range of the mean effective dose values for male and female patients as reported by Huang et al. [7], with effective doses ranging from 13.65 to 32.18 mSv and 13.45 to 31.91 mSv, respectively. These findings demonstrated that the effective doses resulting from the current protocols employed in this study were still lower than in the previously reported studies concerning the radiation dose to patients in a PET/CT imaging study. Therefore, it is justifiable to note that the radiation dose resulting from the PET/CT scan has to be tailored to the needs of the study and the impact of doing so should outweigh the radiation effect.

Variation to the basic CT practice has been employed to optimize the diagnostic capability of both CT and PET systems during an integrated PET/CT study. Low dose CT scan was not employed in our CT scanning protocol rather than NECT and diagnostic CT scans. Different approach of CT practice affects the resulting CT radiation dose in different way. Even though the utilization of IV contrast

enhanced CT has been reported to cause overestimation on the standardized uptake value (SUV) of attenuation corrected PET, which leading to contrast-induced artefacts on PET images [12], however, several evidences have revealed that the effects were statistically and clinically insignificant [13-15]. We optimized the advantage of diagnostic CT in our practice in cases where lesions are non PET-avid. The technique is capable in characterizing tumour physiology with improved visual delineation of tumour margins [16]. As the CT detail information can be optimized and utilized in patient clinical management, the diagnostic CT is being used as a protocol of choice for selected malignant diseases in our PET/CT study.

Our study was limited and had a small number of patients. Hence, to determine better the effective dose in a PET/CT study, further investigation with employment of various CT protocols and a larger group of samples presenting various indications for PET/CT study is warranted. A larger study would ensure a more significant result as there is more variation in the numerical data analysed. Variation in the technique such as low dosed CT would be carried out to test the effect of the image quality and hence would potentially be used as an alternative to the routine NECT technique. Moreover, the method of dose estimation is another limitation in this study. The use of special software for better and more accurate estimation of the effective dose of PET such as OLINDA [17] and effective dose of CT such as CT-Expo [18] and ImPACT [19] are recommended. Since these software programs were not available in our study, the estimation of an effective dose could only be derived from calculation, employing the available dosimetric descriptors including $CTDI_{vol}$ and the activity of the administered FDG.

4. Conclusion

The effective doses of whole body ^{18}F-FDG PET scan may be effective the lowest amongst the conventional CT imaging techniques. The median effective dose for patients undergoing whole body ^{18}F-FDG PET/CT examination at the Centre for Diagnostic Nuclear Imaging of Universiti Putra Malaysia was 21.46 mSv. The radiation exposure of patients during PET/CT study must be justified by clinical outcome throughout the diagnostic process.

Acknowledgements

The authors would like to thank the radiographers of the Centre for Diagnostic Nuclear Imaging of Universiti Putra Malaysia for their assistance in retrieving the PET/CT images and all the staff members of the centre for their kind support in this study. A special word of thanks goes as well to the Universiti Putra Malaysia for funding this work under Research University Grant Scheme (grant number 9331800).

References

[1] Blodgett TM, Meltzer CC and Townsend DW 2007 *Radiology* **242** 360-385
[2] Townsend DW, Carney JP, Yap JT and Hall NC 2004 *J. Nucl. Med.* **45** 4S-14S
[3] Nakamoto Y, Osman M, Cohade C, Marshall LT, Links JM, Kohlmyer S and Wahl RL 2002 *J. Nucl. Med.* **43** 1137-43
[4] Wu TH, Huang YH, Lee JJS, Wang SC, Su CT, Chen LK and Chu TC 2004. *Eur. J. Nucl. Med. Mol. Imaging* **31** 38-43
[5] 2008. *Radiation dose to patients from radiopharmaceuticals. Addendum 3 to ICRP Publication 53*. Ontario: International Commission on Radiological Protection. ICRP publication 106
[6] Brix G, Lechel U, Glatting G, Ziegler SI, Munzing W, Muller SP and Beyer T 2005 *J. Nucl. Med.* **46** 608-13
[7] Huang B, Law M W-M and Khong P-L 2009 *Radiology* **251** 166-74
[8] 2007. *The 2007 recommendations of the International Commission on Radiological Protection*. Ontario: International Commission on Radiological Protection. ICRP Publication 103
[9] Brix G and Beyer T 2005 *Nuklearmed.* **44** S51-7
[10] Khamwan K, Krisanachinda A and Pasawang P 2010 *Radiat. Prot. Dosim.* **141** 50-5
[11] Chawla SC, Federmna N, Zhang D, Nagata K, Nuthakki S, McNitt-Gray M and Boechat MI 2010 *Pediatr. Radiol.* **40** 681-6
[12] Mawlawi O, Erasmus JJ, Munden RF, Pan T, Knight AE, Macapinlac HA, Podoloff DA

and Chasen M 2006 *Am. J. Roentgenol.* **186** 308-19
[13] Hairil Rashmizal AR, Geso M., Noraini AR and Abdul Jalil N. 2010 *ANZ Nucl. Med.* **41** 19-23.
[14] Bunyaviroch T, Turkington TG, Wong TZ, Wilson JW, Colsher JG and Coleman R. 2008. *Mol. Imaging Biol.* **10** 107-13.
[15] Yau YY, Chan W, Tam YM, Vernon P, Wong S, Coel M and Chu SKF 2005 *J. Nucl. Med* **46** 283-91.
[16] Bisdas S, Baghi M, Smolarz A, Pihno NC, Lehnert T, Knecht R, Mck MG, Vogl TJ, Tuerky S and Koh TS 2007 *Invest. Radiol.* **42** 172-79
[17] Stabin MG, Sparks RB and Crowe E 2005 *J. Nucl. Med.* **46** 1023-27
[18] Stamm G and Hagel HD 2002 *Fortschr. Röntgenstr.* **174** 1570-76
[19] 2006. *ImPACT's CT dosimetry tool* [online]. London: ImPACT. Available from: http://www.impactscan.org/ctdosimetry.htm [Accessed 15 March 2014].