RESEARCH ARTICLE

Significantly Low Effective Dose from ^{18}FDG PET/CT Scans Using Dose Reducing Strategies: "Lesser is Better"

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Abstract

Background: Fluorodeoxyglucose (^{18}FDG) PET/CT imaging has become an important component of the management paradigm in oncology. However, the significant imparted radiation exposure is a matter of growing concern especially in younger populations who have better odds of survival. The aim of this study was to estimate the effective dose received by patients having whole body ^{18}F-FDG PET/CT scanning as per recent dose reducing guidelines at a tertiary care hospital. Materials and Methods: This prospective study covered 63 patients with different cancers who were referred for PET/CT study for various indications. Patients were prepared as per departmental protocol and 18FDG was injected at 3 MBq/Kg and a low dose, non-enhanced CT protocol (LD-NECT) was used. Diagnostic CT studies of specific regions were subsequently performed if required. Effective dose imparted by 18FDG (internal exposure) was calculated by using multiplying injected dose in MBq with coefficient 1.9×10-2 mSv/MBq according to ICRP publication 106. Effective dose imparted by CT was calculated by multiplying DLP (mGy.cm) with ICRP conversion coefficient "k" 0.015 [mSv / (mG. cm)]. Results: Mean age of patients was 49 ±18 years with a male to female ratio of 35:28 (56%:44%). Median dose of 18FDG given was 194 MBq (range: 139-293). Median CTDIvol was 3.25 (2.4-6.2) and median DLP was 334.95 (246.70 - 576.70). Estimated median effective dose imparted by ^{18}FDG was 3.69 mSv (range: 2.85-5.57). Similarly the estimated median effective dose by low dose (non-diagnostic) CT examination was 4.93 mSv (range: 2.14 -10.49). Median total effective dose by whole body 18FDG PET plus low dose non-diagnostic CT study was 8.85 mSv (range: 5.56-13.00). Conclusions: We conclude that the median effective dose from a whole body 18FDG PET/CT in our patients was significantly low. We suggest adhering to recently published dose reducing strategies, use of ToF scanner with CT dose reducing option to achieve the lower if not the lowest effective dose. This would certainly reduce the risk of second primary malignancy in younger patients with higher odds of cure from first primary cancer.

Keywords: ^{18}FDG - PET/CT - CT dose index - dose length product - effective dose - low dose non-enhanced

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Introduction

Introduction of hybrid positron emission tomography and computerized tomography (PET/CT) has allowed concurrent functional and morphological imaging with better sensitivity, specificity and diagnostic accuracy (Von Schulthess et al., 2006). For these reasons PET/CT has become an important component of management paradigm in oncology as it helps in diagnosis, staging, restaging, response evaluation and prognostication (Zaman et al., 2014). CT component in hybrid PET/CT is used for attenuation correction, anatomical correlation without or with diagnostic quality imaging.

In recent era, due to arrival of very effective new therapies, overall survival of many cancers has improved especially lymphoma and childhood cancers (Milana et al., 2015; Uslu et al., 2015). These patients on an average do have at least 2-3 PET/CT scans during their management and in view of better survival especially in younger population radiation dose incurred by these procedures is a major concern. CT component contributes more than 60% of effective dose to patients and increase the life time attributable risk (LAR) for second primary malignancy (Jallow et al., 2016). To address this issue, recent guidelines have recommended use of low dose non-contrast enhanced CT for attenuation correction and anatomical mapping and smaller doses of fluorodeoxyglucose (^{18}FDG) (Boellaard et al., 2015).

At the moment in Pakistan, there are four FDG based PET/CT facilities catering a population of more 200 million. Our facility being the youngest and the only accredited tertiary healthcare PET/CT facility by

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Joint Commission is strictly following these recent dose minimizing recommendations. To the best of our search, there is no local data regarding the radiation dose to patients who have FDG based PET/CT as per recently published protocols (Graham et al., 2015).

The objective of this study was to estimate the effective dose received by patients having whole body ^{18}FDG PET/CT scanning as per recent dose reducing guidelines at a tertiary care hospital.

Materials and Methods

This was a prospective study performed at the PET/CT facility of Aga Khan University Hospital, Karachi, Pakistan from March-April 2016. As per departmental protocol, patients were fasted for at least 4 hours but encouraged maintaining hydration with plain water. Diluted oral gastrografin (10 cc in liter water) was given to patient to drink at least 1 hour prior to radiotracer injection. Fasting blood glucose <200 mg/dl was mandatory and test were rescheduled if it ≥200 mg/dl. Patients were positioned on bed/recliner in uptake room and ^{18}FDG was injected intravenously (3 MBq/kg) followed by flush with 10 cc of normal saline. During uptake period (50-75 minute) patients were encouraged to take 500 ml of plain water with gastrografin and were asked to void bladder 5 minutes prior the PET/CT imaging.

PET/CT images were acquired using Toshiba Celesteoin with 16 slice CT (Toshiba Med Corp, Japan). The PET scanner has lutetium oxyorthosilicate (LSO) crystal detectors with a time of flight (ToF) resolution time <450 picoseconds. A scout view was acquired to plan the study, followed by a non-contrast enhanced CT (NECT) protocol in cranio-caudal direction for the purpose of anatomical localization and attenuation correction (Tube Potential: 120 kVp; Tube Current: upto 120 mAs; Rotation Time 0.58 sec/rotation; Slice Thickness: 1mm). Subsequently a three dimensional PET scan was acquired at 3 min/bed position in a caudo-cranial direction.

The effective dose imparted by ^{18}FDG (internal exposure) was calculated by using coefficient 1.9×10-2milliSievert/Mega Becquerel(mSv/MBq) according to ICRP publication 106 (ICRP 2008).To estimate the effective dose from whole body CT scan (external exposure), volume CT Dose Index (CTDIvol in milliGray [mGy]) and Dose length Product (mGy. cm) was directly obtained from the display screen of CT workstation. Effective dose was calculated by multiplying DLP (mGy.cm) with ICRP conversion coefficient "k" 0.015 [mSv / (mG. cm)] (Christner et al., 2010).

Results

Total 63 patients were included in this study who were referred for ^{18}FDG PET/CT examinations for their oncological workup (staging 40%, restaging 11%, response evaluation 30%, Follow-up 17%; Surveillance 02%). Out of these 63 patients, 20 (32%) had lymphoma, 09 (14%) had gastrointestinal, 06 (10%) had breast, 5 (8%) ovarian, 5 (8%) had carcinoma of unknown primary, 4 (6%) each for kidney/urinary bladder and mouth and 10 (16%) miscellaneous cancers. Nineteen (30%) patients have had at least 1 PET/CT examination in past. Mean age

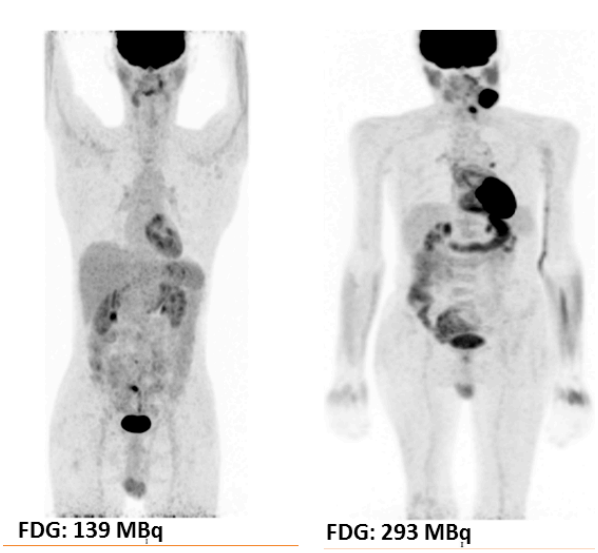

Figure 1. Maximum Intensity Projection (MIP) Whole Body PET Images Acquired with Lowest and Highest Injected Doses of 18FDG

Table 1. Study Demographics

Variables	N=63
Mean Age ± SD	49 ± 18
Male: Female	35:28 (56:44%)
BMI (Kg/m^2)	24.42 ± 4.22
Previous PET-CT study	19 (30%)
Median (range) dose of FDG (MBq)	194 (139-293)
Median (range) Mean Uptake Time	70 (55-97)
Mean FBS ± SD (mg/dl)	111 ± 26
Median (range) CTD_{Ivol}	3.25 (2.4-6.2)
Median (range) DLP	334.95 (246.70-576.70)
Mean ± SD Hepatic SUV_{mean}	1.71 ± 0.44
Indication	
Follow-up	11 (17%)
Response Evaluation	19 (30%)
Re-staging	07 (11%)
Staging	25 (40%)
Surveillance	01 (02%)
Positive: Negative	47:16 (75:25%)

SD=standard deviation; BMI=Body mass index; FDG=Fluorodeoxy Glucose; FBS=Fasting Blood Sugar; CTDI=CT dose Index; DLP= Dose Length Product; FU= Follow-up; RE= Response Evaluation; RS= Re-Staging; SG= Staging; SV= Surveillance

Table 2. Effective Doses (mSv) Imparted by ^{18}FDG, CT and Total by a PET/CT Study

Effective Dose by ^{18}FDG Median (mSv) (Range) (1.9×10-2 mSv/MBq x MBq)	Effective Dose by CT Median (mSv) (Range) (DLP x "k")*	Total Effective Dose Median (mSv) (Range)
3.69 (2.85-5.57)	4.93 (2.14-10.49)	8.85 (5.56-13.00)

* k = 0.015 [mSv / (mG. cm)] (Christner et al., 2010)

of patients was 49 ±18 years with a male to female ratio of 35:28 (56%:44%). Mean body mass index (BMI) of cohort was 24.42 ± 4.22 Kg/m^2. Mean fasting blood glucose level was 111 ± 26 mg/dl. Median dose of ^{18}FDG given was 194 MBq (range: 139-293) and median uptake time was 70 minute (range: 55-97). Mean hepatic standardized uptake value (Hep SUVmean was 1.71 ± 0.44). PET/CT examination was positive for ^{18}FDG avid lesion (s) in 47 (75%) and negative in 15 (25%) cases. Median CTDIvol was 3.25 (2.4-6.2) and median DLP was 334.95 (246.70 - 576.70) (Table 1).

Estimated median effective dose imparted by ^{18}FDG was 3.69 mSv (range: 2.85-5.57). Similarly the estimated median effective dose by low dose (non-diagnostic) CT examination was 4.93 mSv (range: 2.14 -10.49). Median total effective dose by whole body ^{18}FDG PET plus low dose non-diagnostic CT study was 8.85 mSv (range: 5.56-13.00) (Table 2).

Discussion

AIn recent days ^{18}FDG based PET/CT imaging has become an essential component of management paradigm of many cancers (Ghotbi et al., 2007). A whole-body PET/CT scanning is accompanied by substantial radiation dose to the patients. We must be cognizant of importance of potential risk from radiation exposure (i.e. second primary malignancy) which must be gauged and understood so that risk-benefit ratios can be assessed. This is particularly important for younger population with better probability of post-treatment survival. To address this issue, various societies have issued appropriate use criteria, designed imaging protocol and stressed upon using time of flight (ToF) scanners which have better signal to noise ratio even with lower injected dose of radiotracer. In our study, low dose CT contributed about 60% of total effective dose to the patients. This is slightly higher than a recently published study in which CT contribution to total dose was 54% as they have used higher injected dose of ^{18}FDG than our protocol (194 MBq vs 341 MBq) (Mahmud et al., 2014). However, percentage contribution in our study was significantly lower than another published study which has a reported contribution of about 80% but they have used a diagnostic rather than low dose CT scan (Huang et al., 2009).

Median effective dose from PET study in this study was 3.69 mSv for median injected ^{18}FDG dose of 194 MBq. This dose is in accordance with recent European Association of Nuclear Medicine (EANM) guidelines (Boellaard et al., 2015). Effective dose delivered by ^{18}FDG in this study (i.e. 3.69 mSv) is significantly lower than published studies (6.30 and 6.23 mSv) (Huang et al., 2009; Mahmud et al., 2014). The most plausible explanations for this disparity are (1) not following dose reducing strategy; (2) well known concept of lower image quality with lower radiotracer dose. However, it is now a well-established fact that shorter timing resolution of scanner with ToF option ensures better signal to noise ratio, better image quality, reduced imaging time and improve lesion detectability (Surti 2015). Since the timing resolution of our ToF scanner was<450 picoseconds, the image quality was good even with low doses of ^{18}FDG (Figure1). This technical fact seeks attention of those nuclear medicine users who are using higher doses of ^{18}FDG despite of having PET scanners with ToF option. Median effective dose delivered by low dose non-enhanced CT in this study was 4.93 mSv and this is significantly lower than effective dose of 7.50 mSv reported in the published data (Mahmud 2014). The sentinel reason for this low CT effective dose is availability of Adaptive Iterative Dose Reduction-3D (AIDR-3D) technology in our CT scanner. These results endorse the effectiveness of dose reducing strategies recommended by current EANM guidelines which encourage non-diagnostic CT as routine and discourage the use of diagnostic quality CT with intravenous and oral contrasts (Boellaard et al., 2015). We acquired diagnostic CT study for a particular region of the body after acquiring whole body PET/CT with a low-dose CT scan protocol which is also regarded as a preferable option by recent guidelines (Boellaard et al., 2015).

Median total effective dose imparted by PET/CT scan in this study was 8.85 mSv. To the best of our search this is the lowest reported dose imparted to patient by a single PET/CT study. The lowest reported median effective dose is 13.8 mSv using a low dose non-enhanced CT (Mahmud 2014). While median effective doses reported in other studies are 25 mSv (Brix et al., 2005) and 24.8 mSv (Chawla et al., 2010).

So this study draws our attention towards an important fact that the effective dose from a whole body PET/CT scan at our Institute is significantly lower if not lowest (although we could not find any published data matching this low dose). As mentioned above, reasons for this significantly lower (if not lowest) are adherence to the dose reducing strategies mentioned in recent guidelines and use of a scanner with the lowest ToF and CT dose reducing module. We are confident that reducing the effective dose of a whole body PET/CT study would reduce the risk of second primary malignancy in our younger patients who have better odds of cure from their primary cancers like lymphomas (Milana et al., 2015). 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.

This study has some limitations and primary one is smaller sample size. We are cognizant of the fact that larger sample size would enhance the statistical strength but these preliminary results from available data pave the path for a larger prospective study. Second limitation is use of simple strategies for effective dose calculation. However, the coefficients factors used in this study have been derived from well designed and validated studies. Third limitation is that we did not calculate lifetime attributable risk for cancer and would like to use in other prospective study.

We conclude that the median effective dose from a whole body ^{18}FDG PET/CT in our patients was significantly lower if not the lowest. We suggest adhering to recently published dose reducing strategies, use of ToF scanner with CT dose reducing option to achieve this lower if not the lowest effective dose. This would certainly reduce the risk of second primary malignancy in younger

patients with higher odds of cure from first primary cancer.

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