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Estimation of The Patient's Specific Effective Dose for The Total Body F18- FDG PET/CT Scan, A Single Centre Experience.

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ABSTRACT:

The whole-body scanning of fluorine-18-fluoro-2-deoxy-D-glucose (^{18}F-FDG) combined with positron emission tomography/ computed tomography (PET/CT) is considered an important modality used for diagnosis, tracking, and staging of the oncological as well as neurological diseases. On the other hand, the interest is rising as a concern of the radiation exposure for patients during PET/CT because of the higher radiation dose as compared to other imaging modalities.

This study aims at estimating the patient-specific effective dose for ^{18}F- FDG PET/CT studies using the patient's size-dependent correction method at a single centre in Riyadh, KSA. **Patients and methods:**

A total number of 80 patients18F-FDG examinations were recorded. For each patient, the following parameters were recorded the age, sex, weight, height, body mass index (BMI), CT volume dose index (CTDIvol), the dose length product (DLP), and finally the net injected FDG activity. The total patient effective dose was then recorded and evaluated. **Results:** The results show that the mean effective dose for the PET scan for the patients scaled to their body weight was 8.36±1.2 mSv. On the other hand, for the CT part, the patient effective dose estimated by using the DLP method was 26.8% higher than that estimated by the Source- Specific Dose Estimate (SSDE) method which directly involves the patient size in its calculations. The total patient's effective dose resulting from using the DLP method was 18.886 mSv and by using the SSDE method it was 15.138 mSv.

Conclusion: The patient's effective dose estimate from the PET scan should be calculated by considering the weight-scaled.

The estimated patient effective dose from the CT scan during PET-CT F18-FDG using the DLP method was 26.8% higher than that estimated by the SSDE method. The patient's effective dose from the CT part was higher than that of the PET part.

Key Words: Dosimetry, PET/CT, Patient weight.

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INTRODUCTION:

The whole body ^{18}F-FDG PET/CT is a common molecular imaging procedure that are used nowadays for the diagnosis, tracking, and staging of oncological as well as neurological diseases [(1)]. PET/CT is considered as a hybrid imaging scanners that combine (PET) positron emission tomography with computed tomography (CT). Several cyclotrons and generators produced radiopharmaceuticals are used in studying several pathologies using PET/CT [(2)]. The most popular one is F-18 labelled with fluoro-2-deoxy-D-glucose molecule FDG [(3)]. Oncology imaging using ^{18}F-FDG-PET is currently the fourth technology in the ranking of technologies contributing most to the collective effective dose in all European countries [(4, 5)].

The involvement of PET and CT dose in total-body PET/CT scanning has been observed to vary significantly, particularly as the CT's contribution can range from 54% to 81% of the total combined dose measurement depending on the CT parameters using the same scan length. Moreover, the term whole-body PET/CT is being utilized to refer to various body ranges, such as from the vertex to the mid-thighs, the base of the cranium reaching the upper thighs, or another protocol, beginning with the head and ending with the feet, making it difficult in comparing divers centres and studies [(6, 8)].

By gathering data on the administered activity of the PET tracer and the volumetric computed tomography dose index ($CTDI^{vol}$) in the CT part of the study, in addition to dose-length product (DLP), it is possible to measure or estimate the patient dose in PET/CT and produce a diagnostic reference levels (DRL). In several nations, the specifications have been formalized as the DRL. The patient's effective dose can then be determined using all of this data. The International Commission on Radiological Protection (ICRP) has defined an effective dose as the tissue-weighted total of the equivalent doses for all specified human body organs and tissues and indicates the stochastic health risk for the entire body [(9)].

The patient size is an important parameter that should be taken into consideration while calculating the estimated patient dose by using the CT part of the PET/CT study **(10)**. It has been stated that the patient size—dependent factor ie. SSDE could be utilized for this estimation for the $CTDI^{vol}$ parameter. It can be used for a range of different patient sizes with the availability of the $CTDI^{vol}$ from the newer CT devices. The patient size correction method has been used by several groups of researchers which lead to the availability of those correction factors which can be employed by the technologists to evaluate the dose to the patient before the CT part of the PET/CT study **(l11)**.

This study aims at the estimation of the patient-specific effective dose for F18- FDG PET/CT studies using the patient's size-dependent correction method at a single centre in Riyadh, KSA.

PATIENTS AND METHODS:

The study involves a total number of 80 patients (27 Female and 53 Male) ^{18}F-FDG PET/CT examinations in the period between January 2021 and June 2022 were recorded. All patients underwent imaging using a GE Healthcare Discovery PET/CT 16 slice (Milwaukee, Wisconsin) installed at a private PET-CT centre in Riyadh City, Kingdom of Saudi Arabia. All patients have been injected with a dose of ^{18}F-FDG activity equal to 3.7 MBq/kg and spent a waiting time of up to 1-hour duration in the waiting room before starting the whole-body PET/CT examination. Age, sex, weight, height, body mass index (BMI), CT volume dose index ($CTDI^{vol}$), dose length product (DLP), as indicated by the CT, and lastly net injected FDG activity were all recorded for each patient.

The PET scans were acquired for 3 minutes per bed position; the range is 6-11 bed positions. The imaging for all patients is done from the head to the mid-thigh.

The acquisition protocol for the CT portion of the study was determined by the patient's body mass index (BMI), which is shown in ***Table (1)***. A total-body PET/CT examination took an average of 26 minutes to complete.

Table (1): The CT acquisition parameter.

Parameter	BMI <20	20 <BMI <27	BMI> 27
Number of Patients	9	32	39
Tube voltage (kVp)	100	120	120
Tube current (mA)	200	250	280
Rotation time (sec)	0.5	0.5	0.5
Average Scan time (sec)	11.2	11.2	11.2
Collimation	16x1.25	16x1.25	16x1.25
Pitch	0.938	0.938	0.938

Using ICRP values [5] derived as follows, the effective dose arising from the PET section of the PET/CT exam (EDPT) resulting from the activity of the injected FDG was calculated: 0.019 mSv/MBq for a 70 kg adult, 0.025 mSv/MBq for a 57 kg adult, and 0.036 mSv/MBq for a 33 kg child, each applied as necessary to individuals who fit into the most suitable weight group (i.e., greater than 65 kg, 45-65 kg, and less than 45 kg):

$$\text{ED (mSv)} = \text{Injected FDG MBq X (mSv/MBq)} \quad \text{Eq. (1)}$$

The weight-scaled effective dose (ED^{PTWS}), which takes into account the individual patient weights rather than the conventional ICRP model sizes, was then calculated using this value modified for each individual patient:

$$ED^{PTWS} = \text{ED PT (mSv) X (Model weight/PT weight) kg} \quad \text{Eq. (2)}$$

As regards to the radiation doses from the CT acquisition is so considerable in the total effective dose delivered to the patient in PET/CT scanning. To obtain the effective dose from the whole length of the scan, the dose-length product (DLP) is estimated and displayed by the newer scanners for each patient. DLP could be calculated directly by multiplying $CTDI^{vol}$ by the scan length L [12].

$$DLP = CTDI^{vol} \times L \text{ (mGy.cm)} \quad \text{Eq. (3)}$$

To determine the patient's effective dose ED from DLP data we can use the following equation:

$$ED^{DLP} = DLP \; x \; k \quad \text{Eq. (4)}$$

This equation was used by the International Commission on Radiological Protection (ICRP) 60 and revised in ICRP 103 [13, 14] using a weighting factor that has been estimated from a radiobiological point of view. In the present study k, a coefficient obtained from ICRP 103, in units of mSv/ (mGy cm) was k = 0.015 for the trunk region.

Another method was applied by using ($CTDI^{vol}$) data from the CT scanner, however, from the AAPM report 204 [15] it was approved that it is independent of the patient size. To take the patient size into consideration, the patient-specific dose estimate (SSDE) for each patient has been introduced for a proper methodology to be used to find the difference in the effective dose from patient to another. The patient size can be calculated from the patient's effective diameter which has been calculated by measuring the X anteroposterior (AP) and Y lateral dimensions (LAT) and then using the following formula described in [11]:

$$\text{Effective Diameter (Dia}^{\text{effective}}) = (AP \times LAT)^{\frac{1}{2}} \quad \text{Eq. (5)}$$

Then the SSDE can be estimated by

$$SSDE = CTDI^{vol} \times f^{size} \quad \text{Eq. (6)}$$

The effective diameter calculated using Equation 5 to search for the coefficient of the conversion factor, f^{size} to scale the $CTDI^{vol}$ values obtained by using a 32 cm diameter CTDI phantom illustrated in the AAPM Report 204.

Using spreadsheet software, the statistical analysis was performed using descriptive and summary statistics (Excel 2010, Microsoft and Redmond, WA). The average, standard deviation, minimum, maximum, and range for each parameter under study were all included in this statistical analysis.

RESULTS:

PET Dosimetry: Using equations 1 and 2, the corrected effective dose for the patients has been calculated as tabulated in the following ***(Table 2)***:

Table (2): PET dosimetry results among different body weight.

Weight range	No. patient	Age (year)	Length Cm	Weight kg	BMI kg/m2	Activity mCi	Effective dose mSv
Less than 45	2	(32.50±6.36) (28-37)	(158.00±8.49) (152-164)	(43±1.41) (42-44)	(17.33±2.42) (15.62-19.04)	(7.30±0.42) (7-7.60)	(9.72±0.56) (9.32-10.12)
45-65	21	(49.62±15.82) (19-77)	(165.76±6.76) (152-164)	(58.62±6.18) (45-65)	(21.42±2.69) (15.21-5.96)	(8.59±1.18) (6-10.40)	(7.94±1.09) (5.55-9.62)
Larger than 65	57	(49.00±13.42) (21-73)	(167.70±8.59) (150-189)	(82.60±13.47) (65-119)	(29.48±5.00) (21.46-3.82)	(10.59±1.69) (6-15.40)	(7.44±1.19) (4.22-0.82)
Total	80	(49.36±14.53) (19-78)	(166.67±8.3) (150-189)	(74.86±17.16) (42-119)	(26.96±5.99) (15.21-43.81)	(9.95±1.85) (6-15.4)	(8.36±1.2) (4.22-0.82)

In ***Table (2)***, the total number of studied patients was 80, two patients only were less than 45 kg, 21 were between 45-65 kg, and 57 were over 65 kg. The range of injected radioactivity of F18-FDG was between 6-15.4 mCi with a mean dose of 9.95 mCi. Also, it was found that the mean body mass index was 26.96 ranging between 15.21 to 43.81. Lastly, the mean effective dose according to the grouping of the patients according to their body weight was 8.36±1.2 mSv.

CT Dosimetry: The patient's effective dose has been calculated by two different methods: *DLP method*:

It has been calculated using equation 4, where the DLP values were obtained from the CT output data for each patient and the k factor from ICRP 103, in units of mSv/ (mGy cm) was k = 0.015 for the trunk region. The results show that the mean effective dose for the patients was 10.526 ±0.529 mSv and ranged from 9.259 to 11.667 mSv.

SSDE Method: In this method, all the patient's effective diameter has been calculated by using equation 5, then using the result to search for the f^{size} derived from AAPM report No. 204 and then using those conversion factors the SSDE can be calculated using equation 6.

The results in this method indicated that the mean patient's effective dose was 6.778± 0.65 mSv, ranging from 5.098 to 7.245 mSv. The estimated patient effective dose obtained by using the DLP method was 26.8% higher than that obtained by the SSDE method which involves the patient size. The total patient's effective dose resulting from using the DLP method was 18.886 mSv and by using the SSDE method it was 15.138 mSv. Comparisons with other previous studies are illustrated in ***Table (3)***.

Table (3): Contribution of CT and PET effective dose with previous studies

Study	Scan Length	Activity	PET scan (mSv)	CT scan (mSv)	PET/CT (mSv)
Huang *et al.* [8]	Base of the skull to upper thighs	370 MBq	6.23	7.32	13.55
Willowson *et al.* [6]	Base of the skull to mid-thighs	304 MBq	6.30	8.20	14.50
S. Avramova et al. [7]	Head to feet	370 MBq	4.90	8.90	13.80
Sabri et al. [17] (DLP based)	Base of the skull to upper thigh	212 MBq	4.02	10.8	14.82
Sabri et al. [17] SSDE	Base of the skull to upper thigh	211.63 MBq	4.02	5.45	9.47
The current study DLP	Head to mid-thigh	3.7 $MBq.kg^{-1}$	8.36	10.526	18.886
The current study SSDE	Head to mid-thigh	3.7 $MBq.kg^{-1}$	8.36	6.778	15.138

DISCUSSION:

Radiation exposure risks for individual patients are important for the justification of the risk-benefit assessments and also are relevant for protocol optimization and staff protection. Dose calculation methods could depend on a combination of the reference values and patient-specific as well as scanner-specific data. Optimized patient dose estimates, are more important than conservatively high estimates for many patients who may have perform many PET/CT investigations and need to follow their cumulative exposure radiation dose. The precision of the doses to the patient used for this estimation depends on the dose calculation method used and the parameters involved in that estimation. The precision of dose estimates based on special information depends on the extent to which the unique information is employed, but dose estimates based on reference values depend on specific characteristics of the patient population in relation to the reference population.

Exam and patient-specific characteristics would be taken into account in the ideal dosimetry method. The current study estimated the ^{18}F-FDG PET/CT radiation dosimetry using patient- and study-specific data and commonly available dosimetric resources from several reports. Studies on patient dose estimations should also critically address these issues, such as machine parameters, the diagnostic protocol used, tissue weighting factors, and analysis algorithms used, in order to reach a realistic implication of the results obtained **(16, 17)**. In the current study, the mean effective dose for the PET scan for the patients has been scaled to their body weight and found to be 8.36±1.2 mSv.

Although, it was determined that for the CT component, the patient effective dose calculated using the DLP technique was 26.8% greater than the patient size-adjusted SSDE method's estimate. The total patient's effective dose resulting from using the DLP method was 18.886 mSv and by using the SSDE method it was 15.138 mSv. In comparison with other previous studies as illustrated in ***Table (3)***, it was revealed that as regards the PET effective dose for patients, the results estimated by or study were slightly higher than other studies by Huang et al. 2009, ***Avramova et al***. 2015 and ***Sabri et al.*** 2019 **(8, 7 and 17)**, as the dose given to the patient was according to his/her weight and the estimation was made by involving the weight scaling method which gives a more accurate estimation for the effective dose for the PET scan as described by ***Willowson et al***. **(6)**.

On the other hand, the results for the PET effective doses for the patient in the study done by ***Sabri et al***. were much lower than our study due to the given dose for patients was a fixed dose with a lower value than in the present study **(17)**. Investigating the CT part of the PET/CT scan, comparison with other studies revealed that all the reviewed studies have used fixed tube voltage and a variable tube current-time products, All of the studies have measured the DLP as well as the CTDI $^{(vol)}$, the effective dose from the CT part in the studies of ***Huang et al.*** **(8)**, ***Willowson et al***. and ***Avramova et al***. have used the DLP method in their calculation and it was found to be higher than our study **(6,7)**. On the other hand, ***Sabri et al***. used two different methods in our study the DLP method gives results that was matching our study results while by using the SSDE method their results show lower effective dose value due to their justification of the smaller size of average Malaysian population which in turn affects the correction factor for the patient size **(17)**.

As a consequence of the calculated PET part and CT part effective doses and comparisons with other studies it was revealed that using the weight-scaled method for PET calculation, then using the SSDE method will result in accurate effective dose calculations for the ^{18}F-FDG PET/CT total body exams.

CONCLUSION:

The patient's effective dose estimate from the PET scan should be calculated by considering the weight-scaled. The estimated patient effective dose from the CT scan during PET-CT ^{18}F-FDG using the DLP method was 26.8% higher than that estimated by the SSDE method. The patient's effective dose resulting from the CT part is higher than that of the PET part.

Author's statement: This submission complies with ethical guidelines and approved by the Internal Review Board (IRB) at Inaya Medical Colleges, the results is the own original work of the authors and has not been published previously elsewhere.

Declaration of competing interest: Authors declares that there is no conflict of Interest.

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