Pediatric Dose Assessment in Combined 18F (FDG) PET/CT Procedures

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Abstract. The fast growing use of hybrid Positron Emission Tomography (PET) combined with Computed Tomography (CT) in diagnosis has proven to provide more accurate diagnostic information on cancer diseases. This is true for both adult and pediatric patients because of the ability for CT to give anatomic information supporting the metabolic information obtained from PET. Although the practice of using PET/CT is found to give clinical benefits, concerns on the doses delivered to pediatric patients continue to rise because of limited data. At King Faisal Specialist Hospital, Riyadh, Saudi Arabia, PET/CT was introduced in the year 2006. PET procedures are performed using 18F fluorodeoxyglucose (FDG) and CT scanning is performed using 80 kVp, 75 mA, 1.675:1 pitch and scan length from mid brain to mid thigh. For ages 14 and 15 years old, the kVp and mAs are 140 and 100 respectively. This study aims to provide data on effective doses to pediatric patients for PET/CT procedures which could contribute to the establishment of reference dose levels. It is also aimed to investigate possible means to reduce pediatric doses to limit the risks of exposures. A total of 113 patients were included in the study and were grouped as age 0 (less 1 year old), 1 (1 to less 5 years old), 5 (5 to less 10 years old), 10 (10 to less 14 years old) and 15 (14 to 15 years old). Age groups 5 and 10 years old give the highest percentage of patients (38 and 37% respectively). Results show that CT doses are in the range of 15 to 25% of the PET doses. The combined mean effective dose due to PET and CT is highest for neonates (15.5 mSv) and age group 1 year old (15.9mSv). Studies have shown that low dose CT provides adequate attenuation and does not contribute high noise to PET images. Reducing the mA from 75 to 10 for age groups 0 and 1 will reduce the dose by a factor of 100.

KEYWORDS: PET; CT; effective dose; attenuation; age group

1. Introduction

The emergence of PET/CT technology in imaging has made possible the combined registration of two images from two different modalities. CT gives the anatomical images and PET gives the functional information which when combined improves diagnosis [1]. The CT based attenuation correction contributes to better imaging because of lesser noise and it reduces the PET scanning time [2]. PET/CT utilizes whole body imaging from head or neck to the upper thigh. With the longer scan length and with the use of high resolution CT scanner, the effective dose can reach to about 30 mSv [3]. PET effective doses depend on the amount of activity of 18F-Fluorodeoxyglucose (FDG) administered. For pediatric patients the dose coefficient varies with the age of the patients. Using the dose coefficient in the International Commission on Radiological Protection (ICRP) Report 80, the activity of a 274 MBq for six (6) years old patients gives an effective dose of about 12 mSv [4]. The use of PET/CT imaging modality is aimed to produce accurate fusion of image registration with the lowest possible dose to patients [5].

The new GE Discovery ST PET/CT unit at King Faisal Specialist Hospital & Research Centre, Riyadh, Saudi Arabia, is the first unit installed in the country. It started to become operational in year 2006. For these two years, there were already about 2,000 pediatric and adults patients for whole body PET/CT imaging. This study aims to establish a data base on the combined effective doses due to PET and CT to pediatric patients, determine the factors that can result to high doses and recommend methods for reducing the doses. It also aims to determine the CT dose conversion coefficient that can be used to easily estimate patient effective doses for Saudi children.
2. Methods

2.1 Patient Data
Record of patients for years 2006 and 2007 were retrieved and data of patients' weight, age, gender and activity of 18F (FDG) were recorded. Patients were grouped in accordance with the National Radiation Protection Board (NRPB) standard reference age groups of 0, 1, 5, 10 and 15 years old. Age ranges for each age group are as follows: neonates less than 1 year old for group 0 age; 1 to less that 5 years old for age group 1; 5 to less than 10 years old for age group 5; 10 to less than 14 years old for age group 10; and 14-15 years old for age group 15. Patients of ages 14 and 15 years old are being considered in the CT whole body imaging protocol to be in the adult age.

2.2 CT dose Estimation
The results of the acceptance test performed for the new unit were verified for compliance and calibration. All tests were recorded as successfully passing the pass/fail criteria. The patient weight, height gender and age were taken from the computerized patient information system. The CT exposure parameters that were taken from the protocol were kVp, mA, rotation time (sec), pitch, and slice thickness (mm). To evaluate the agreement of patient sizes of Saudi children with the standard values of the National Radiological Protection Board (NRPB), the equivalent cylindrical diameter (ECD) in cm was calculated using the equation:

\[ ECD = 2\left[\frac{w}{\pi \cdot h}\right]^{0.5} \]

where \( w \) is weight (grams) and \( h \) is height (cm). This equation approximates the average trunk thickness of the patient.

The CT effective dose of each patient was estimated using the IMPACT dose calculator. The software program uses the Monte Carlo normalized organ dose data. Since Impact dose calculator uses CTDI\textsubscript{air} which is CT scanner specific and the GE Discovery ST data is not available, the CT scanner which gives the closest value of the CTDI\textsubscript{air} was selected. In the estimation of the CT effective doses, the contribution of the topogram when performed was neglected. The CT dose index (CTDI) and CT dose length (CTDL) values were taken from the monitor display and were used to estimate the CT dose conversion coefficient.

2.3 PET Dose Estimation
The PET effective dose for each patient was estimated by multiplying the activity administered and the dose coefficients for ages 1, 5, 10 and 15 years old. Interpolation was made for 0 age and for ages that lie in between. The mean effective dose due to PET for each age group was determined and the combined mean effective dose due to CT and PET were obtained by pooling all ages together. The Pearson correlation (\( p < 0.001 \)) of administered activity with weight and age and the PET effective doses with weight were determined. A student t-test at 95% confidence level was performed between age group 0 and 1. Factors for high doses were investigated for each age range.

3. Results and Discussion
A total of 113 pediatric patients were included in the study. Male patients comprise 60% of the total patients. Table 1 shows the demographic information of the patients and Fig. 1 shows the distribution of the patients for each age group. The mean age is about 10 years old and there is a wide variation in the age (Table1).
Table 1: Summary of the pediatric patient demographic data on age, gender, weight and height.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Age (Years)</th>
<th>Weight (kg)</th>
<th>Height(cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>Mean 68</td>
<td>SD 9.2</td>
<td>Median 45</td>
</tr>
<tr>
<td>Female</td>
<td>Mean 45</td>
<td>SD 3.7</td>
<td>Median 3.7</td>
</tr>
</tbody>
</table>

Figure 1: Distribution of patients per age group.

About 75% belongs to age groups 5 and 10 and only 3% for 0 age group (Fig.1). The calculated ECD for age groups 1 to 10 agrees with the NRPB standard trunk sizes except for age group 0. This is due to the small number of patients for this group. More data should be collected for age group 0 to verify this result.

Figure 2: Graph showing the calculated ECD with an error bar of about 10% of the value and the NRPB standard sizes.

The CT whole body imaging has the scan length from mid brain to mid thigh. The kVp and mAs for age group 0 to 10 are 80 and 75 respectively. The kVp and mAs changed for ages 14 and 15 years old where the values for adult patients were used (Table2). Although they were considered as adults in the
CT protocol for exposure parameters, this study is considering them to belong to the pediatric age group of 15 years old.

Table 2: Exposure parameters for CT whole body imaging and PET administered mean activity of 18F (FDG).

<table>
<thead>
<tr>
<th>CT Exposure Parameters</th>
<th>PET 18F (FDG) Activity (MBq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>kVp</td>
<td>mAs</td>
</tr>
<tr>
<td>80/140</td>
<td>75/100</td>
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</tbody>
</table>

The estimated mean effective dose due to the contribution of CT for each age group is shown in Table 3.

Table 3: Mean effective doses due to CT and PET and the combined effective doses for each age group.

<table>
<thead>
<tr>
<th>Age group</th>
<th>PET dose (mSv)</th>
<th>CT dose (mSv)</th>
<th>Total (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>12.9</td>
<td>2.63</td>
<td>15.53</td>
</tr>
<tr>
<td>1</td>
<td>13.48</td>
<td>2.42</td>
<td>15.9</td>
</tr>
<tr>
<td>5</td>
<td>10.61</td>
<td>1.79</td>
<td>12.4</td>
</tr>
<tr>
<td>10</td>
<td>9.85</td>
<td>1.65</td>
<td>11.5</td>
</tr>
<tr>
<td>15</td>
<td>8.7</td>
<td>2.08</td>
<td>10.78</td>
</tr>
</tbody>
</table>

The neonates and the 1 year old age group have the highest mean effective dose (2.63 and 2.42 mSv) due to CT. The use of high kVp and mAs has contributed to the high effective dose for this age group. The study of G. Brix and T. Beyer [2], shows that low dose CT procedures contribute to adequate attenuation and does not contribute to high noise to PET images. Changing the mAs from 75 to about 10 to 20 mAs will reduce the effective dose to neonates and age group 1 year old patients by a factor of 100. The estimated mean effective dose of 2.1 mSv for age group 15 years old is attributed to the high kVp and mAs. The kVp for this group is almost double the value for the other age groups and a 25% increase in the mAs.

The error in estimating the effective doses from specific scanner using Monte Carlo data derived for a different CT scanner was estimated to be up to 25% [6]. However, deriving a dose conversion coefficient for trunk sizes that are in good agreement to the standard trunk sizes using the Monte Carlo data can be an easier method for estimating effective doses. Pooling all ages, the mean effective dose was obtained to be 1.8 mSv. The obtained CTDI value was 9.07 mGy and the CTDL was 505.5 mGy-cm. The derived dose conversion coefficients using CTDI and CTDL were 0.2 mSv/mGy and 0.003 mSv/mGy-cm respectively.

The mean administered activity of 18F (FDG) is 266 MBq and there is a wide variation from patient to patient (standard deviation =74). The maximum activity was 418 MBq which was administered to a patient in the 10 years old age group. This amount of activity is administered to adult patients. Fig. 3 shows that the activity of 18F (FDG) is weight dependent (Fig. 3). The Pearson correlation (p<0.001) between administered activity and weight is significant ($r^2 = 0.63$). The estimated mean effective doses due to PET for neonates and 1 year old age group have the highest values of 12.9 and 13.48 mSv respectively (Table3).

Combining the estimated mean effective doses due to CT and PET, it gives the total effective dose for each age group. The CT effective doses are in the range of 15 to 25% of the PET effective doses. The
combined mean effective dose is highest for the neonates (15.5mSv) and for 1 year old age group (15.9 mSv). Since the administered activity of the administered 18F (FDG) is weight dependent, a review of the protocol for neonates and 1 year old age group is needed for possible dose reduction.

The establishment of an image quality criteria for both CT and PET images should be studied as the CT exposure parameters and PET administered activities are being reduced to ensure that optimum diagnostic information is obtained.

**Figure 3:** Scatter graph of the administered activity of 18F (FDG) with the weight (kg) showing the Pearson correlation coefficient (p<0.001).

![Figure 3: Scatter graph of the administered activity of 18F (FDG) with the weight (kg) showing the Pearson correlation coefficient (p<0.001).](image)

**Figure 4:** Mean effective doses due to CT and PET for each age group.

![Figure 4: Mean effective doses due to CT and PET for each age group.](image)

The student t-test for the mean effective dose for the neonates and the 1 year old age group with unequal variance and at 95% confidence level was 0.77. This showed that there is no significant difference in the mean effective doses for the two age groups and that the trunk size did not have any influence even though the mean trunk size of the neonates is outside the NRPB standard value.

4. Conclusion

PET/CT has been found to be a useful tool for diagnosis of cancer malignancies even in children. High dose diagnostic CT imaging was used for all ages. It is recommended that for neonates and 1 year old age group, the CT protocol be modified to a lower kVp and mAs since GE Discovery ST has a very good resolution for both CT and PET imaging [7]. Results of this study show that neonates and 1 year old patients can have an effective dose due to CT and PET of
about 15 mSv which is found to be the highest among the values for other age groups. The primary contributing factors to the high mean effective dose values are the CT exposure parameter (kVp and mAs) and the administered activity of 18F (FDG). Since low dose CT can provide better attenuation and lesser noise to PET images, a study to reduce the kVp and mAs should be done. The International Commission on Radiological Protection (ICRP) Report No. 102 [8] states that where diagnosis may be unknown, CT procedures should be performed with reduced dose parameters. A review of the protocol to decrease the activity of 18F (FDG) should also be undertaken to reduce the effective dose. The review should also include the establishment of image quality criteria for the two age groups when the kVp, mAs and activity are reduced.

The activity of 18F (FDG) can be reached to about 418 MBq (11 mCi) for some patients in the 10 years old age group. This amount of activity is usually given to adult patients. Protocol for the administration of activity should also be reviewed.

It is important that the effective dose due to CT be easily assessed for the pediatric patients to evaluate the radiation burden. The CT dose conversion coefficient of 0.2 mSv/mGy was derived from the IMPACT dose calculator using the CTDI values given by the software program. This value can be used to easily estimate the CT effective doses for all pediatric patients.

Reducing the CT exposure parameters and the administered activity will affect the image quality. With the image quality criteria established, radiologists would need to be given training on CT and PET image quality and techniques.

References

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