Development of pediatric CT protocols to obtain minimal doses in PET/CT studies – a physicists approach.

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Til slutt et utvalg fra foredraget til barneradiolog Lise Heiberg på ECR i Wien 2008

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Children are assumed to be especially sensitive to radiation, and in PET/CT the whole body is scanned (1). Cancer patients constitute the main group of patients referred to PET/CT examination, and are subjected to repeated imaging with ionizing radiation.

The pediatric CT protocol for PET/CT examinations supplied by the manufacturer (Table 1) gave an unnecessarily high image quality as reported by our pediatric radiologists. The CT images obtained as part of the PET/CT study are not intended for diagnostic purposes, but serve to identify gross anatomical structures and provide a basis for attenuation correction (AC).

Our goal was therefore to develop new pediatric CT protocols for different body weight groups and reduce the dose to a minimum (the ALARA principle).
Table 1. The pediatric protocol from the manufacturer and the adult whole-body AC_CT protocol on the PET/CT scanner are given.

<table>
<thead>
<tr>
<th>Protocol</th>
<th>kV</th>
<th>Effective mAs</th>
<th>Slice thickness (mm)</th>
<th>AEC technique: CareDose 4D</th>
<th>pitch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pediatric</td>
<td>120</td>
<td>40</td>
<td>3</td>
<td>yes</td>
<td>1.4</td>
</tr>
<tr>
<td>Adult</td>
<td>120</td>
<td>50</td>
<td>5</td>
<td>no</td>
<td>0.8</td>
</tr>
</tbody>
</table>
This work was carried out on a Siemens Biograph 64 PET/CT scanner.

Homogenous cylindrical phantoms of Perspex with diameters 10, 16 and 32 cm were models of different body sizes (Figure 1), and the standard deviation of the CT-number in a ROI was used as a measure of noise.

The automated exposure control (AEC) is applied to ensure a certain image quality in all the images while keeping the dose low. In stead of focusing on image quality, we wanted to keep the dose as low as reasonably achievable. Therefore a manual control with a constant tube current (mA) was preferred.

Initially, the reference noise level was established in images of the large 32 cm phantom scanned with an adult protocol that was considered by the radiologists to give adequate image quality for PET/CT (Table 1). The resulting “adult” noise of 27 HU was used as a reference noise for the pediatric protocols, where the goal was to achieve the same or lower level of noise in the 16 and 10 cm phantoms representing the body weight groups of 25-54 kg and 0-24 kg, respectively.
The homogenous phantoms

Figure 1. The different PMMA phantoms (10, 16 and 32 cm) used to evaluate the impact different technical parameters have on image noise and patient dose.
RESULTS

There was a linear relationship between the dose relative to 100 mAs at 120 kV and phantom size (Figure 2), meaning that there is a constant increase in dose per mAs with decreasing phantom size. This finding supports published results (2).

However, since the image noise decreased dramatically with decreasing phantom size, the tube current could be reduced significantly in the small phantoms in order to reach the reference noise of 27 HU.
RESULTS

Figure 2. The figure shows the nCTDlw-dose relative to 100 mAs and image noise as a function of the phantom diameter when using the adult protocol in Table 1.

Normalized dose = -0.4719*Diameter (cm) + 21.722

\[ R^2 = 0.9946 \]
The tube voltage was reduced to 80 kV for the children who weighed less than 25 kg, which will slightly improve the low-contrast resolution and give a significant reduction in dose (3, 4). In the literature there is a discussion going on about the impact that the quality of the attenuation correction images has on the interpretation of PET images (5, 6), especially for low kV, but this seems not to have any impact on small children (6).

As demonstrated in Figure 3 the image quality was still more than adequate with the small phantoms. The noise was only 59 and 29 % of the reference for the child and baby phantoms, respectively, but it was impossible to decrease the tube current any further. The effective doses were calculated in the CT-Expo program (7) where all the organs of the body were taken into account.
RESULTS

Figure 3. Image noise from ROI’s in the images of the adult (reference), child and baby phantoms, where the latter two were scanned with a pediatric protocol using a kV of 80 and the lowest possible mAs setting of 18. The calculated effective doses are displayed as blue bars.
On the basis of the results obtained in the phantom study, the protocols in Table 2 were suggested. Here the patient doses will be reduced by 50-87% compared to the initial protocols depending on the body weight.

Figure 3 shows that the images from the 16 cm phantom are less noisy than the reference using the lowest possible kV and mAs settings. Therefore one should consider reducing the tube voltage from 120 kV to 100 kV in the body weight group of 25-54 kg, to verify whether the image quality and dose may be further reduced.
Table 2. The new low-dose pediatric AC_CT protocols on the PET/CT scanner are given. The protocol for children heavier than 55 kg is the adult protocol. Further optimization of image quality can be done by repeating the reconstruction with smaller FOV and different choices of slice thicknesses and reconstruction kernels. For AC, the FOV has to be 700 millimeters.

<table>
<thead>
<tr>
<th>Body weight (kg)</th>
<th>kV</th>
<th>Effective mAs</th>
<th>Pitch</th>
<th>Det. comb.</th>
<th>FOV</th>
<th>Slice (mm)</th>
<th>Incr. (mm)</th>
<th>Recon. kernel</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-24</td>
<td>80</td>
<td>18</td>
<td>1.4</td>
<td>24x1.2</td>
<td>700</td>
<td>3</td>
<td>3</td>
<td>B19 PET</td>
</tr>
<tr>
<td>25-45</td>
<td>120</td>
<td>18</td>
<td>1.4</td>
<td>24x1.2</td>
<td>700</td>
<td>3</td>
<td>3</td>
<td>B19 PET</td>
</tr>
<tr>
<td>45-54</td>
<td>120</td>
<td>25</td>
<td>1.4</td>
<td>24x1.2</td>
<td>700</td>
<td>3</td>
<td>3</td>
<td>B19 PET</td>
</tr>
<tr>
<td>&gt;55</td>
<td>120</td>
<td>50</td>
<td>0.8</td>
<td>24x1.2</td>
<td>700</td>
<td>5</td>
<td>3</td>
<td>B19 PET</td>
</tr>
</tbody>
</table>
The approach to establish these low-dose non-diagnostic CT protocols was on purpose made simple. **Its main goal was to establish a few good protocols as a starting point.** The new protocols have been used on some children and the images have been evaluated by the radiologists and nuclear medicine specialists.

The image quality and dose was still considered more than adequate, especially for the smallest children. **Therefore we wanted to go further down in mAs, but this was not possible with the actual scanner.**

After the protocol changes were introduced, **the PET part of a PET/CT study now contributes to about 90 % of the total patient dose in the smallest children.**
How low can we go?
Low dose 64 slice PET/CT protocols for paediatric patients -
the importance of multidisciplinary teamwork

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Boy 5 years, ca 25 kg, operated for hepatoblastoma.

Exam 1) Recurrent disease?
**Pediatric protocol, application specialist:**
120 kV, 50 mAs, pitch 1.4, no CARE Dose

Exam 2) Effect of chemotherapy?
**The new pediatric protocol:**
80 kV, 18 mAs, pitch 1.4, no CARE Dose

1) 16.01.07  2) 08.03.07
Estimated effective dose from:

**CT:** 7,1 mSv versus 0,7 mSv  
= 10 times reduction of radiation dose!

**PET:** 8,5 mSv versus 9,6 mSv (27 vs. 21 kg)

**Total CT + PET**  15,6 mSv versus 10,3 mSv
## Present CT protocols for pediatric PET/CT

For all protocols: collimation 24 x 1.2 mm, rotation time 0.37 sec. Effective mAs as low as allowed by the machine

<table>
<thead>
<tr>
<th>Patient weight (kg)</th>
<th>kV</th>
<th>Effective mAs</th>
<th>Pitch</th>
<th>Slice thickness/increment (mm)</th>
<th>CARE Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 20</td>
<td>80</td>
<td>Minimum (19)</td>
<td>1</td>
<td>5 / 5 for AC 3 / 2</td>
<td>no</td>
</tr>
<tr>
<td>21 - 70</td>
<td>100</td>
<td>Minimum (13)</td>
<td>1.4</td>
<td>5 / 5 for AC 3 / 2</td>
<td>no</td>
</tr>
</tbody>
</table>

I ettertid av våre foreslåtte protokoller har det skjedd flere endringer i protokollene som er oppsummert her. Dette var status i mars 2008, hvor 80 kV brukes for barn opptil 21 kg, og 100 kV for resten av barna. Pitch ble endret fra 1.4 til 1 for de minste barna for å redusere overskanning.
Boy, 14 years, Hodgkin’s lymphoma. PET/CT at diagnosis (1) and after chemotherapy (2)

1) 65 kg, 120 kV, 50 mAs
   **Effektive doser:** 6.6 mSv (CT), 8.8 mSv (FDG), CT + FDG = 15.4 mSv

2) 70 kg, 100 kV, 14 mAs –
   **Effektive doser:** 1.3 mSv (CT), 7.8 mSv (PET), CT + FDG = 9.1 mSv