Optimisation of CT thorax protocol for obese paediatric patients: A phantom study

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Abstract. The objective of this research was to obtain the optimal automatic exposure control (AEC) settings for CT thorax examinations for obese paediatric patients. This was to ensure lower radiation dose for this special cohort while maintaining diagnostic image quality. A layer of fat tissue equivalent material was used to wrap around the torso of a paediatric phantom to simulate an obese patient. Optically stimulated luminescence dosimeters (OSLDs) were inserted at different positions within the thorax region. Three sets of CT images were acquired at DoseRight Indices (DRI) of 13, 15 and 17. The CT images were used for qualitative and quantitative assessments. The contrast to noise ratio (CNR) of images with DRI of 13 (211.08 ± 21.35) were significantly lower than CNR of images with DRI of 15 (231.67 ± 20.35) and 17 (245.10 ± 25.44; \(p < 0.01\)). For signal to noise ratio (SNR), there were significant differences among images with all DRI settings (\(p < 0.01\)). The mean absorbed dose received by the phantom at DRI of 13, 15 and 17 were 1.07 ± 0.05 mSv, 1.16 ± 0.07 mSv and 1.75 ± 0.08 mSv, respectively. In this study, DRI of 15 was determined as the optimal setting for obese paediatric patients for the age group of 5 to 14 years old. We have demonstrated that there is scope to reduce radiation dose to obese paediatric patients in CT thorax examinations while still maintaining diagnostic quality images.

1. Introduction

Today, computed tomography (CT) is considered as an indispensable medical imaging modality in diagnostic radiology \cite{1}. However, the major drawback of CT is the use of ionising radiation which leads to concerns about potential stochastic risks of radiation exposure. In CT, higher radiation dose to patient generally produce higher quality images. The optimal use of ionising radiation in medical imaging requires a delicate balance between radiation dose incurred by patient and quality of image. In other words, effort is needed to keep the patient dose as low as possible while achieving images with enough diagnostic information.

The wide availability of CT scanners and technical advances have expanded the clinical applications of CT, particularly for paediatric patients. The applications of helical scanning technique and multi-detector row CT (MDCT) systems have improved spatial resolution and reduced acquisition time. However, there is a growing concern about ionising radiation related risks from CT examinations \cite{2}. The most concerned side effect is radiation related cancer risks. Cancer is a stochastic event and
there is no “safe” threshold of radiation but the incidence of cancer increases together with increased radiation dose [3]. Besides, it is necessary to be extremely cautious when carry out CT procedures on children because they are very sensitive to radiation and with longer life expectancy than adults, potential risk to develop radiation related cancer is higher [4,5].

Various strategies have been launched to reduce radiation dose to patient. In 1998, the introduction of automatic exposure control (AEC) allowed effective compromise between radiation dose and image quality [6]. It works by determining the X-ray attenuation and quantum noise of the CT image based on patient size and tissue densities. Based on the image quality predefined by the radiographer, tube current can be automatically adjusted to decrease at low attenuated locations and vice versa. However, there is a potential risk of very high radiation dose when using AEC on oversized patient because their larger body mass inadvertently result in higher noise levels in images due to increased scattered radiation [6]. Tube current will be automatically increased to achieve desired image quality.

Having an optimal CT setting for obese patient – especially obese paediatric patient, is essential to satisfy the principle on optimisation (ALARA – As Low As Reasonably Achievable). Therefore, the objective of this study was to determine the optimal settings of AEC base on Dose Right Indices (DRI) in CT thorax examination for obese paediatric patients.

2. Materials and methods

2.1. Materials
Paediatric phantom used in this research represented a six-year-old child with head, neck, thorax, spine, two lobes of lungs, two arms and two legs (Figure 1). The weight and height of phantom were (25 ± 0.1) kg and (115.0 ± 0.1) cm, respectively. The phantom was made by solid nylon type 6 with density of 1.15 g/cm³, CT number was in the range of 60 to 140 HU. There were depressions in the thorax region which can be filled with lung simulated materials.

![Figure 1. Six-year-old paediatric phantom.](image)

To simulate lung tissues, various materials can be used such as cork, microsphere and mixture of urethane rubber compound [7]. In this study, cork and microsphere were chosen because of their availability. A fat layer with thickness of 2 cm was made by mixing olive oil (Naturel Pure olive oil, Lam Soon Edible Oils Sdn Bhd, Selangor, Malaysia) (ρ = 0.918 g.cm⁻³) with beeswax. CT number of materials were determined by scanning with CT scanner at tube potential of 100 kV.

2.2. Methods
To produce subcutaneous fat tissue equivalent material, mixtures of beeswax and olive oil at various ratios of weight were made. Beeswax were first melted in a hot pot to completely change them to liquid form. Then olive oil was pour into the pot to be mixed with the beeswax. The mixture was stirred continuously until it became a homogeneous mixture. Then it was poured into a 30 cm × 75 cm plastic bag and let to be cool and hardened. Figure 2 shows the hardened fat layer.
Figure 2. Hardened mixture of olive oil and beeswax

Twelve nanoDot OSLDs (Landauer Inc. Glenwood, IL, USA) were inserted at selected positions to measure absorbed dose to organs. The organs were thyroid, stomach, liver, oesophagus (2 OSLDs per organ) and lungs (4 OSLDs). Absorbed dose in the other organs that were located out of the radiation fields were considered negligible. Mean absorbed dose was achieved by summing all the organ doses.

Figure 3. Lung region of phantom was filled by lung tissue-equivalent material (a). The entire thoracic section of phantom was wrapped by fat tissue layer (b).

After being filled with simulated lung tissue and wrapped by fat tissue layer (Figure 3), phantom was scanned using Ingenuity Core 128 CT scanner (Philips Medical Systems, Inc., Cleveland, USA). The thorax (WED 24) protocol which is applied for paediatric patients from 5 to 14 years old was used. All the scans were performed with spiral mode. Other CT parameters were set as follows: 100 kV tube voltage, 1.572 pitch factor, 3 mm slice thickness, AEC was switched on to modulate the tube current.

DoseRight Index (DRI) is the AEC tube current modulation tool for Philips Ingenuity CT scanners. DRI allows the user to define the desired image quality level. Increasing DRI by one unit will increase the average tube current by 12% and decrease the image noise by 6% and vice versa [8] (Table 1). In the protocol used, DRIs were set at 15 for standard patients and 17 for very large and obese patients. The authors attempted to reduce dose for obese paediatric patients by decreasing DRI to lower levels which were 15 and 13. Quality of images were then evaluated to determine whether lower DRI can be used for obese patients.

Table 1. Influence of DRI on tube current and image noise

| DRI     | Tube current | Image noise |
|---------|--------------|-------------|
| ↑ 1 unit| ↑ 12%        | ↓ 6%        |
| ↓ 1 unit| ↓ 12%        | ↑ 6%        |

Three sets of images which were acquired with DRI of 13, 15 and 17 and displayed at the same window level were used for image quality assessment. Image J (National Institute of Mental Health,
Bethesda, Maryland, USA) tool was used to obtain signal as the mean value and noise as standard deviation of CT number within a region of interest (ROI).

One-way ANOVA was used to conduct the statistical analysis by using SPSS 20 (IBM® Predictive software). The α value was set to 0.05. Tukey post hoc analysis was used to determine which set of image was different from the others.

3. Results and Discussions

3.1. Phantom material

After scanning with CT scanner at 100 kV, CT numbers of cork, microsphere and fat simulated mixtures were determined. CT number of cork and microsphere were -837.9 ± 19.5 HU and -986.7 ± 8.1 HU, respectively. Both materials have suitable radiation attenuation properties to simulate lung tissues. However, in this work, cork was selected as the lung tissue simulated material due to the ease of shaping it to lung cavities. Radiation attenuation properties of fat tissue simulated mixtures were presented in Table 2.

Table 2. CT number of fat simulated mixtures

| m_ol : m_beeswax | CT number (HU) |
|------------------|----------------|
| 8 : 1            | -123.4 ± 5.4   |
| 12 : 1           | -126.4 ± 5.2   |
| 20 : 1           | -132.3 ± 6.4   |

Kim et al. (2012) showed that the CT number range for adipose tissue was -140 to -30 HU [9]. Thus, it can be seen that all of the mixtures presented in Table 2 could be used to simulate fat tissue. However, the 8:1 oil and beeswax ratio mixture was selected because of the suitable hardness to shape and wrap fat layer around paediatric phantom. The other mixtures were found to be too soft and melted easily under room temperature.

3.2. Image quality evaluation

3.2.1. Qualitative analysis of image quality.

A radiologist (W Y Chan) with eight-year experience was asked to subjectively assess the levels of noise and contrast as well as spatial resolution of the acquired image of the phantom.

For noise, images with DRI of 13 were assessed as the most noise-contained images, followed by images with DRI of 15. Images in the set with DRI of 17 had the least noise. However, differences in noise level among images were not significant. Noise is dependent on the number of photons reaching detector and therefore is dependent on tube current – time product. Higher tube current – time product provides images with lower noise. With the same subject scanned, at lower DRI settings, lower tube current – time product resulted in a higher level of noise in images. Hence, images with DRI of 13 contained more noise than those scanned using DRI of 15 and 17 settings.

Contrast is another measure of image quality influenced by the tube voltage used. In this research, the tube voltage of 100 kV was applied for all scans resulting in the similar levels of contrast were observed in images of all DRI settings. In general, visual assessment by the radiologist confirmed that there were not much differences in the quality of images from all DRI settings.

3.2.2. Quantitative analysis of image quality.

Quantitative evaluation of the images was carried out by determining signal to noise ratio (SNR) and contrast to noise ratio (CNR) of the images. There were significant difference in SNR among images (p < 0.01). The highest SNR was in the images with DRI of 17, followed by images with DRI of 15. Images with DRI of 13 contained the most noise resulting in the lowest SNR. According to Table 1, decreasing DRI from recommended level of 17 to
15 and 13 increased the image noise by approximately 12% and 24%, respectively. Thus SNRs of images with DRI of 13 were substantially reduced compared to those of other settings.

The CNR for images scanned with DRI of 13 (211.08 ± 21.35) were significantly lower than the other DRI settings (p < 0.01) while there were not significant differences in CNR of images with DRI of 15 (231.67 ± 20.35) and 17 (245.10 ± 25.44). Although the same tube voltage of 100 kV was applied for all scans, images with DRI of 13 contained higher amount of noise than the others. This affected the visibility of small details and low contrast organs thus degraded the CNR.

3.3. Radiation dose estimation

The minimum and maximum values of tube current – time product (min and max mAs) were predefined for each setting of DRI. In Table 3, it can be seen that higher limits were applied for higher DRIs to achieve desired quality of image. Mean mAs, CTDI_{vol} and DLP were the values displayed on the control monitor after exposing. Mean absorbed doses were calculated from the OSLD values at certain organ positions and corresponding tissue weighting factors (according to ICRP 103 Publication [10]). The absorbed dose for CT thorax scan using DRI settings of 13, 15 and 17 were found to be 1.07 ± 0.05 mSv, 1.16 ± 0.07 mSv and 1.75 ± 0.08 mSv, respectively. When DRI was decreased from 17 to 15, the absorbed dose reduced by approximately 33.5%, from 1.75 mSv to 1.16 mSv. This is because decreasing DRI settings leads to lower mAs or lower number of X-rays reaching the phantom and thus dose also decreased. However, a further decrease in DRI to 13 reduced only 8% in absorbed dose compared to that at DRI of 15.

| DoseRight Index (DRI) | Min mAs | Max mAs | Mean mAs | CTDI_{vol} (mGy) | DLP (mGy.cm) | Mean absorbed dose (mSv) |
|-----------------------|---------|---------|----------|------------------|--------------|-------------------------|
| 13                    | 19      | 65      | 49       | 1.9              | 46.55        | 1.07 ± 0.05             |
| 15                    | 25      | 81      | 63       | 2.4              | 58.80        | 1.16 ± 0.07             |
| 17                    | 29      | 102     | 77       | 3.0              | 73.50        | 1.75 ± 0.08             |

Thus, a comprehensive assessment on the effectiveness of decreasing DRI from recommended level of 17 to lower levels was considered both image quality and mean absorbed dose. Compared to DRI of 17, the DRI of 15 reduced dose by 33.5% while the images contained the same contrast level and higher noise level. The efficiency in dose reduction of DRI of 13 was not significantly higher than DRI of 15 whereas in terms of quantitatively evaluating, the quality of images with DRI of 13 were significantly lower. Therefore, it might be considered that the DRI of 15 was an optimal setting in this case.

There are several limitations in this study. The research was done only for a single age group (5 to 14 years old). A further study on other age groups is essential to have more comprehensive result. Besides, in this study, thickness of subcutaneous adipose tissue was 2 cm simulating only one specific size of obese patient. Various layers of adipose tissue with different thickness may be needed to represent different levels of obesity. From that, the dose of obese patients can be better estimated and the solution to optimising dose for these special group will be more effective.

4. Conclusions

Image quality and dose assessment for CT thorax examination for paediatric patient was carried out for selected AEC control settings. We found that for obese paediatric patient within the age group of 5 and 14 years old, DRI setting of 15 could provide mean absorbed dose reduction to patient while the image quality was not significantly degraded. This study showed that there is scope to reducing radiation dose to obese paediatric patients in CT thorax examinations while still maintaining image quality with enough diagnostic information.
5. References

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