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Original Paper

CT dose reduction using Automatic Exposure Control and iterative reconstruction: A chest paediatric phantoms study

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ABSTRACT

Purpose: To evaluate the impact of Automatic Exposure Control (AEC) on radiation dose and image quality in paediatric chest scans (MDCT), with or without iterative reconstruction (IR).

Methods: Three anthropomorphic phantoms representing children aged one, five and 10-year-old were explored using AEC system (CARE Dose 4D) with five modulation strength options. For each phantom, six acquisitions were carried out: one with fixed mAs (without AEC) and five each with different modulation strength. Raw data were reconstructed with Filtered Back Projection (FBP) and with two distinct levels of IR using soft and strong kernels. Dose reduction and image quality indices (Noise, SNR, CNR) were measured in lung and soft tissues. Noise Power Spectrum (NPS) was evaluated with a Catphan 600 phantom.

Results: The use of AEC produced a significant dose reduction ($p < 0.01$) for all anthropomorphic sizes employed. According to the modulation strength applied, dose delivered was reduced from 43% to 91%. This pattern led to significantly increased noise ($p < 0.01$) and reduced SNR and CNR ($p < 0.01$). However, IR was able to improve these indices. The use of AEC/IR preserved image quality indices with a lower dose delivered. Doses were reduced from 39% to 58% for the one-year-old phantom, from 46% to 63% for the five-year-old phantom, and from 58% to 74% for the 10-year-old phantom. In addition, AEC/IR changed the patterns of NPS curves in amplitude and in spatial frequency.

Conclusions: In chest paediatric MDCT, the use of AEC with IR allows one to obtain a significant dose reduction while maintaining constant image quality indices.

Introduction

The number of Multi Detector Computed Tomography (MDCT) examinations has been vertiginously increasing over the time. This tendency leads to a major public health concern due to the increasing risk of collective radiation dose [1]. Paediatric MDCT cumulates even higher risks because children are more sensitive to radiation-induced carcinogenesis and they have longer lifetime to develop cancer [1–5]. To minimise radiation exposure in children patients, MDCT manufacturers have developed protocols that employ adapted parameters in paediatric scans. However, radiation dose has direct influence on image quality [6–9]. Any attempt to reduce the dose delivered should ensure that image quality remains adequate for a reliable diagnosis [10,11].

Manufacturers have developed several tools to reduce doses, such as tube current modulation (or Automatic Exposure Control; AEC). These systems modulate mAs in function of the patient's attenuation and the parameters defined by users (e.g. image quality reference, reference image, target image quality level, etc). These systems provide a more uniform dose distribution which improves image quality and reduces the artefacts [12–17].

The AEC can be obtained with different types of modulation [15,17]. Basically, modulations are implemented on the z-axis (longitudinal modulation) or on the orthogonal plane $x-y$ (angular modulation). The former, adjusts the mAs along patient's length (z-direction) based on topographic images (anterior–posterior, lateral, or both) whereas the latter, adjusts the mAs for each rotation of the X-ray tube around the patient. In recent CT-scan, AEC systems combine both, angular and longitudinal modulations (x, y, and z-axis).

Abbreviations: AEC, Automatic Exposure Control; CNR, contrast-to-noise ratio; CTDIvol, volume CT dose index; DRLs, Diagnostic Reference Levels; FBP, Filtered Back Projection; IR, iterative reconstruction; mAs_{eff}, effective or modulated mAs; mAs_{fix}, fixed mAs; mAs_{mod}, modulated mAs; mAs_{ref}, image quality reference mAs; MDCT, Multi Detector Computed Tomography; NPS, Noise Power Spectrum; ROI, Region of Interest; SAFIRE, Sinogram Affirmed Iterative Reconstruction; SNR, signal-to-noise ratio; SSDE, size-specific dose estimate.

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The parameters defined by the users vary among the manufacturers [15,17]. For instance, on GE Healthcare system (Milwaukee, Wisconsin), operators may define the "noise index values", which is applied on each image. On Toshiba systems (Tokyo, Japan), users may specify the "standard deviation of pixel values in an image". On Philips systems (Andover, Massachusetts), operators can target an "ideal reference image" to replicate the image quality.

In the present work, a Siemens system with a CARE Dose 4D (VA40, 2011) was used. This facility allows users to specify a parameter named "image quality reference mAs" (mAs_{ref}), which expresses the mAs applied on an average-sized patient ("reference patient" weighing 70–80 kg) [15,18]. In contrast, the previous version used two types of "reference patient": a "typical children" (20 kg and 5 years old) and adult (70–80 kg) [18–21].

The CARE Dose 4D system combines the longitudinal and angular modulations and adapts the mAs automatically for each rotation around the patient with a half-rotation delay [15,17,18]. In addition, distinct values for mAs_{ref} can also be specified as function of the location of the exam. The operator defines a single mAs_{ref} for each examination according to the image quality required for a reliable diagnosis. For instance, thorax scans require lower mAs_{ref} than abdomen ones. Finally, this system also modulates mAs automatically for each slice when the patient's weigh (or attenuation) differs from the "reference patient". Indeed, mAs is decreased for subjects weighing less than the "reference patient" whereas it is increased on heavier patients. Therefore, due to the automatic mAs modulation, distinct values are applied in each slice. The average of modulate mAs (mAs_{mod}) along the entire examination is defined as effective mAs (mAs_{eff}).

Modulation strength is a supplementary user-controlled parameter mainly used to optimise the image quality and the dose delivered. Five levels of modulation are available: 'very weak', 'weak', 'average', 'strong' and 'very strong' modulations [15,18]. Hence, operators can use this parameter before the acquisition in order to increase or to decrease the effect of AEC modulation for each organ characteristic. However, once the user selects one out five alternatives, the degree of changes in the mAs values is determined in the system routines. For paediatric patients, the attenuation is lower than the "reference patient". 'Very weak', 'average' and 'very strong' modulation strengths result in "very weak", "average" and "very strong" dose reduction respectively, which also changes the image quality.

Several tools have been developed to compensate image noise increases due to dose reduction. Iterative reconstruction (IR), such the Sinogram Affirmed Iterative Reconstruction (SAFIRE), is one of the most popular methods to achieve this goal. To reduce image noise, IR was demonstrated to be more efficient than its similar standard approach, the Filtered Back Projection (FBP). For this reason, SAFIRE has been applied to numerous clinical studies [22–26].

In the present paper, we hypothesised that combining AEC and IR would further reduce the dose while maintaining an acceptable diagnostic image quality. Therefore, we investigated the impact of modulation strength on radiation dose and its influences on thoracic image quality of paediatric anthropomorphic phantoms. In addition, we evaluated the combined effect of modulation strength and the iterative reconstruction SAFIRE in optimising delivered doses. Finally, we assessed noise texture changes, estimated with the Noise Power Spectrum (NPS), due to AEC/IR combinations.

Materials and methods

Anthropomorphic phantoms

Three physical anthropomorphic phantoms (ATOM® Dosimetry Phantoms, CIRS, Norfolk, USA) equivalent to patients aged one, five and 10-year-old were used. These phantoms have internal structures corresponding to patient tissues and contain an artificial skeleton, lungs and soft tissue that enable precise simulation of medical radiological exposure. The phantoms' weight and height were 10 kg and 75 cm for the one-year-old phantom, 19 kg and 110 cm for the five-year-old phantom, and 32 kg and 140 cm for the 10-year-old phantom.

Data acquisition and reconstruction

Acquisitions were performed on a 64-detector row MDCT SOMATOM Definition AS+(Siemens, Erlangen, Germany). To evaluate the impact of different modulation strengths on the delivered dose and image quality, MDCT acquisitions were performed using the routine examination protocols specified for children (Table 1). These protocols used 100 kVp with mAs_{ref} to obtain 75% of the values indicated in the national Diagnostic Reference Levels (DRLs) [29], for children aged one, five and 10-year-old. In the present study, six thoracic acquisitions were performed for each phantom: one with fixed mAs (mAs_{fix}) equal to mAs_{ref} and five with different modulation strengths.

To assess the impact of IR on the image quality, raw data were reconstructed using the standard FBP and IR algorithms. Two levels of SAFIRE were independently applied (S3 and S5). Images were reconstructed to 1 mm of thickness. Reconstruction kernels were set to 'moderately smooth' (B30f/I30f) to assess the soft tissue and 'very strong' (B70f/I70f) to study the lung tissue.

Image quality assessment

Image quality evaluations were carried out using in-house Matlab (MathWorks, Natick, USA) routines. Three Regions of Interest (ROI) were defined in the thorax, two on each side of the lung tissue, one in the soft tissue (Fig. 1a). The sizes of the ROIs were 0.8 cm^2, 1.5 cm^2 and 3 cm^2 for the one, five and 10-year-old phantoms, respectively. The signal (average) and noise (standard deviation) were computed within each ROI. The signal-to-noise ratio (SNR) for all tissues and contrast-to-noise ratio (CNR) between the lung and the soft tissue were calculated as follows:

$$\mathrm{SNR} = \frac{|\mathrm{HU_{ROI}}|}{\sigma_{\mathrm{ROI}}} \quad (1)$$

$$\mathrm{CNR} = \frac{|\mathrm{HU_{Lung\text{-}tissue}} - \mathrm{HU_{Soft\text{-}tissue}}|}{\sqrt{\frac{\left(\sigma^2_{\mathrm{Lung\text{-}tissue}} + \sigma^2_{\mathrm{Soft\text{-}tissue}}\right)}{2}}} \quad (2)$$

where HU is Hounsfield Unit.

Image quality metrics

Iterative reconstruction algorithms require several metrics that are commonly employed (noise, SNR, CNR) [27,28]. For instance, Noise Power Spectrum is used to obtain a complete description

Table 1
Routine paediatric examination protocols.

	Thorax protocol		
	1 year	5 years	10 years
kV	100		
Ref. mAs	72	96	121
Beam width (mm)	64 × 0.6 (1)		
Pitch	1.4		
Rotation time (s)	0.33		
Reconstruction kernel	B/I30f and B/I70f		
Reconstruction algorithms	FBP, S1, S3, S5		