

Radiation Dose Optimization in Pediatric Ct (Computer Tomography)

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Abstract—Computed tomography (CT) dose optimization is an important issue in radiography because CT is the largest contributor to medical radiation dose and its use is increasing. However, CT dose optimization for pediatric patients could be more challenging than their adult counterparts. The purpose of this literature review was to identify and discuss the current pediatric CT dose saving techniques. This review includes Strategies for optimizing a range of scan parameters and technical considerations including tube voltage and current, iterative reconstruction, diagnostic reference levels, bowtie filters, scout view, pitch, scan collimation and time, over scanning, and over beaming for pediatric patients with different ages and body sizes and compositions. The purpose of this literature review was to identify and discuss the current pediatric CT dose saving techniques. Optimized pediatric protocols and further study directions were also proposed. It is expected that this review could potentially increase the awareness of medical radiation technologists on the range of dose saving techniques available in the literature and encourage them to optimize their protocols, reducing the risk of pediatric CT examinations.

Index Terms—CT, pediatric optimization, protocol, and radiation dose

I. INTRODUCTION

Computed tomography (CT) dose optimization is an important issue in radiography because CT is the largest contributor to medical radiation dose and its use is increasing. However, CT dose optimization for pediatric patients could be more challenging than their adult counterparts because children are more radiosensitive to radiation, they have longer lifetimes, allowing potential radiation effects to manifest and there are large variations of body size and

composition (percentages of fat, muscle, and bone) within each age group and across different groups. Some clinical centers have implemented age and child-size-specific CT scan protocols, and their effect on dose reduction has been recognized. However, variations of these age and child-size-specific protocols exist, which makes it difficult for other departments to follow them. Also, there is a lack of standardization with respect to the definition of pediatric patients. One of the common definitions defines pediatric patients as those aged 0–15 years. This definition is used in the present article.

Protocols Specific to Age, Body Size, and Composition

According to the International Atomic Energy Agency survey of pediatric CT practices in 40 countries published in 2013, more than half of the clinical centers relied on preprogrammed scan protocols provided by manufacturers. In most of these scan protocols, specific techniques are suggested for each patient age group because it is assumed that body sizes and compositions (percentages of fat, muscle, and bone) of patients within the same age group should be similar. However, recent studies indicated that even in the same age group there are great variations of body size and composition because of factors such as obesity. Since the last decade, some manufacturers and clinical centers have started to optimize their protocols based not only on patient age, but also their body size in terms of weight. This is known as the color-coded system. The scan settings such as tube potential and current and exposure time are tailored to specific patient conditions, leading to lower dose and better image outcome. However, this approach requires medical physicists possessing sound

knowledge of scanner specifications with support from radiologists and medical radiation technologists to develop these optimized protocols, which is not feasible in many health institutions. Patient size parameters such as weight and body mass index are commonly used for developing size-specific protocols for pediatric and adult patients. Recently, effective diameter and cross-sectional dimension have been considered as more accurate indicators of body size and habits. Also, awareness about variation of organ radio sensitivity across the child age range as well as between genders has been increased. The following sections discuss individual scan parameters and other technical considerations for developing protocols specific to age, body size, and composition.

A. Tube Voltage

Both phantom and clinical studies showed a lower tube voltage (with other settings such as tube current unchanged) could reduce radiation dose and improve image contrast for small-sized patients. For example, a tube voltage as low as 60 kV could be used in pediatric CT examinations for structures with high subject contrast such as chest and bone. Also, in (iodinated) contrast studies, a low tube voltage closer to the absorption edge of iodine (33 keV) would increase the probability of photoelectric interaction, improving the conspicuity of hyper- or hypovascular structures. The amount of contrast medium could also be reduced in this case, minimizing the chance of contrast-induced nephropathy. However, an inappropriate low tube voltage could cause the beam hardening artifact and decrease the image contrast because of the increase of image noise. If the image noise is excessive when using a lower tube voltage, adjustment of other parameters such as tube current will become essential. The impact of image contrast reduction on pediatric abdominal examinations tends to be more significant when compared with those for adults because less fatty tissue would normally be present between visceral organs of children, representing a lower subject contrast. In contrast-enhanced soft tissue procedures, for example, to assess the small lesions in the abdomen, the use of higher tube voltage would be necessary. Although patient weight, body mass index, effective diameter, or cross-sectional dimension of the body part can be used to indicate the body size for optimizing tube voltage in pediatric examinations, this information

may not always be available. Automatic tube potential selection with tube current modulation is a relatively new function available in some of the latest CT scanners. It can assess the attenuation property of the body part (i.e., body composition), which is difficult to measure in traditional settings, and select the optimal tube voltage (in the range of 70–140 kV) for achieving a balance between radiation dose and image quality automatically. Although its dose reduction capability was demonstrated in studies focusing on adult Patients, its potential for pediatric CT dose optimization still needs to be confirmed. In a recent study of automatic tube potential selection with tube current modulation in pediatric imaging, 94% of the chest and abdomen examinations of this study had the tube voltage reduced to 70, 80, or 100 kV, resulting in a dose decrease up to 27% when compared with the standard setting at 120 Kv

B. Tube Current

Similar to tube voltage, a decrease in tube current with other parameters unchanged reduces radiation dose, but it could potentially increase image noise. Phantom studies showed that the tube current could be halved for every 3.5-4 cm reduction of diameter of body part; and if image noise is a concern, the mA could be decreased by 50% when there is a 4-6 cm reduction in diameter. However, this rule of thumb does not apply to pediatric head CT because the tube current selection mainly depends on the skull bone composition (amount of calcium content) rather than the diameter of the body part. The skull bone composition is more related to age. Tube current modulation (TCM) is another recent CT system development. It only requires medical radiation technologists to provide image quality reference inputs. Automatic tube current adjustment takes place subsequently based on the size and attenuation property of the body part (ie, body composition) in the x-y plane (angular modulation), along the z-axis (z-axis modulation) or combined modulation. Studies reported the extent of dose reduction would be in the range of 26%–50%. They highly recommended that medical radiation technologists apply TCM to their clinical practices for dose reduction while maintaining the image quality. When it is used with a low tube voltage, the dose reduction effect will become more prominent. However, the challenge associated with this function in pediatric imaging is

the lack of established guidelines of image quality reference values, because they vary across manufacturers. The reference values depend on specific detector configuration, scanning geometry, and beam filtration of different scanner models and manufacturers. Although TCM is developed for dose reduction, in some situations such as the use of thin slice, low pitch, and short scan time, the dose might increase unexpectedly for maintaining the target image quality (offsetting the negative effect on quality induced by these settings).

C. Iterative Reconstruction

Filtered back projection is the standard image processing method for CT image formation. Recently, some CT manufacturers have provided the option to use iterative algorithms to reconstruct images, and it is known as iterative reconstruction (IR). This technique could reduce image noise and hence address the potential problems of tube voltage and current reduction for dose optimization. Recently, successful use of IR has been reported in pediatric CT studies such as cardiac, chest, and abdomen with possible dose reduction up to 50% depending on the diagnostic requirement and patient condition. Further reduction up to 90% could be achieved in CT follow-up procedures. Nevertheless, IR in pediatric routine examinations is a controversial area because various factors such as detector efficiency and TCM can affect the reconstruction performance. Also, the individual preferences of practicing radiologists should be considered because some described IR images as “plastic” or “foggy” in appearance. A standard protocol for the appropriate use of IR should be established based on specific pathology, body size, and selection of reconstruction kernel.

D. Diagnostic Reference

Levels

Diagnostic reference levels (DRLs) are percentile points (commonly 75th percentile) of radiologic examination dose distributions. They provide clinical centers references of

examination doses for protocol optimization. However, the majority of published DRLs for pediatric CT imaging are just age specific, and their inadequacy was noted. Also, accurate CT dose measurements are not always readily available, which makes it difficult to compare the examination doses with DRLs. The established CT DRLs is normally expressed in the quantities of volume CT dose index (CTDI_{vol}), dose length product (DLP), and effective dose (E). Although readings of CTDI_{vol} and DLP are provided by modern scanners, their accuracies are questionable. For example, they determine the CTDI_{vol} and DLP based on 16 and/or 32 cm phantom(s) rather than specific to individual patient sizes. If a 32 cm phantom is used, the dose reading provided would underestimate the actual dose received. Further inaccuracies would be introduced if the effective dose is obtained through converting the DLP to E based on age and region-specific conversion coefficients.

E. Bowtie Filters

CT scanners are normally equipped with bowtie filters to shape the x-ray beam for uniform photon distribution, leading to optimal radiation dose and image quality. However, cautions should be taken for pediatric cases because of their smaller body sizes. If patients are not placed to the gantry center, increases of dose to the peripheral and noise to the center will be expected. The situation may be even worse when a low-dose or TCM technique is used inappropriately because it could be another potential source of noise as discussed previously.

F. Optimized Scanogram or Scout View

The optimization of a scanogram or scout view is commonly neglected by medical radiation technologists. However, studies reported the arrangement of placing the x-ray tube under the table for the scout view could reduce the dose to one third of the original. Although this arrangement is only available in newer scanners, the length of the scout view should always be optimized to just cover the region of interest in any case. This is especially important when considering the smaller body sizes of pediatric patients.

Optimized Pitch and Scan Collimation

Higher pitch or thinner collimation is important in pediatric cases for obtaining adequate image spatial resolution along the z-axis. However, this would increase the image noise, and hence decrease the contrast-to-noise ratio. This is a potential problem in pediatric imaging because of their lower subject contrast. To address this issue, some CT scanners would increase the tube current automatically to compensate for the loss in image quality, which may go against the concept of dose optimization. A better approach could be to use special post processing reconstruction software such as algorithm filters and IR to optimize the image outcome.

G. Scan Time

A short scan time is preferable in pediatric imaging for motion

unsharpness reduction and hence the higher temporal resolution. This also minimizes the need for the use of sedation. However, the potential issue associated with its use is the introduction of image noise because the number of profiles for image reconstruction would reduce and an increase of radiation dose might be needed to suppress this. Although modern scanners provide a range of scan time selections from 0.28 to 0.5 seconds, a rotation time of 0.5 seconds should be used to achieve a balance between temporal and contrast resolutions and radiation dose.

H. Overscanning (Overranging) and Overbeaming

Overscanning (overranging) refers to scanning a body part greater than the one planned for obtaining adequate data for image reconstruction. Its effect is greater in pediatric patients than adults because of the smaller body sizes of children. Generally, the extent of overranging mainly depends on detector collimation and pitch because they affect the dose profile. When they increase, the dose profile will expand and cover a greater area, leading to a higher overrange dose (dose deposited outside the imaged volume). However, the modern scanners (64 slices or above) provide adaptive prepatient collimators to reduce the excessive radiation at the start and end of the scan range. The use of newer systems also has a positive effect on minimizing overbeaming. Overbeaming refers to the radiation dose falling outside the active detector area in a gantry rotation because of the focal spot penumbra. When a scanner

(such as 32 slices or above) provides a greater active detector area, the effect of overbeaming reduces. Its effect is inversely proportional to the number of detectors and collimation width. Its impact is not significant for the latest scanners.

I. Optimized Pediatric Protocols and Further Study Directions

In this literature review, the needs and challenges of optimizing pediatric protocols specific to age, body size, and composition were discussed. Through exploring individual scan parameters and technical considerations, basic strategies for pediatric CT dose optimization were identified. However, cautions should be taken when applying these techniques into clinical centers because the specifications of various scanners would be different. It is expected that this example would provide medical radiation technologists, radiologists, and medical physicists with more ideas about developing protocols specific to age and body size, and encourage them to review and optimize the pediatric protocols in their departments. Although there is limited discussion on protocols specific to gender because of insufficient information provided by the literature, this could be considered another future study direction.

II. DISCUSSION

Radiation dose optimization in pediatric CT imaging is a critical aspect of ensuring diagnostic accuracy while minimizing radiation exposure. Children are more radiosensitive than adults due to their developing tissues and longer life expectancy, which increases the potential risk of radiation-induced malignancies. Therefore, strategies must be implemented to reduce unnecessary exposure while maintaining image quality.

One of the key principles in radiation dose optimization is the application of the ALARA (As Low as Reasonably Achievable) principle. This involves adjusting scanning parameters such as tube current, voltage (kVp), and pitch to suit the patient's size and the diagnostic requirement. Automatic exposure control (AEC) systems play a significant role in tailoring the radiation dose based on the child's anatomy, reducing exposure without compromising image quality. Another approach to dose optimization is the use of pediatric-specific

protocols. Unlike adult protocols, pediatric CT protocols consider body size, weight, and clinical indication to fine-tune scanning parameters. The use of lower tube voltage and current for smaller patients effectively decreases radiation dose while preserving diagnostic integrity. Additionally, iterative reconstruction techniques can enhance image quality while allowing for dose reduction. Shielding is another technique employed to protect radiosensitive organs, such as the thyroid, breasts, and gonads. However, recent studies suggest that proper protocol optimization may be more effective than shielding, as improper use of lead shields can interfere with automatic exposure control systems, potentially leading to increased radiation dose. Furthermore, the justification of CT scans is crucial. Physicians and radiologists must evaluate whether CT is necessary or if alternative imaging modalities such as ultrasound or MRI, which do not use ionizing radiation, could provide adequate diagnostic information. Clinical decision support systems (CDSS) can assist healthcare providers in making informed decisions regarding the appropriateness of CT examinations. Education and training for radiologists and technologists also play a vital role in optimizing radiation dose. Awareness programs and continuous education ensure that professionals stay updated on advancements in dose-reduction technologies and best practices.

In conclusion, optimizing radiation dose in pediatric CT requires a multifaceted approach, incorporating technological advancements, protocol customization, proper justification, and continuous education. Implementing these strategies effectively can significantly reduce radiation risks while maintaining high-quality imaging necessary for accurate diagnosis and treatment planning.

III. CONCLUSION

Since the last decade, manufacturers and clinical centers have started to develop pediatric scanning protocols specific to age, body size, and composition for better dose optimization. However, the recent International Atomic Energy Agency survey suggested many departments still rely on default protocols provided by manufacturers without further optimization. The literature identified a range of scan parameters and technical considerations that should

be optimized for pediatric patients with different ages and body sizes including tube voltage and current, IR, DRLs, bowtie filters, scout view, pitch, scan collimation and time, overscanning, and overbeaming. Although the discussion is not comprehensive, basic strategies to optimize these factors were suggested. An example of optimized pediatric protocols specific to age and body size for the 64-slice CT scanners was devised. It is expected that this example could provide more ideas to medical radiation technologists, radiologists, and medical physicists to optimize their pediatric protocols.

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