Pointers for Optimizing Radiation Dose in Pediatric CT Protocols

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According to recent estimates, close to 7 million to 8 million CT examinations were performed for various pediatric clinical indications per year in the United States [1]. Children are normally more susceptible to radiation-related risks because of greater organ radiosensitivity and a longer life span to potentially develop radiation-induced carcinogenesis [2]. Although there are uncertainties regarding the lack of substantial data on the long-term radiation risks at dose levels associated with CT scans, it is still our responsibility to limit the amount of radiation used to only what is absolutely necessary. In this article, we review various strategies for reducing radiation dose associated with pediatric CT examinations.

APPROPRIATE USE OF CT

Justification of clinical indication is the most important aspect of reducing radiation dose with CT scanning. A substantial number of pediatric CT scans lack appropriate justification or can be replaced with other imaging modalities with lower or no ionizing radiation, such as radiography, ultrasonography, and MRI, which can provide similar diagnostic information for some clinical indications. In particular, ultrasonography can provide required information for several clinical queries in pediatric abdominal, neck, and musculoskeletal regions.

Search for justification of CT can be aided by Web-based computerized radiology order entry systems, which use clinical decision support rules governed by appropriateness guidelines such as the ACR Appropriateness Criteria® [3]. These platforms allow physicians to order appropriate examinations for given patient ages and clinical indications. They also suggest alternative "safer" or cheaper imaging modalities when appropriate. At the Massachusetts General Hospital, the decision support system also helps avoid duplicate or repeat CT examinations.

OPTIMIZING PEDIATRIC CT PROTOCOLS

To optimize CT protocols, it is important to have a basic understanding of CT scan parameters [4], and their effects on image quality and radiation dose is required. CT protocols should be strictly optimized on the basis of body size, body region, clinical indication, and the availability of prior imaging.

Body region is an important determining factor for radiation dose management. For example, air in the lungs provides high inherent tissue contrast on chest CT and facilitates the detection of tiny or subtle pulmonary abnormalities at relatively lower radiation. Thus, most pediatric chest CT studies can be performed at fixed tube currents in the range of 10 to 50 mAs at 120 kVp with retained information [5]. Likewise, musculoskeletal indications can be scanned at lower radiation doses because of higher tissue contrast of the bones and at the interfaces between fat and musculoskeletal tissue. Most pediatric CT for bones, such as chest CT for pectus deformities, whole-spine CT for scoliosis evaluation, and extremity CT for bone trauma, can be performed at very low or the lowest allowed fixed tube currents. Paranasal sinus CT in children should also be done at similar lower radiation doses. However, it may be challenging to aggressively reduce doses for abdominal CT because of higher attentuation compared to chest, higher prevalence of low contrast structures and lesions and in very small children presence of low intra-abdominal fatty tissue between organs and tissue planes [6].

Protocols should also be designed to enable stratified dose reduction for certain clinical indications in the same body region. Because urinary tract calculi are hard to miss at even lower doses and frequently require several follow-up CT studies even in younger children, radiation doses for stone evaluation should be reduced compared with other abdominal indications.

Higher image noise in low-dose head CT images can interfere with the visualization of gray and white matter differentiation or the cortical ribbon. At the Massachusetts General Hospital, pediatric head CT is generally limited to assessing for intracranial hemorrhage, shunt patency for hydrocephalus, and bony skull, all of which can be assessed with substantially low radiation dose (<1 mSv). For example, CT for craniosynostosis in infants can be very well assessed at 80 kVp and 20 to 30 mAs to achieve very low doses.

Some clinical situations, such as urinary tract calculi, ventriculoperitoneal shunt patency, and cystic fibrosis, often require multiple follow-up CT studies, which for at least the benign indications must be acquired at lower radiation doses and also by limiting the scan region during repeat scans to further minimize radiation risk.

SPECIFIC STEPS TO REDUCE PEDIATRIC CT DOSE

Localizer Radiographs

Localizer radiographs must be acquired at the lowest possible tube current-time

0091-2182/12/$36.00 • DOI 10.1016/j.jacr.2011.10.005

product of 10 to 20 mAs and 80 kVp. Adequate centering can enable scan planning with just one localizer radiograph, which is restricted to anticipated region of scanning.

Tube Current

Tube current is the most commonly used scanning parameter for radiation dose optimization. Most young children have much smaller anteroposterior and lateral diameters compared to adults and hence need lower tube currents to achieve adequate image quality. This can be achieved with either automatic exposure control (AEC) or lower fixed tube currents for pediatric CT [7]. The Image Gently^{sm} Web site (http://www.imagegently.org) provides an excellent way to adapt tube current for children of variable sizes for head, chest, and abdominal CT.

There are substantial variations in the way different vendors apply AEC in their CT scanners, and it is therefore imperative that users become familiar with the variations. Automatic exposure control requires users to specify an image quality surrogate, such as the noise index (AutomA; GE Healthcare, Milwaukee, Wisconsin) or reference tube current-time product (CARE Dose 4D; Siemens Healthcare, Erlangen, Germany) for different patient sizes or clinical indications [7]. Prior studies on AEC have shown dose reductions of up to 53% in the shoulder region, 25% in the pelvis, 22% in the thorax, and 18% in the head, compared with fixed tube currents. Singh et al [6] documented 50% to 75% dose reduction with AEC in pediatric chest and abdominal CT stratified according to weight and clinical indications.

Tube Voltage

Lower tube potential results in higher image noise and lowered diagnostic confidence, but in children, this effect is less pronounced, which should enable more liberal use of lower tube voltages for dose reduction [6,8]. Small infants can certainly be scanned at 80 kVp, whereas larger children may need 100 to 120 kVp [6]. At our institutions, most clinical indications with high contrast, such as CT angiography, are performed at 80 to 100 kVp to reduce radiation dose while improving image contrast.

Pitch

Patient motion is a constraint for data acquisition, and uncooperative children may require sedation or even controlled ventilation for CT scanning. Increase in pitch increases table speed and reduces scan time and may reduce motion artifacts. However, with certain CT scanners, increases in pitch result in compensatory increases in tube current to keep the image quality and therefore radiation dose constant [4]. With second-generation dual-source CT scanners, a very high nonoverlapping pitch (pitch factor up to 1.6:1 to 3.4:1) with a table speed of up to 450 mm/s can allow much faster scanning with few motion artifacts and substantial radiation dose savings [9] (Figure 1).

Scan Length

Scan length for all pediatric CT examinations should be absolutely restricted to the region of interest. For example, chest CT examinations should generally cover the lungs only,

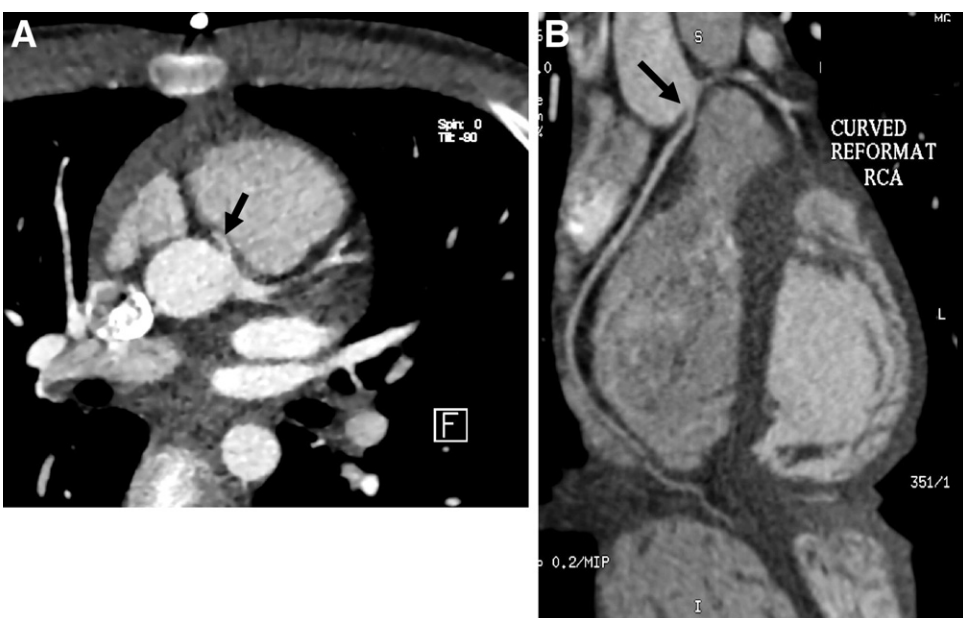

Fig 1. A 9-year-old boy (weight, 32 kg) underwent coronary CT angiography for anomalous coronary artery at 80 kVp and 110 mAs (volume CT dose index, 0.5 mGy; dose-length product, 8 mGy · cm; estimated effective dose, 0.1 mSv). Contrast-enhanced transverse (A) and curved planar reformat (B) images demonstrate anomalous origin of the right coronary artery (RCA) from the left coronary sinus (arrows).

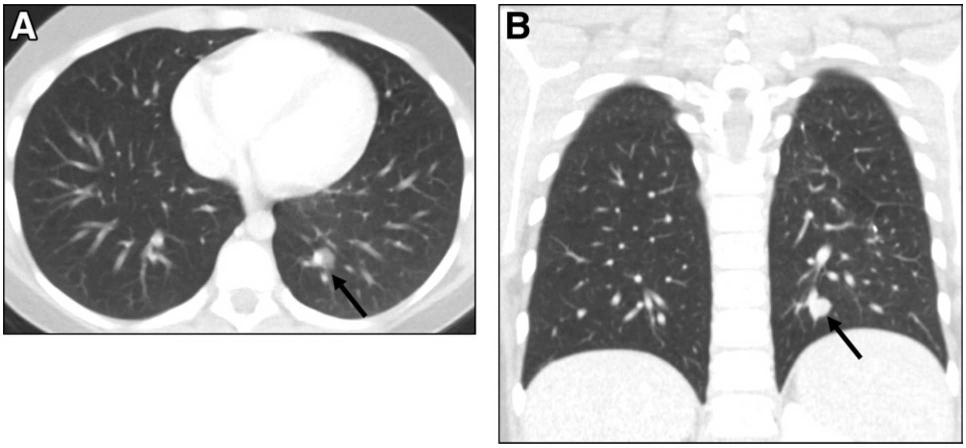

Fig 2. A 10-year-old girl (weight, 42 kg) with a history of metastatic rhabdomyosarcoma underwent follow-up chest CT at 100 kVp, 80 mA, a noise index of 14.1, and pitch of 1.375 (volume CT dose index, 1.5 mGy; dose-length product, 49 mGy · cm; estimated effective radiation dose, 0.7 mSv). Transverse (A) and coronal (B) chest images reconstructed with Adaptive Statistical Iterative Reconstruction demonstrate new nodular opacity in left lower lobe (arrows).

without extending to cover the adrenal glands, and abdominal CT should be limited from the dome of the diaphragm to the inferior margin of the pubic symphysis.

Image Processing

Newer techniques of image postprocessing and reconstruction have shown potential for pediatric CT radiation dose reduction. Vorona et al [10] documented 33% dose reduction in pediatric abdominal CT reconstructed using newer image reconstruction techniques (Adaptive Statistical Iterative Reconstruction; GE Healthcare) (Figure 2). Image postprocessing filters can also help lower noise and allow up to 30% radiation dose reduction for chest and abdominal CT examinations [11].

CONCLUSIONS

Children are more sensitive to radiation-induced risks and need special attention. Therefore, while designing CT protocols, it is crucial to keep clinical indications, weight, and prior available imaging in mind to optimize radiation dose.

REFERENCES

1. Mettler FA Jr, Wiest PW, Locken JA, Kelsey CA. CT scanning: patterns of use and dose. J Radiol Prot 2000;20:353-9.
2. Brenner D, Elliston C, Hall E, Berdon W. Estimated risks of radiation-induced fatal cancer from pediatric CT. AJR Am J Roentgenol 2001;176:289-96.
3. Sistrom CL, Dang PA, Weilburg JB, Dreyer KJ, Rosenthal DI, Thrall JH. Effect of computerized order entry with integrated decision support on the growth of outpatient procedure volumes: seven-year time series analysis. Radiology 2009;251:147-55.
4. Mahesh M. MDCT physics: the basics—technology, image quality and radiation dose. Philadelphia, Pa: Lippincott Williams & Wilkins; 2009.
5. Rogalla P, Stöver B, Scheer I, Juran R, Gaedicke G, Hamm B. Low-dose spiral CT: applicability to paediatric chest imaging. Pediatr Radiol 1999;29:565-9.
6. Singh S, Kalra MK, Moore MA, et al. Dose reduction and compliance with pediatric CT protocols adapted to patient size, clinical indication, and number of prior studies. Radiology 2009;252:200-8.
7. Singh S, Kalra MK, Thrall JH, Mahesh M. Automatic exposure control in CT: applications and limitations. J Am Coll Radiol. 2011;8:446-9.
8. Boone JM, Geraghty EM, Seibert JA, Wootton-Gorges SL. Dose reduction in pediatric CT: a rational approach. Radiology 2003;228:352-60.
9. Lell MM, May M, Deak P, et al. High-pitch spiral computed tomography: effect on image quality and radiation dose in pediatric chest computed tomography. Invest Radiol 2011;46:116-23.
10. Vorona GA, Ceschin RC, Clayton BL, Sutcavage T, Tadros SS, Panigrahy A. Reducing abdominal CT radiation dose with the adaptive statistical iterative reconstruction technique in children: a feasibility study. Pediatr Radiol 2011;41:1174-82.
11. Nishimaru E, Ichikawa K, Okita I, et al. Development of a noise reduction filter algorithm for pediatric body images in multidetector CT. J Digit Imaging 2010;23:806-18.

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