

Optimal Tube Potential in Pediatric CT for Radiation Dose Reduction: Principle, Clinical Implementation, and Pitfalls

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Purpose

1. To summarize currently available strategies for dose reduction in pediatric CT
2. To describe the principle of optimal tube potential (kV) techniques for dose reduction in pediatric CT
3. To provide step-by-step guidance on how to clinically implement kV/mAs technique charts
4. To describe common pitfalls of using lower kV in pediatric CT

Introduction

CT contributes almost half of the radiation exposure to the US population from the medical use of radiation [1]. Despite universal consensus that CT overwhelmingly benefits the patient in the appropriate clinical settings, public health concerns have arisen due to the potential risk of cancer induction resulting from the increased use of CT in medicine [2-5].

Mostly driven by the tremendously faster scanning speeds and the ease with which accurate diagnostic information can be obtained with CT, the use of CT in pediatric patients has grown dramatically, reaching at least 4 million exams in the US in 2006 [2].

Minimization of radiation dose associated with pediatric CT exams is of particular importance because the risk to children due to radiation exposure is two to three times greater than the risk to adults [6]. This is because children's organs are more sensitive to radiation and children have a much longer life expectancy relative to adults, thereby allowing more time for a potential radiation-induced cancer to develop.

Currently Available Techniques

Currently available techniques for dose reduction in pediatric CT

Carefully assess the risk/benefit of CT before the exam is ordered.

To reduce radiation dose in pediatric CT, the most important first step is to carefully assess the risk and benefit of CT for each patient. When alternative imaging modalities with less or no radiation exposure are readily available and that can adequately answer the clinical question, these methods should be considered for use instead of CT. In addition, multi-phase exams should be avoided if the information obtained from a single-phase scan is sufficient [7].

Use scanning techniques specifically designed for children.

When a CT exam is deemed necessary for a pediatric patient, scanning protocols specifically designed for children must be used. Previously, considerable attention was drawn to the inappropriate use of adult techniques for children and small adults [8, 9]. It is encouraging that a recent survey found that 98% of radiologists used weight-based tube current adjustments [10]. Thus, adapting the dose level to patient size has become a common practice in the CT community, which is further endorsed by the special requirements for pediatric CT techniques in the ACR accreditation program [11]. Patient-size dependent scanning techniques include the use of size-dependent bowtie filters, manual technique charts, automatic exposure control (AEC), and optimal tube potential.

Bowtie filter

Special bowtie filters designed for the body size and shape of pediatric patients can significantly reduce the radiation dose, particularly the skin dose, to children.

Tube current technique chart

Manually adjusting the tube current according to the patient size is probably the most straightforward way to reduce the radiation dose to pediatric patients. Because the attenuation level of children is not as high as adults, a reduced tube current can be used to achieve sufficient diagnostic image quality. For body CT, a reduction in mAs of a factor of 4 to 5 from adult techniques is acceptable in infants [12]. For head CT, mAs reduction from an adult to a newborn of approximately a factor of 2 to 2.5 is appropriate.

Automatic exposure control (AEC)

In AEC, the tube current is automatically modulated according to the patient size. The adjustment is based on target image quality or noise levels for different patient sizes. Lower noise images with thinner slice thickness in children are usually demanded.

Task-specific scanning techniques

Radiation dose should be adjusted based on the diagnostic task. For example, solid organ evaluation generally requires a higher radiation dose, while evaluation of high-contrast structures can use lower radiation doses without sacrificing diagnostic value. Figure 2 shows one example where only 1/5 of the routine dose was required.

Optimal tube potential (kV)

The use of lower kVs in pediatric patients to reduce radiation dose has been actively investigated [13-16]. The principle and implementation will be described in detail in the following sections.

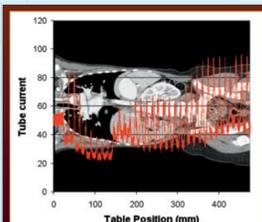


Figure 1. An example of automatic exposure control (AEC). The tube current was automatically modulated according to the attenuation level at each x-ray projection angle. Due to the continuous translation of patient table through the CT gantry in the helical scan, each projection angle corresponds to a particular table position.

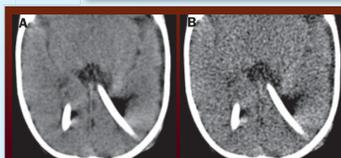


Figure 2. 80% dose reduction for a shunt follow-up exam for a 15-month-old girl. (A) Image acquired with the original scanning technique (CTDIvol=24.2 mGy). (B) Image reconstructed from data simulating 1/5 of the original dose, which is still acceptable to neuro radiologists for the purpose of assessing the size of the ventricle.

Principle of Optimal Tube Potential Techniques

Principle of optimal tube potential techniques for dose reduction in pediatric CT

Most body CT exams involve the use of iodinated contrast media. There is a marked increase in the signal of iodine at lower kVs, thereby improving the conspicuity of hypervascular or hypovascular pathologies (e.g., renal and hepatic masses, inflamed bowel segments, etc.). Pediatric patients are less attenuating than adults, so the lower kV settings can provide better iodine contrast, without significantly increasing the image noise, for the same radiation dose. Figure 3 shows the significant enhancement of iodine signal at lower kV without increasing noise for a small phantom (corresponding to a pediatric size patient).

Alternatively, one could reduce the radiation dose and achieve similar or improved iodine contrast to noise ratio (CNR) relative to 120 kV. Figure 4 shows one clinical example of using lower kV to reduce radiation dose by 25% while improving the image quality.

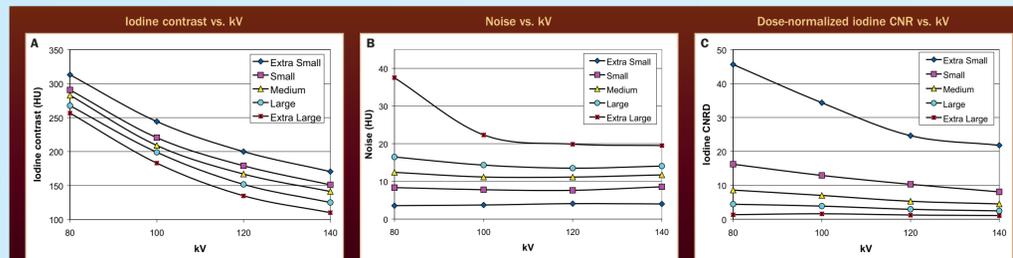


Figure 3. The change of (A) iodine contrast, (B) noise, and (C) dose-normalized iodine contrast to noise ratio (CNR) with the tube potential (kV) for different phantom sizes. The thoracic phantom lateral width was 20 cm (Extra small), 30 cm (Small), 35 cm (Medium), 40 cm (Large), and 48 cm (Extra Large). At each phantom size, the radiation dose was held constant as kV varied.



Figure 4. 11 year old boy scanned with a 120 kV protocol and a 100 kV protocol. Note the improved contrast-to-noise and visualization of mural stratification of the 100 kV image despite a 25% radiation dose reduction. (Note: both scans were obtained following the same 50 second delay after injection of the same amount of iodine. Display window/level = 400/40.)

Implementing kV/mAs Technique Charts

How we developed our kV/mAs technique charts for pediatric chest and abdomen protocols.

Step 1: Determine the lowest acceptable dose level at 120 kV

We simulated images with 25%, 50%, 70%, and 90% of the original dose level for 12 pediatric exams scanned using the typical 120 kV techniques. Figure 5 shows one example of the low-dose simulation. Two pediatric radiologists evaluated image quality to determine the lowest acceptable dose level for each exam.

Step 2: Create a weight-based kV/mAs technique chart

Noise as a function of dose was determined using nine acrylic phantoms (diameter range: 8.7 to 26 cm) at 80, 100, and 120 kV. The lowest acceptable doses at 120 kV (from Step 1) were converted to noise-matched dose values at 80 kV and 100 kV for each phantom size. The attenuation of each phantom was translated into a corresponding patient weight for the technique chart.

Step 3: Refine the techniques at 80 kV and 100 kV

We refined the reduced-kV technique chart clinically in order to take into account the potential benefit of increased iodine contrast enhancement at lower kV settings. Using the technique chart from Step 2, 33 pediatric body cases acquired with the reduced-kV techniques were collected (17 with 80 kV, 16 with 100 kV; 12 chest, 18 abdomen/pelvis, 3 chest/abdomen/pelvis; 27 with contrast, 6 without contrast). Then, similar to Step 1, we simulated images with 25%, 50%, 70%, 90% of the original dose level for these reduced-kV cases. Two pediatric radiologists evaluated image quality to determine the lowest acceptable dose levels for the 80 kV and 100 kV cases, resulting in the final reduced-kV technique chart (Tables 1 and 2).

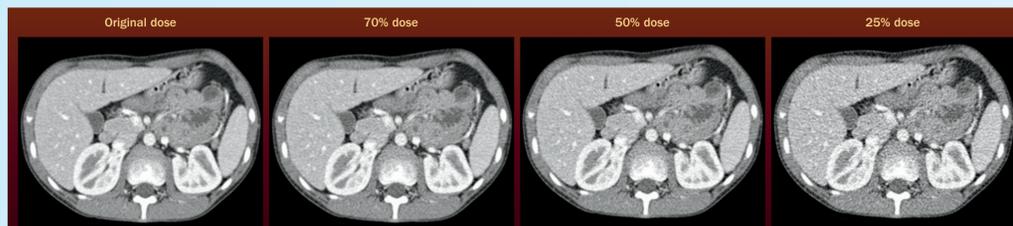


Figure 5. An example of lower-dose simulation from a routine-dose exam. (a) Original dose, (b) 70% dose, (c) 50% dose, (d) 25% dose.

Table 1. Weight-based kV/mAs technique chart for pediatric routine chest CT exam. (Siemens Sensation 64)

Weight	kV	Chest Protocol							CTDIvol (mGy) ** (mean ± std)
		QRM*	CARE Dose4D	Pitch	Rot. Time	Kernel	Slice/interval	Collimation	
<10 kg	80	150	On	1.2	0.33	B40f	3mm/3mm	64x0.6	2.09 ± 0.2
10-20 kg	100	70	On	1.4	0.33	B40f	3mm/3mm	64x0.6	3.53 ± 0.3
20-45 kg	120	40	On	1.4	0.33	B40f	3mm/3mm	64x0.6	5.16 ± 1.2

Table 2. Weight-based kV/mAs technique chart for pediatric routine abdomen/pelvis CT exam. (Siemens Sensation 64)

Weight	kV	Abdomen/Pelvis Protocol							CTDIvol (mGy) ** (mean ± std)
		QRM*	CARE Dose4D	Pitch	Rot. Time	Kernel	Slice/interval	Collimation	
<10 kg	80	190	On	1.1	0.33	B40f	3mm/3mm	64x0.6	2.20 ± 0.3
10-20 kg	100	90	On	1.4	0.33	B40f	3mm/3mm	64x0.6	3.84 ± 0.4
20-45 kg	120	50	On	1.4	0.33	B40f	3mm/3mm	64x0.6	5.10 ± 0.7

*QRM = Quality reference mAs, which prescribes the desired image quality.
**As specified by [17], a 32cm CTDI phantom is used.

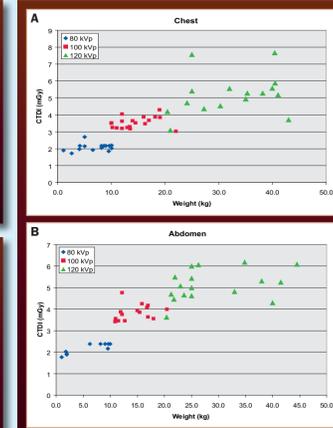


Figure 6. CTDIvol vs. patient weight for patients utilizing the kV/mAs technique charts in Tables 1 and 2: (A) chest (50 patients), (B) abdomen/pelvis (42 patients).

Common Pitfalls

Common pitfalls of using lower-kV for pediatric CT

Several factors should be considered when lower-kV techniques are used.

- The tube current-time product (mAs) at lower kVs has to be increased appropriately relative to 120 kV in order to avoid excessive noise.
- A fast rotation time and a high helical pitch are desirable in pediatric CT in order to reduce motion artifacts. Because of tube current limitations, the maximum achievable dose level (determined by maximum mAs/pitch) can also be limited, especially for lower tube potential settings. Therefore, a higher tube potential may still be necessary for bigger children. It is essential to use a weight or size-based kV/mAs technique chart to know what mAs/kV to use as patient size varies.
- Lower kVs tend to generate more artifacts than higher kVs in the presence of highly attenuating objects, such as dense iodine contrast media and bone, due to the more significant beam-hardening that occurs.
- Lower kVs may lead to increased noise and/or decreased contrast of soft tissues or structures without iodine uptake. Thus, lower kVs may not be appropriate for every exam and have to be carefully evaluated before use.
- For any kV, any patient shielding should be placed very carefully, as it can lead to significantly increased radiation dose and artifacts if it is in the scan volume. The artifacts are particularly more severe in lower kVs (Figure 7).

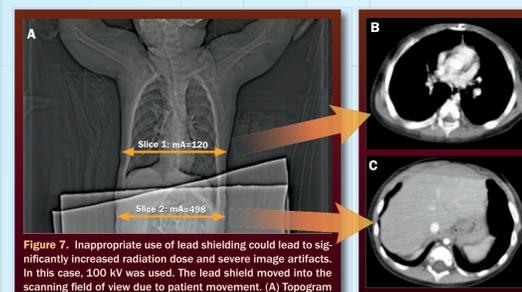


Figure 7. Inappropriate use of lead shielding could lead to significantly increased radiation dose and severe image artifacts. In this case, 100 kV was used. The lead shield moved into the scanning field of view due to patient movement. (A) Topogram showing the position of the lead shield. (B) One slice outside of the lead shield, tube current was normal. (C) One slice inside the lead shield, severe artifacts occurred and the tube current increased dramatically.

Main Teaching Points

- Besides automatic tube current modulation, selection of optimal kV for pediatric patients has the potential to improve image quality and reduce radiation dose.
- Lower kV has better iodine contrast but usually increased noise and artifacts in images. Hence, the use of lower-kV should be carefully evaluated for each exam type for an optimal tradeoff between increased iodine contrast, noise, and artifacts.
- A kV/mAs technique chart for different patient sizes and clinical exams is necessary to generate the best dose/image quality outcome.
- A step-by-step approach to generating a kV/mAs technique chart is recommended to refine technical parameters.

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