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Pediatric CT: practical approach to diminish the radiation dose

Introduction

CT is an invaluable imaging modality for infants and children. However, the practice of CT has been increasingly under scrutiny because of the association between cancer and low levels of childhood radiation such as in CT [1, 2]. While for most patients the benefits of CT greatly exceed the risks, this margin narrows when an excess of radiation is used [2, 3]. In the past 18 months, new information seems to have led to some reduction in the amount of radiation children receive during CT [4]. There is still a substantial need to modify pediatric CT scanning practice, including techniques, to avoid unnecessary radiation. The following discussion focuses on dose-reducing strategies for the CT of infants and children. It is ultimately the responsibility of the radiologist to see that such strategies are implemented. Many of these suggestions take some thought and effort, but their absence has led to the problems we currently face.

Strategies to reduce CT radiation in children

Strategies to minimize the radiation children receive from CT can be divided into those that stress judicious use of CT and those that involve adjustment of individual scan parameters.

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Judicious use of CT

The most effective measure to minimize CT radiation is to do no unnecessary examinations. Perhaps 40% of all pediatric CT examinations are not clearly indicated [2]. If those scans were not done, the dose to the pediatric population would immediately be reduced by 40%.

Moreover, the use of CT is increasing. In both adults and children, there was a 600% increase in the number of examinations in a recent 10-year period [5]. The current prevalence of multidetector CT (MDCT) may mean that this is effectively an underestimate. MDCT is used not only with the established CT applications, but also increasingly in other common disorders such as renal stones and appendicitis. Screening examinations for coronary artery calcifications and colon cancer may make CT even more recognized as a routine imaging modality for adults [6]. As CT becomes a more familiar modality, it is reasonable to expect that the number of CT examinations for questionable or spurious indications will increase.

It is impossible to determine the appropriateness of every CT examination. However, there are a few potential strategies to minimize the number of unnecessary CT examinations. There must be good communication between radiologists and pediatric care providers. A brief consultation might result in an alternative examination, such as a sonogram or MR examination, neither of which use ionizing radiation. Periodic review of patterns of CT requests can lead to recommendations and advice for those who order poorly indicated examinations. We radiologists must be governed by what is good for children, not by what is good for business.

Judicious CT use also means that the examination even when indicated should be limited to the area in question. For example, evaluation of a renal abnormality seldom requires scanning through the entire abdomen and pelvis. Evaluation of cardiovascular disorders such as aortic arch abnormalities can be limited to the area in question. Limited CT examinations can be performed for follow-up, especially for a focal abnormality. Another example of focused CT includes high-resolution chest evaluation. In many cases, it is not necessary to get an entire helical examination with subsequent high-resolution cuts. A focused, thin-section, low-dose examination performed axially at intervals, sparing the intervening sections of the lung from all but scatter radiation, has been shown to be feasible [7].

Modifying CT scan parameters

Once it has been determined that a CT scan is indicated and the examination is limited to the region of interest, the technique factors should be adjusted to reduce the radiation dose. They should be modified to fit the scan indication. Sometimes the question will be answered with a relatively low detail (low resolution or noisy) examination. For example, in our practice small bowel obstruction, pancreatitis pseudocyst formation, and even urinary tract stones are shown satisfactorily with low-detail settings. Some of these cases can be followed by sonography but CT is useful in problematic cases. Higher detail examinations are sometimes necessary. It is beyond the scope of this paper to define these situations; nevertheless, it is the responsibility of the radiologist to determine the appropriate examination as well as the appropriate technique. An example of this approach is pediatric fluoroscopy: the length of fluoroscopic time, the number of images, and the image intensifier setting are all almost by reflex adjusted to the indication. Radiologists must learn to accept noisier images that are nevertheless diagnostic. Adequate diagnostic quality must replace highest resolution diagnostic quality.

One of the simplest adjustments is to limit multiple sequences or scans during the same CT examination – the "multiphase examination". Many pre-contrast examinations can be dispensed with. The indications for scanning through a region more than once are few. About 31% of pediatric abdominal CT examinations are in fact multiphase examinations [3]. There are no data to indicate that routine use of multiphase examinations improves diagnostic yield. Since few or no adjustments are made from one phase to the next, multiphase examinations usually multiply the radiation received by a factor equal to the number of phases [3]. A dual phase (pre- and post-contrast) examination usually doubles the amount of radiation. If the use of multiphase examinations were limited, the overall radiation would be at least 15% lower [3]. The few indications for multiphase examinations will not be discussed here.

Multiphase CT in children should be at the discretion of the radiologist, and that discretion should be used. At our hospital, pediatric CT involves multiphase abdominal examinations less than 5% of the time. If additional phases are necessary (e.g., for opacification of the ureter or for additional contrast filling of bowel), then the scan parameters, including length of scan, slice thickness, and tube current should be adjusted to minimize the further radiation received. For example, a pre-contrast examination looking for calcification should use a lower tube current, since calcium is highly attenuating.

The parameters which most strongly govern radiation dose in CT are tube current (mA), gantry rotation time (seconds) – the product of these is mAs, tablespeed ($cm \cdot s^{-1}$), detector configuration (mm), and kilovoltage (kVp).

Perhaps the most familiar factor contributing to radiation is tube current. This is typified by discussion of "low-dose" chest CT where low dose equates to reduced mAs [7, 8, 9, 10]. Adjustments in tube current should obviously be made for children. It is not necessary to have the same number of photons for a 10-kg child as for a 40-kg child or an 80-kg adult. General guidelines, based on size (usually weight), are becoming increasingly available for tube current [11]. The issue of tube current and scan detail is beginning to be addressed [12]. In this investigation, CT scans performed for assessment of smaller, low visibility structures (e.g., small vessels), reductions of 33% from a tube current of 120 mA did not cause significant loss of detail.

The CT factors should be based on the region scanned. Lower tube currents are sufficient to evaluate the lung parenchyma [7, 8, 9, 10]. Because bone intrinsically has high contrast, the tube current should be lowered when a bone is of primary interest.

Gantry cycle time is another feature that will affect the amount of radiation delivered by a CT scan. Reducing cycle time, keeping all other parameters the same, decreases the radiation proportionately. For example, going from a cycle of 1.0 s to a cycle of 0.5 s will decrease the radiation by 50%. By decreasing the tube current by 50% and simultaneously halving the gantry cycle time, a scan can be performed at only a quarter of the original radiation dose.

With multidetector CT scanning, cycle times can be as short as 0.5 s. For children, we use shorter times and increase the tube current to give a mAs similar to that of a longer time and lower tube current. For example, options for an 80-mAs abdomen scan would be 80 mA with a 1.0-s rotation time, 100 mA with a 0.8-s time, and 160 mA with a 0.5-s time. Faster times are desirable in pediatric CT since children have difficulty holding their breath or holding still.

For single detector helical CT (SDCT), table speed, collimation (or detector configuration), and cycle time all determine pitch. The concept of pitch is more complex with four- and eight-array MDCT scanners [13]. With MDCT, the beam collimation (combination of all the detector thicknesses) and table speed (independent of gantry rotation time) determine pitch. The higher the pitch, the lower the radiation dose. For SDCT, pitches of 1.5–2.0 or greater are acceptable for pediatric abdominal CT [14, 15]. Data are lacking for the best pitch for pediatric body MDCT. The effect of MDCT pitch on image quality and diagnostic capability needs to be investigated; until this is done, radiologists must determine protocols empirically.

Lower pitches and narrower collimation or detector configuration (1.0–1.5 with SDCT, <1.0 with MDCT) provide higher detail and less artifact and this should be kept in mind when high detail is important. For MDCT, increasing the table speed while keeping the detector configuration thickness unchanged will increase the pitch and decrease the radiation dose. This means that, for symmetric configuration MDCT where all detector widths are equal (such as General Electric LightSpeed scanner), the pitch option of 0.75 (previously High Quality or HQ mode) results in overlapping coverage and increased radiation compared with the other pitch option of 1.5 (previously, HS or High Speed mode) where there is no overlap. Increasing the table speed and detector configuration thickness to maintain the same pitch will also lower the dose. This is due to the geometry of the MDCT beam, and the phenomenon of imperfect collimation at the periphery of the detectors ("overbeaming"). There is an essentially fixed portion of the beam (a few millimeters) that is not used in image formation. This amount is the same irrespective of configuration thickness. The greater the collimation (simplistically, the fewer rotations to cover the same area compared with narrower collimation), the smaller the contribution of overbeaming and the less radiation delivered. One advantage of eight-array (and eventually 16-array) MDCT compared with four-array MDCT is that this overbeaming is minimized even with identical detector thickness due to an increase in the rows or arrays of detectors. For example, a 4×1.25 mm (5.0 mm per rotation) configuration for the four-array MDCT would take twice as many rotations and more overbeaming to complete an equal length of coverage compared to an 8×1.25 mm (10 mm per rotation) configuration. For any individual scan, adjusting parameters to maximize the pitch, and using the thickest detector configuration should be considered when lower detail is acceptable.

Kilovoltage (kVp) also determines radiation dose. Kilovoltage has an impact on image contrast as well. In children, the relationship between kilovoltage, image quality as measured by contrast-to-noise ratio, and radiation delivered is complex and is only beginning to be addressed [16]. Only recently has attention been focused on how kilovoltage affects image quality in children [17]. Most pediatric body CT is performed at 120 kVp [18]. The second most common kilovoltage is 140 kVp, followed by 130 and 110 kVp. At our hospital, we have traditionally used 140 kVp, and to limit the dose, use relatively low tube current. However, preliminary scanning with 120 kVp has not resulted in any detectable change in image quality. While no firm data exist on the effect of kilovoltage on diagnostic quality, simply defaulting to a single, or higher kilovoltage (e.g., 140 kVp) for children of all sizes and for all indications may not be justified [16, 17]. The data are preliminary, but recommendations to adjust kilovoltage in children downward from 120 kVp will likely be forthcoming.

Assessing radiation dose: individualizing CT parameters

Manufacturers provide estimates of radiation dose on the CT console. Typical values are the weighted CT dose index ($CTDI_w$, in units of milliGray), or the dose length product (DLP, in units of milliGray·centimeters). These are determined by phantom measurements and are not organ doses or effective doses; the latter are useful in assessing radiation risks. Nevertheless, these values are a gauge to the dose a child will get from a scan. The radiologist and technologist can see the radiation dose before changing technique and then see the effect on dose of those changes. On equipment displaying these values before scanning, changes in parameters will be reflected in the displayed radiation dose, giving the radiologist and CT technologist an idea of how the dose to the child would be changed. There will soon be adjustments in scanning automatically performed by the equipment during scanning to account for differences from slice to slice in attenuation of the X-ray beam. This tube current modulation will help individualize CT scanning for children and for their body regions.

Long-term strategies

Long-term strategies include education of radiologists and other health-care providers about the relationship between CT parameters, image quality, and radiation dose and risks. Guidelines for pediatric CT should be derived from investigations assessing diagnostic quality with various parameters affecting radiation dose. Both radiologists and manufacturers can then use this information to develop scanning practice that is tailored to the unique aspects of pediatric CT [19].

Conclusion

CT is a valuable modality in which the benefits generally far outweigh individual risks. However, given the increasing frequency of CT examinations and the accumulating data about the risks of cancer development after low-level radiation, radiologists must avoid excessive radiation in infants and children. Strategies to do this include the judicious use of CT (making sure that the scan is indicated and focusing the examination on the region in question) and adjusting scan parameters based on the size of the child, the region scanned, and the indication. These simple measures will have a large impact on the welfare of children.

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