

ALARA: is there a cause for alarm? Reducing radiation risks from computed tomography scanning in children

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Purpose of review

Radiation exposure from computed tomography is associated with a small but significant increase in risk for fatal cancer over a child's lifetime. This review aims to heighten awareness and spearhead efforts to reduce unnecessary computed tomography scans in children.

Recent findings

The use of pediatric computed tomography continues to grow despite evidence on known risks of computed tomography-related radiation and induction of fatal cancers in children. More than 60 million computed tomography scans are estimated to be performed annually in the USA, with 7 million in children. Pediatric radiologists apply the practice of ALARA ('as low as reasonably achievable') to reduce radiation exposure. Education and advocacy directed to the referring clinician reinforce these principles. Radiation exposure may be further reduced by developing clinical pathways limiting computed tomography scanning and encourage alternate, nonradiation imaging modalities, such as ultrasound and magnetic resonance imaging. Although individual risk estimates are small, widespread use of computed tomography in the population may implicate a future public health issue.

Summary

Advocacy by pediatric healthcare providers to promote intelligent dose reduction based on the principles of ALARA and the judicious use of computed tomography scanning is essential to foster the safest possible care of children.

Keywords

ALARA, as low as reasonably achievable, children, computed tomography, radiation, safety

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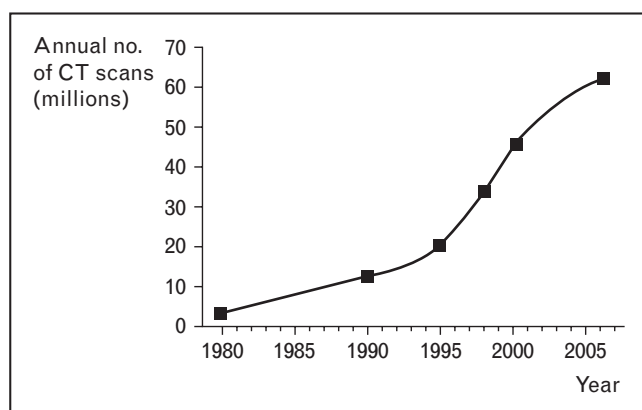
Introduction

The use of pediatric computed tomography (CT) has increased significantly over the past two decades. Current estimates reveal that more than 60 million CT scans are performed annually in the USA, including as many as 7 million in children [1,2]. Although CT has evolved into an invaluable diagnostic tool, recent attention has focused on the potential for increased radiation exposure to children undergoing these scans and its commonplace use has now become a public health concern. Unique physiologic considerations in children make them particularly vulnerable to the deleterious effects of ionizing radiation. This is substantiated by long-term studies which have shown that low-dose radiation in childhood carries a small but significant increase in the lifetime risk for fatal cancer [3,4]. Therefore the role of the pediatric healthcare provider is critical in reducing

or eliminating the unnecessary radiation that children receive from CT examinations.

Impact of computed tomography in children

CT scan techniques were first introduced more than three decades ago. In the past 10 years alone the use of CT has dramatically increased, nearly 700% [5], both in the USA and worldwide. It is estimated that more than 62 million CT scans are currently obtained in the USA, compared to three million in 1980 (Fig. 1) [1]. Approximately 11% of CT scans are performed on children every year in the USA, accounting for nearly 7 million pediatric CT studies [2,6]. The frequency of CT examinations in children continues to increase, with a growth rate of almost 10% per year according to some reports. CT has become a standard modality in the evaluation of many common illnesses and injuries in children. This sharp upsurge has been

Figure 1 Estimated number of CT scans performed annually in the USA

CT, computed tomography. Reproduced with permission from [1*].

attributable largely to increased availability and recent refinements in CT technology such as helical CT and, more recently, multidetector scanners. These technical improvements have enabled a striking decrease in the length of time needed to perform a scan – in many cases even less than 1 s – largely obviating the need for sedation to acquire optimal images.

Despite the many benefits of CT, the radiation exposure associated with this modality has come under increasing scrutiny. Although CT examinations account for only about 15% of imaging examinations that use ionizing radiation, they are estimated to contribute approximately 70% of the effective radiation dose from all medical imaging to patients [2*,7]. Radiation effects may be expressed in several ways. The amount of energy absorbed by tissue when exposed to a radiation source is known as the absorbed dose, measured in rads or grays (1 Gy = 100 rad). A radiation weighting factor is applied to the absorbed dose to provide a dose equivalent, measured in rems or sieverts (1 Sv = 100 rem). This helps to compare the radiation dose from a variety of sources, both medical and nonmedical. The effective dose is the dose of radiation absorbed, taking into consideration factors such as body mass and tissue-specific differences in radiosensitivity [2*,8]. In considering the effective dose of radiation it is helpful to compare the effective dose for different radiologic studies (Table 1) [2*]. For example, the radiation from a single abdominal CT is nearly 250 times that of a plain chest radiograph.

Unique considerations for radiation exposure in children

There are considerations unique to the pediatric population which render them particularly susceptible to the harmful effects of ionizing radiation. First, because grow-

Table 1 Comparison of effective radiation doses from X-ray and CT

Imaging study	Effective dose (mSv)	Equivalent number of chest X-rays
Chest X-ray	0.02	1
Head CT	4	200
Abdominal CT	5	250
Chest CT	3	150

CT, computed tomography. Reproduced with permission from [2*].

ing children have rapidly dividing cells, they are more sensitive to the effects of radiation. In fact, a dose of radiation in a child would result in a 10-fold increase in neoplastic potential compared to an equivalent dose in an adult [2*,3]. This particularly holds true for thyroid, breast, and gonadal tissue. Second, children have a longer lifetime during which radiation-related cancers may evolve [2*]. Finally, until recently most CT scans were not performed with consideration for the smaller size of children. This resulted in children receiving a higher radiation dose per unit of tissue compared to an adult for a given study [1*,9].

Risk of low-level radiation and computed tomography

Ionizing radiation has many documented adverse effects, the most serious of which is the induction of fatal cancers. Most of the quantitative information regarding the risks of radiation-induced cancer is derived from follow-up studies of a cohort of more than 35 000 atomic bomb survivors who had received low doses of radiation, comparable to the dose of a single helical CT scan [2*,3,10,11]. Based on this outcome data, it is estimated that 1 in 1000 children who have had a CT scan will develop a radiation-induced fatal cancer in their lifetime, correlating to a 0.35% increase over the expected baseline lifetime risk for cancer [3]. This small but meaningful risk has influenced efforts to obtain high-quality diagnostic imaging with the minimum possible amount of radiation exposure. While the increased risk of radiation-induced cancer is small for any one individual, given the large number of CT scans performed, the risk to the population as a whole is considerable.

While high-dose radiation exposure is well known to be associated with the development of malignancy, even low doses of radiation, in ranges of 10–50 mSv, incur an increased lifetime risk for fatal cancer [2*]. The effective dose from a single pediatric CT scan may range from 5 to 60 mSv [5]. It is reported that nearly 30% of all individuals who have a CT study performed will have more than one study [6,9]. Since the dose from each CT scan is cumulative over the life of an individual, multiple scans result in an even greater lifetime risk of fatal cancer for the individual [9].

ALARA for the radiologist

The concept of ALARA ('as low as reasonably achievable') addresses the role for the pediatric radiologist in reducing the amount of radiation a child is exposed to while maintaining efficiency and reliability of the diagnostic modality. There are a variety of methods to achieve ALARA from the perspective of the radiologist [2^{*},9,12,13,14^{*}].

First, develop weight-based protocols. For each CT study in a child, the total dose of radiation may be reduced by developing weight-based protocols. This is of particular concern for the very small, premature neonate. Historically, the perspective on CT scan was 'more is better', meaning, the higher the radiation dose, the better the image quality. With increasing awareness of radiation risks among experienced pediatric radiologists, the emphasis is now on reducing dose while maintaining reliability [15,16].

Second, consider alternative nonradiation modalities: ultrasound and magnetic resonance imaging (MRI) are nonradiation modalities used to evaluate disease. The safety of these options must be weighed against availability, skill and experience of the technician and radiologist, as well as the time required to perform the study.

Third, improve shielding. Technicians require ongoing education and support to maximize shielding when possible. Newly fabricated thyroid and breast shields may be utilized during CT scan without impacting the quality of the study [12,17,18].

Fourth, focused and/or limited-view studies: when clinically appropriate, focused and/or limited-view studies may be obtained. Technicians require education or well-defined protocols to identify indications for limited-view studies. For example, in the case of likely uncomplicated appendicitis, when a CT scan is still desired, a complete abdominal and pelvic CT scan is not required, and a focused exam is recommended. Alternatively, when a diagnosis of appendicitis is less obvious, and perhaps unlikely, a complete CT study to explore all possible diagnoses is appropriate and preferable.

Finally, discourage repeat CT studies: the practice of repeat CT scan studies, such as 'with and without' contrast, is often unnecessary. In most cases, pathology is equally identifiable prior to contrast or after contrast is instilled, depending on the suspected etiology. It is rarely the case that a pre *and* postcontrast CT scan is needed. The supervising radiologist may appropriately suggest modifying a request to include only a single, rather than a paired, study [19].

ALARA for the referring clinician

Pediatric radiologists have been advocating ALARA since the first publications on radiation risk from CT scan in 2001. Educating clinicians about the judicious use of CT may have the most impact in reducing radiation exposure in children. One recent survey reported that patients, emergency-department physicians, and radiologists are unable to provide accurate estimates of CT doses and lifetime cancer risk [20]. It is believed that between 10 and 30% of all CT scans performed may be deemed 'unnecessary' [21]. Since CT provides a wealth of information about the internal composition of nearly all body areas, it is being used not only for diagnostic purposes but also for screening of disease. Exploring alternative options and considering the true need for a study, based on an individualized case-by-case assessment, is essential. The role of the pediatric radiologist in this decision-making cannot be overemphasized.

Appendicitis is arguably the principal pathologic entity accounting for the surge in utilization of abdominal CT scan in children. Radiologic confirmation of diagnosis prior to surgical intervention has become the mainstay for both surgeons and parents. Imaging is found to reduce the negative appendectomy rate from 14 to 2% [22,23]. There is much literature on the use of ultrasound and CT scanning in diagnosing appendicitis [24]. A meta-analysis comparing the two modalities in children and adults reports a sensitivity of 0.88 (95% confidence interval 0.86–0.90) for ultrasound and 0.94 (95% confidence interval 0.92–0.97) for CT scan. A limitation of this study, however, is the inclusion of adults in the analysis, and weak methodologic quality of the studies included [19]. Clinical practice guidelines (CPGs) utilizing CT to reduce negative appendectomy rates may be partly responsible for increasing CT utilization. In a study by Smink *et al.* [25], the rate of performing a CT for this indication was 5% (18/388) in 1997 and 60% (344/571) in 2001. Alternatively, CPGs may actually be helpful in reducing CT use. Another report of a CPG utilizing ultrasound as a screen for a positive appendicitis, in which only patients with negative or equivocal ultrasound were required to undergo CT scan, resulted in a sensitivity of 96% and a negative predictive value of 98%. Therefore, by reserving CT for patients with clinical and ultrasonographic uncertainty, there was a reduction in CT performance and unnecessary radiation exposure, while maintaining diagnostic accuracy [26,27]. While ultrasound may offer a substantial opportunity to reduce radiation exposure in children, there remain barriers to its routine use. The diagnostic efficacy of ultrasound may be impaired in cases of a retrocecal appendix and in obese individuals. Even in the hands of the experienced sonographer, the appendix may not be visible. Ultrasound is further limited by availability, particularly during

off-hours. Many institutions have a modified approach to clinical evaluation based on time of day and resource availability. The goals for reducing the risks of CT scan in children need to be considered in the development of this dichotomous practice.

There is very sparse current literature on the use of MRI in the evaluation of acute appendicitis in children. One report found MRI to accurately identify 100% of acute appendicitis in 20 patients (two of whom had equivocal ultrasound readings), and concluded that MRI is a valuable imaging technique for diagnosing appendicitis, particularly in children and women of child-bearing age [28]. As MRI technology develops to enable more rapid sequences and accommodate minor motion artifact, thereby reducing the need for sedation in young children, this modality may become a more viable alternative to CT scan. Cost, availability and the need for sedation remain current barriers to the routine use of MRI in children.

Another clinical area of potential overuse of CT radiography is in evaluation of the trauma patient. In 2005, a study performed at a level I pediatric trauma center estimated the mean total effective dose of radiation related to the radiologic assessment of a typical pediatric trauma patient to be 14.9 mSv (interquartile range 2.2–27.4 mSv) in 506 patients [8]. Of interest, CT scan accounted for 97.5% of total effective dose. Based on previously described estimates of cancer mortality risk per unit of radiation exposure [3], this result reflects a risk from 0.12–0.21% of cancer mortality over the baseline lifetime risk. While the evaluation of a trauma patient is critical, the use of CT scan in this setting requires ongoing scrutiny and reassessment within the framework of ALARA.

Finally, the use of CT for the evaluation of minor head trauma, concussion and ventriculo-peritoneal shunt function is a considerable challenge when considering radiation reduction. Though a head CT does not introduce substantial doses of radiation, the brain is a rapidly growing organ, particularly in the very young infant or child, and CT presents an unknown risk for future malignancy. Clinical practice guidelines for head trauma, as well as modification of scanning protocols based on disease entity, may result in a lower radiation exposure than has been previously administered [29].

While reinforcing the risks of radiation exposure to the referring clinician is essential, issues of parent education and informed consent arise. A recent study examining the impact of an educational handout given to parents on radiation risks identified that while parents are not initially aware of these risks, education did not alter consent for performing indicated studies [30*]. The

authors support informing parents routinely on the radiation dose and risk for children undergoing CT scan.

Conclusion

It is important to emphasize that the benefits of CT scan far outweigh the individual risks, when medically indicated. However, with the increasing number of scans performed and injudicious ordering practices, the potential for CT to become a public health concern looms in the near future. Therefore public awareness and education is essential. The clinician and pediatric radiologist should present a unified team, who together advocate safe practice in children.

References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

- of special interest
- of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 347).

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