Is utilisation of computed tomography justified in clinical practice? Part IV: applications of paediatric computed tomography

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ABSTRACT

Computed tomography (CT) has been recognised as the most widely used imaging technique in both adults and children, owing to technological developments, especially with the recent innovations in multislice CT. This has resulted in an increase in the use of CT examinations in children younger than 15 years of age in developed countries. The increasing use of paediatric CT in clinical practice has raised concerns regarding the potential risk of radiation-induced malignancy. This is because CT examinations deliver a much higher radiation dose than conventional radiographic techniques. Children are more sensitive to radiation exposure than adults and have a longer time ahead of them to manifest radiation-induced effects and injuries. Therefore, it is of paramount importance to reduce or minimise the radiation dose to children when choosing CT as the major imaging modality for diagnostic purposes. This article reviews the clinical applications of paediatric CT with regard to the adjustment of imaging protocols in routine clinical practice and in the emergency department, the justification of CT use in paediatric imaging, clinical awareness of CT-associated radiation risk and strategies to minimise radiation exposure to children.

Keywords: children, computed tomography, paediatric imaging, radiation dose, radiation risk

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INTRODUCTION

The diagnostic value of computed tomography (CT) is unquestionable. The use of helical CT, in particular, multislice CT, is rapidly growing due to technological improvements to modern CT scanners. Advances in CT imaging have resulted in a significant increase in the frequency of CT examinations in children. Before 2002, an estimated 7.1 million annual paediatric CT examinations were performed in the United States.[1] Since 2002, CT examinations have been increasingly performed in the paediatric population.[2] The increase in CT use in children is mainly due to the decrease in the time required to complete a scan, which is currently less than one second, largely eliminating the need for sedation or anaesthesia to prevent the child from moving during image acquisition.[3] However, the justification for this increasing use has been questioned, given the potential risks of radiation exposure to children.[3] The radiation doses associated with CT examinations are among the highest in diagnostic radiology. While CT accounts for about 10%–15% of radiography based examinations, it delivers up to 70% of the collective radiation dose to patients.[4,5]

Efforts to reduce and minimise radiation dose associated with paediatric CT have made significant progress since the publication of some articles in the February 2001 American Journal of Roentgenology.[6-8] These articles discussed the potential risks associated with paediatric CT imaging, indicated a lack of attention to the radiation risks that could be posed to children by paediatric CT protocols within the radiology community and proposed suggestions or recommendations for adjusting CT technical parameters to minimise radiation dose.[6-8] Since the last several years, increased attention has been given to the issue of radiation dose in paediatric imaging procedures. According to the National Conference on Dose Reduction held in 2002, approximately 43% of imaging departments reported introducing programmes to adjust CT parameters for children.[9] Although there is still room for improvement, the change signals a dramatic and positive development, compared with the near-universal lack of such practices as early as 2001.[8]

CT dose reduction in paediatric imaging requires a combination of different approaches or strategies.

These include the optimisation of scanning protocols for children according to age- or weight-based adjustments, justification of paediatric CT use in paediatric clinics and emergency departments, reduction of unnecessary examinations, development of automatic exposure control devices by manufacturers, and user education for paediatricians and radiological technologists. In the following sections, this paper discusses the clinical applications of CT in paediatric imaging with respect to the abovementioned areas, with the aim of reducing radiation dose to paediatric patients.

RADIATION EXPOSURE IN CHILDREN: UNIQUE ISSUES

Radiation dose exposure due to CT in children has increased significantly since the imaging modality has progressed from single-slice to helical CT and multislice CT examinations that are widely available today. Children are at a greater risk than adults from a given dose of radiation because they are inherently more radiosensitive to radiation exposure due to the increased number of dividing cells in growing children and the higher remaining years of life ahead of them, which indicates that they have more time to develop a radiation-induced cancer.[3] It is estimated that children are ten times more sensitive to the effects of radiation than middle-aged adults.[10,11] Girls have also been found to be more radiosensitive than boys. The risk of developing a radiation-induced cancer has been estimated to be 5% per Sv at all ages;[12] however, this figure is close to 15% if the exposure occurs in the first decade of life.[13] According to the recent Biological Effects of Ionising Radiation (BEIR VII) report,[14] it is estimated that an exposure of 10 mSv carries a 1 in 1,000 risk of developing a solid cancer or leukaemia. The small individual risk of developing cancer becomes a greater public health issue when a large number of CT examinations (more than seven million per year) is multiplied by a small risk (0.35%).[6,15]

Brenner et al assessed the lifetime risk of developing a fatal cancer that is attributable to radiation from two common routine paediatric CT examinations, namely, abdominal and head examinations. Their estimates suggested that the risk of dying from cancer is approximately 1 in 550 for a single abdominal CT examination and 1 in 1,500 for a head CT examination, if the scan is performed in a one-year-old child.[6] However, it is necessary to point out that these estimates were based on the assumption that the same CT scanning protocols used in adult examinations were applied in children without adjustments. Thus, the risk would be lower if paediatric CT protocols were adopted and the paediatricians were aware of applying specific protocols in CT imaging in children.

AWARENESS OF RADIATION RISKS ASSOCIATED WITH PAEDIATRIC CT

While the number of paediatric CT examinations has significantly increased in the past few years, especially with the development of multislice CT, adequate attention has not been paid to the potential hazards for children or to the need for reduction of radiation dose according to the body size of a small patient. Concerns regarding CT radiation risk to paediatric patients have earlier prompted activities by the Society of Paediatric Radiology.[9]

Paterson et al, in their early study, reported that there were few or no appreciable adjustments in CT scanning parameters (both peak kilovoltage-kVp and tube current) in paediatric imaging. Their data indicated that paediatric patients are most likely to receive high radiation exposure due to unnecessary body CT examinations.[8] Hollingsworth et al investigated the practice of helical CT of the body in paediatric patients, and their results showed that paediatric radiologists paid more attention to size-based adjustments when using CT in children. However, 15%–40% of respondents in their survey were unaware of the techniques used at their institutions, particularly the CT scanning parameters that determined radiation dose.[16] The need for continued size-based scanning and adjustments, as well as awareness of the issues of radiation dose associated with paediatric CT imaging is necessary, as few adjustments have been made in a substantial number of CT examinations.

A recent study surveying the members of the Society of Paediatric Radiology shows a significant increase in awareness of radiation risks that CT could pose to children. Arch et al, in their five-year follow-up survey, concluded that the parameters for paediatric body CT imaging have changed significantly over the five-year interval between surveys, indicating that technical modifications of CT protocols have lowered radiation dose. Nearly all of the respondents in their survey used age- or weight-based adjustments for paediatric CT imaging.[2] The tube current was found to have decreased across all age groups, at between 31 mA and 61 mA when compared to early reports.[2,8,16] Another important finding is that 120 kVp was the maximum kVp used in all examinations and that choosing 110 kVp or less increased the number of examinations for chest CT from 4% to 48%, and from 1% to 32% for abdominal CT examinations. This indicates that the radiation doses delivered to children are lower than those previously reported.

Despite the increased awareness of radiation dose among paediatric radiologists, the awareness of radiation protection issues among paediatricians and physicians is generally low.[17-21] Thomas et al, in their survey of paediatricians with regard to the level of knowledge of radiation dose and risks associated with radiological examinations in children, reported that 94% of the responses underestimated the relative effective doses of CT imaging.[17] Similarly, Rice et al reported that more than 75% of the paediatric surgeons in their survey underestimated the dose from a CT to be comparable to a chest radiograph.[20] In their recent survey of chest imaging, Heyer et al demonstrated a significant improvement in paediatricians' awareness of radiation dose. However, only 15% of the paediatricians were familiar with the "as low as reasonably achievable" (ALARA) principle, and 56% underestimated the effective dose of a chest CT.[21]

Since the majority of radiological examinations are requested by non-radiologists, increasing paediatricians' knowledge of radiation dose is necessary to optimise their daily practice. It is also important to implement various approaches such as conducting formal lectures or workshops, providing regularly updated information about advanced imaging technology and conducting training programmes. Most importantly, paediatric radiologists should take a leading role and assume responsibility in promoting the reduction of radiation dose from paediatric CT imaging, in line with support from medical physicists.[17] Since the primary operators of CT scanners are medical imaging technologists, increasing their awareness and understanding of radiation issue is also important. Technologists should take advantage of the free online technologist education modules available on the Image Gently website (www.imagegently.org).

RADIATION RISKS IN CHILDREN: ADJUSTMENT OF SCANNING PARAMETERS

There are anatomical and physiological differences between children and adults that make paediatric CT imaging a challenging task. Lower bone density, smaller vessels and significantly less fat surrounding the organs produce different image quality requirements. Thus, radiologists and technologists are faced with a selection of CT imaging parameters that are tailored to paediatric imaging. These parameters include tube current, peak kilovoltage, slice thickness and pitch. Since there is a wide variability in body size in the paediatric population, adjustments to the CT imaging parameters are essential and important because these parameters are the main determinants of radiation dose that children receive from CT imaging.

Radiation risks in children: routine radiological examinations

In paediatric CT imaging, tube current (mA) is one of the key factors that must be modified as the patients' sizes vary widely. Different approaches can be used to optimise the mA settings.[2,7,22-24] Adjustments of CT imaging protocols based on weight and age are found to be convenient in clinical practice, according to these early studies.[7,22,23] For head CT imaging, mA should be modified according to the different age groups, as the attenuation in the head largely depends on the thickness of the skull, which changes with age.[23] Suess and Chen suggested that after the age of six years, adult mA settings can be used since the size of the head and the ossification of the skull would have nearly reached the adult levels. For paediatric body CT (chest/abdomen/pelvis) protocols, the authors have suggested that modifications should be made based on weight categories.[23] This is supported by other reports that advocate weight-based adjustments in the tube current for body paediatric CT.[2,7,22]

The adjustment of the tube current is not only based on the age or the weight of patients, but is also controlled using automatic current modulation techniques to reduce radiation dose in paediatric CT examination without affecting the diagnostic image quality. The patient's body attenuation is measured online rather than manually during the imaging, and the tube output is controlled for all viewing angles according to the detected attenuation. This helps to reduce radiation exposure in all types of patients and body regions. Clinical studies have demonstrated highly efficient dose reduction based on online tube current modulation.[25-29]

In their studies, Greess et al concluded that a significant dose reduction was achieved in the thorax and abdomen with the use of attenuation-based online modulation, resulting in up to 20%–40% dose reduction without compromising the image quality.[28,29] This feature has been implemented in many modern CT scanners, and thus has the potential to work as an automatic exposure control for paediatric dose reduction when compared to conventional exposure control methods. More importantly, the online modulation of tube current enables the acquisition of a desired noise level in different anatomical regions or in patients of different sizes.[23] This is also supported by a recent study using 64-slice paediatric CT in young children.[30] Peng et al compared the study groups using automatic tube current modulation (mAs ranging from 20–79 mAs) with the control group using fixed mAs (120 mAs and 150 mAs), where each group consisted of 50 children suspected of pulmonary diseases. A reduction of 65% radiation exposure was achieved in the study group, while the image quality was clinically acceptable despite the increased image noise measured with lower mA settings.[30]

Peak kilovoltage (kVp) is another key factor that determines radiation dose in CT imaging. As smaller volumes are scanned in paediatric CT imaging, tube voltage should therefore be reduced accordingly. A standard 120 kVp setting for adult CT protocols is no longer suitable for paediatric imaging, especially in young patients. Many institutions have adopted an 80 kVp or 100 kVp setting for their paediatric CT imaging, and satisfactory diagnostic images have been achieved.[2,23,31,32] Lowering of the tube voltage to 80 kVp in children has recently been recommended in paediatric CT without compromising the image quality.[32-34] Lee et al, in their study, showed that the average dose length product in children with congenital heart disease was reduced by 70% at 80 kVp when compared to that acquired at 120 kVp.[33] Saad et al combined a tube voltage of 80 kVp and adjusted the tube current using dual-source CT angiography in 110 infants with congenital heart disease, and their results demonstrated a significant reduction of radiation dose without impairing the image quality. In the majority of these cases, the effective dose was less than 2.5 mSv.[31] Low dose protocol also applies to the latest CT scanner, such as 320-slice CT. Kroft et al have recently reported their experience with using 320-slice thoracic CT in neonates and small children when compared to 64-, 32- and 16-slice CT. Volumetric 320-slice paediatric CT allows for the acquisition of images 5–24 times faster than the early types of scanners, but with an 18%–40% reduction in radiation dose.[32]

Other factors that may play a role in the reduction of radiation dose from paediatric CT examinations are beam collimation and pitch. As 64-slice CT is widely available and thinner slice thickness (such as 0.5 mm and 0.625 mm) is commonly used for paediatric chest or abdominal CT imaging, it leads to a higher radiation dose than that obtained with thicker slice thickness (3 mm or 5 mm). Thicker slice thickness is recommended for routine paediatric CT, while thin slice should only be reserved for cases that require multiplanar reformation and 3D reconstructions.

It is well-known that pitch is inversely proportional to the radiation dose, which indicates that higher pitches provide lower doses than lower pitches. Early studies with helical CT have shown that pitches of 1.5 are adequate for diagnosis in paediatric CT;[35,36] however, lower pitches of less than 1.0, which are usually used with multislice CT technology, are not uncommon.[2] The routine use of pitches between 1.0 and 1.5, or even as high as 2.0, could lead to a further reduction in radiation dose without compromising the image quality, and a lower pitch of less than 1.0 should only be reserved for cardiac paediatric imaging.

Radiation risks in children: emergency examinations

Trauma is a significant source of morbidity and mortality in paediatric patients.[35] An accurate and prompt assessment of trauma-associated injuries is essential so as to improve treatment outcomes. Helical CT has become an important and integral part of the initial assessment of paediatric patients with traumatic injuries as clinical examination is considered unreliable.[37,38] CT is often used to provide important information as physicians tend to request CT examinations frequently even if in the presence of minimal or moderate paediatric trauma.[38] To minimise radiation exposure from CT imaging, it is recommended that hospitals implement the ALARA concept.[39] This indicates that there is a strategy in place to limit the number of CT examinations performed routinely and in emergency situations. However, the literature reports an increasing overuse of CT in paediatric trauma patients.[38,40,41]

Broder et al reported increasing utilisation of paediatric CT in the emergency department over a six-year study period. Their results indicated that the increase in head, cervical spine, chest and abdomen CT examinations was 23%, 366%, 435% and 49%, respectively. The increase was reported predominantly in adolescents aged 13–17 years.[41] Other studies raised similar concerns with regard to the overuse of CT in paediatric emergency imaging.[38,40,42,43] Early studies reported normal CT imaging in more than 70% of abdominal CT imaging in paediatric trauma patients.[42,43] Fenton et al supported the above observation in their retrospective study that was performed in a large paediatric centre. Their results demonstrated that normal findings were obtained in 54% of CT imagings, which indicated the overuse of CT imaging in children. In particular, they noticed that abdominal CT imaging was used too frequently, with 67% of the results being normal.[38] Jindal et al reported similar findings in their study cohort, which consisted of young children (seven years old or younger) presenting with mild to moderate trauma. A more significant increase in the use of CT imaging was found in children than in adults, particularly the more liberal use of abdominal CT without leading to diagnostic or treatment benefit.[40]

It is undeniable that CT, especially with the recent emergence of multislice CT along with 3D reconstruction visualisations, has proven to be valuable in detecting and characterising injuries associated with trauma patients.[44,45] Several reports have recommended the use of CT as both a screening and diagnostic tool, and some have suggested that CT could replace the use of radiography in certain traumatic situations.[46,47] Performing a whole body imaging on unevaluable patients has become an accepted protocol for imaging adult patients in many trauma centres.[48-50] Similarly, the number of multislice CT imaging of polytraumatised children has also increased rapidly.[40,51-54] One of the principal challenges of paediatric trauma CT imaging is to maximise diagnostic information, while simultaneously minimising the radiation exposure to children. Paediatric trauma may result in a variety of organ injuries, so the top priority in the management of polytraumatised children is to obtain the diagnosis as quickly as possible, so that life-threatening injuries can be treated quickly.

Munk et al recently reported the superiority of using whole-body CT in polytrauma children aged 0–16 years. The mean effective dose for whole-body CT imaging (including at least the head, chest and abdomen regions) was 20.8 mSv in their study,[53] which provided all the relevant information for appropriate patient management and therapy. Despite the usefulness and significant value of whole-body CT in paediatric trauma patients, CT protocols should be adjusted to reduce the dose while maintaining the diagnostic image quality. Similarly, Moore et al supported the diagnostic value of multislice CT in paediatric thoracic trauma when compared to conventional radiography; however, the authors emphasised the importance of tailoring CT protocols to the individual child with the aim of minimising radiation dose to paediatric patients.[54] The appropriate manipulation of CT imaging parameters, including kVp, mAs and pitch, as well as the incorporation of automatic tube current modulation lead to a significant reduction in radiation dose, as reported by Huda and Vance.[55]

RADIATION RISKS IN CHILDREN: JUSTIFICATION OF CT USE

The European Commission's directive 97/43/EURATOM, which was published in 1997, recommends decreasing excessive exposure of patients to ionising radiation, as radiation increases the potential risk of fatal cancer, resulting in mortality.[56] In addition to the importance of adapting paediatric CT protocols, it is highly important to provide education to medical practitioners regarding the risk of radiation exposure so as to reduce or eliminate unnecessary referrals, as radiation risks are frequently underestimated.[19,57] One important approach to decrease radiation is the replacement of nonessential CT examinations with ultrasonography or magnetic resonance (MR) imaging in paediatric patients.

Early studies conducted with regard to the justification of CT examinations in adult patients concluded that 60%–90% of examinations could be replaced with MR imaging or ultrasonography.[58,59] Oikarinen et al's study,[60] which was based on a single centre experience, retrospectively analysed whether CT examinations performed in young patients were justified. The authors selected CT examinations in the head, cervical and lumbar spine, abdomen and nasal sinuses that could be replaced by other imaging modalities without involving ionising radiation. The study revealed that 30% of all CT examinations were not justified. Of these examinations, 77% of the lumbar CT examinations were unjustified, as most of them could have been replaced with MR imaging. 36% of the head, 37% of the abdomen and 20% of the nasal sinuses CT examinations were also unjustified, since a reasonable number of these examinations could be replaced with MR imaging or ultrasonography.[60] In their study, Ashley et al described the use of rapid, single-sequence MR imaging as an alternative to repeated head CT in children with hydrocephalus.[61]

Since there are limited currently available studies in the literature regarding the justification of CT examination in paediatric imaging due to radiation risk, physicians are recommended to follow the practical guidelines regarding referral criteria for paediatric CT imaging.[56,62-64] A recent article published in the American Journal of Roentgenology (AJR) that suggested ten steps to optimise image quality and lower CT dose for paediatric patients is a highly recommended read.[65]

SUMMARY AND CONCLUSION

CT has become a widely used imaging modality in paediatric patients. Although the benefits of CT examinations for clinical diagnosis are unquestionable, the potential risk of high radiation exposure associated with CT should not be ignored by medical practitioners when choosing CT as the major imaging modality. In the medical community, there has been an increased awareness regarding the radiation risk to paediatric patients since the AJR publications in 2001, and more studies are being performed to address this issue. More effort is required to ensure the judicious use of CT in paediatric patients. While the adjustment of CT imaging protocols is one of the effective approaches to reduce radiation dose, the justification of CT use in paediatric patients is equally important. The benefit-to-risk ratio for imaging paediatric patients must be driven by the benefit and appropriateness of the CT examinations requested by the physicians.

The rapid development of multislice CT technology has improved our ability to diagnose a disease, so there is no doubt that CT will continue to play an increasing role in paediatric imaging. We expect that in the future, paediatric radiologists and physicians, with support from medical physicists and CT manufacturers, will work together to optimise imaging for patients and achieve the goals of ALARA and Image Gently.

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