



Paediatric computed tomography radiation dose: A review of the global dilemma

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Abstract

Computed tomography (CT) has earned a well-deserved role in diagnostic radiology, producing cross-sectional and three-dimensional images which permit enhanced diagnosis of many pathogenic processes. The speed, versatility, accuracy, and non-invasiveness of this procedure have resulted in a rapid increase in its use. CT imaging, however, delivers a substantially higher radiation dose than alternative imaging methodologies, particularly in children due to their smaller body dimensions. In addition, CT use in children produces an increased lifetime risk of cancer, as children's developing organs and tissues are inherently more vulnerable to cellular damage than those of adults. Though individual risks are small, the increasing use of CT scans in children make this an important public health problem. Various organizations have recommended measures to minimize unnecessary exposures to radiation through CT scanning. These include elimination of multiple or medically unnecessary scans, development of patient-specific dosing guidelines, and use of alternative radiographic methodology wherever possible. Another important factor in excessive CT exposures, however, is a documented lack of awareness among medical practitioners of the doses involved in CT usage as well as its

significant potential dangers. This review examines the effects of paediatric CT radiation, discusses the level of medical practitioner awareness of these effects, and offers recommendations on alternative diagnostic methods and practitioner education.

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Key words: Computed tomography; Diagnostic imaging; Paediatric imaging; Radiation dose; Computed tomography dose

Core tip: Computed tomography (CT) delivers substantially radiation dose and risk of cancer than alternative imaging methodologies, particularly in children, and use of paediatric CT scans is increasing. Radiation exposure from CT scanning can be minimized by eliminating multiple or medically unnecessary scans, patient-specific dosing guidelines, and use of other radiographic methods where appropriate; however, medical practitioners' lack of awareness of CT dose and its potential dangers are also important. Improvements to CT protocols, referral practices and imaging professionals' education are needed to minimise unnecessary CT radiation exposure in children.

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INTRODUCTION

Computed tomography (CT) is used extensively in diagnostic radiology, primarily for examination of human soft tissues. CT scans produce serial cross-sectional images of the body and generate three-dimensional views which

facilitate detailed examination of specific anatomical and pathological areas of concern. CT is used in paediatric patients as well as adults, and its use has increased rapidly since the technology's inception in the 1970s^[1]. More than 60 million CT examinations were performed in the United States in 2006, with an estimated growth rate of 10% per year; about four million of those 60 million were performed in children^[1]. Japan, the United States and Australia lead the world in number of CT scanners per head, with 64, 26 and 18 scanners per million citizens respectively^[2]. Although typical CT radiation doses have not significantly changed over the years, use of CT as a diagnostic tool has dramatically increased.

Children are being increasingly referred for CT examinations. Increased demand for CT in children is partially due to the advent of fast scanning techniques. Fast helical/multi-slice scanning can negate the need for sedation and allows the evaluation of younger or less co-operative children^[3]. The tremendous rise in the use of CT imaging is also related to the development of advanced and reliable diagnostic radiology techniques. For example, CT is now a standard diagnostic tool for paediatric cancer detection, trauma, renal calculi, appendicitis, and heart conditions^[3]. Patient-generated demand, medical insurance coverage, physicians' fear of medical malpractice lawsuits and the desire to monitor clinical progress, especially in cancer patients, have also increased the demand for CT imaging. CT has reduced the failure rate of laparotomy from 18% in 1997 to less than 5% currently, and also decreased the cost related to number of inpatient days per patient^[4]. In certain instances, it has also obviated the need for exploratory surgery^[4].

The speed, accuracy, versatility and availability of CT technology have rapidly raised the volume of CT scans performed in paediatric patients, despite the fact that CT scanning delivers a higher radiation dose to the patient than other available procedures. The radiation dose is particularly important in paediatric patients or small adults because of the increased life-time cancer risk associated with the amount of ionising radiation dose received per square meter of body surface^[5]. While the use of CT for paediatric cases has increased, often little attention is paid to adapting examination protocols developed for adult patients to suit children. The result is significantly higher doses, approximately two to six times greater than necessary, for an adequate level of image quality. As children are inherently more sensitive to the effects of ionising radiation than adults, there is a pressing need to optimize this high-dose imaging modality for these especially vulnerable patients. Numerous international organizations, including the International Commission on Radiological Protection^[5], the International Atomic Energy Agency^[6] and the European Commission^[7] have made recommendations aimed at minimizing CT doses, particularly in the paediatric population. The European Commission, to ensure optimization of performance and patient protection in CT procedures, established a set of quality criteria for adult CT examinations, published as the European

Guidelines on Quality Criteria for Computed Tomography^[8]. The US Food and Drug Administration (FDA) has similarly published a set of recommendations with the objective of keeping CT radiation doses as low as reasonably achievable, especially for children and small adults. The FDA stresses the importance of customizing CT scanner parameters for each individual's weight, size and scan region^[9].

In this article I describe CT and its advantages and review the effects of paediatric CT radiation. I examine current knowledge about the level of medical practitioner awareness of the effects of CT dose in children and offer strategies to reduce CT dose.

CT: ADVANTAGES OVER OTHER IMAGING MODALITIES

CT is an advanced imaging technology that has been in use since 1972^[10]. By rotating the X-ray beam around the patient and analysing the resulting data, the technique allows physicians to examine the body, bones, and organs one narrow "slice" at a time^[10]. Some non-ionising methodologies can obtain comparable diagnostic information, particularly ultrasound and magnetic resonance imaging (MRI). Ultrasound is very useful in paediatrics, since image quality and resolution improve with a smaller patient size. Ultrasound can also be used to image almost any area of the body, with the exception of those composed mainly of bone or air. MRI uses magnetic fields and radio waves to create a set of 2D slices of the body and thus does not expose the patient to ionising radiation. Its use in children, however, is constrained by the fact that patients need to remain absolutely still as even small amounts of motion can affect the image quality. Younger children often require sedation, necessitating specialized equipment and staff which may not be accessible in all imaging centres. Faster MRI scanning has helped to reduce blur from patient motion and coaching and distraction techniques can also help obtain a quality image^[11]. The traditional planar X-ray, developed in, only allows visual outline of bones and organs^[11]. CT differentiates overlying structures much better than planar X-ray techniques^[12] and allows greater contrast differentiation than other imaging modalities. Many medical conditions are more accurately imaged and diagnosed using CT, for example, vascular diseases with the potential to cause renal failure, stroke, or death. Thus CT is the best imaging option in many cases, and if the protocol is well optimized the value of the information obtained will offset the risks associated with the relatively large radiation dose.

ACHIEVING AN OPTIMAL RADIATION DOSE

Radiation doses from CT scanning are considerably larger than those from corresponding conventional radiography procedures. For example, a planar anterior-pos-

terior abdominal X-ray examination results in a dose to the stomach of approximately 0.25 mGy, approximately 2% of the corresponding dose from an abdominal CT scan^[13], and a CT scan of the chest delivers 100 times the radiation of a conventional chest X-ray^[10]. Although CT examinations make up 5%-11% of all radiological examinations, they contribute an estimated 40%-70% of the collective dose derived from diagnostic radiology^[11,14-16]. Moreover, many CT procedures involve multiple scans, with one study finding that 30% of CT patients were scanned three times, 7% of patients scanned five times, and 4% scanned nine times or more^[16].

The bio-effects associated with radiation exposure can be divided into two main groups: deterministic risk and stochastic effects. The deterministic risk is a function of radiation dose delivered to an organ or body region. Deterministic effects of radiation are seen above a threshold dose, with higher doses promoting more severe effects; these are rarely seen in diagnostic radiology, but may become a problem with angiographic procedures, including CT fluoroscopy^[17]. In addition, temporary hair loss has been reported in patients undergoing multi-detector row computed tomography brain perfusion studies in combination with digital subtraction angiography^[18]. Stochastic effects are dependent upon a complex series of events, including cell transformation. Stochastic effects may appear as a cancer in the patient or as genetic abnormalities in their children. The probability of seeing stochastic effects increases with the amount of radiation but the severity of the effect is independent of the dose of radiation received^[18].

Oncogenesis is a major stochastic effect of CT radiation exposure. Children's organs and tissues are highly sensitive to the oncogenic effects of radiation because they contain a large proportion of cells that are dividing and reproducing. The radiation-induced risk is also higher in paediatric patients due to wider and increased cellular distribution of red bone marrow and their greater post-exposure life expectancy^[19]. The effective radiation doses received by children are about 50% higher than those received by adults due to their smaller body size and related attenuation^[20]. At ages up to 10 years, children are more sensitive than adults by a factor of three, as their longer expected life span is combined with the higher radiation sensitivity of the developing organs^[5]. For example, the potential impact of a single 15 mSv CT examination (equivalent to 500 standard chest X-rays) on an adult is only half that of a child^[21].

The risks of paediatric CT have been assessed in several studies. Israeli researchers estimated that 9.5 lifetime deaths were associated with one year of paediatric CT scanning^[22].

Researchers from the National Cancer Institute and the Society of Paediatric Radiology in the US estimated the risk of dying from cancer to be 1 in 550 following abdominal CT and 1 in 1500 for a brain CT performed in infancy, approximately 0.35% more cancer deaths than expected in the general population^[23]. These figures were

calculated on the assumption that children were being imaged using adult CT parameters; the risk would be lower if specific paediatric CT protocols were uniformly adopted. Although the increased risk of cancer is small for each individual scanned, the impact on public health is substantial due to the increasingly large number of CT examinations being performed^[24].

ACHIEVING AN OPTIMAL CT RADIATION DOSE

As noted earlier, efforts towards dose reduction in CT have been recommended by major international organizations such as the International Commission on Radiological Protection^[24] the International Atomic Energy Agency^[25] and the European Commission^[7]. These agencies recommended the implementation of CT dose guidance levels for the most frequent examinations to promote strategies for the optimization of CT doses.

Patients undergoing CT examinations range from neonates to oversized adults. Radiation doses in CT are generally measured in cylindrical acrylic phantoms designed to simulate the head (16 cm) or body (32 cm). Because patients differ in sizes and body composition, it is often difficult to obtain reliable values of patient doses from such phantoms. If scan parameters are kept constant for all CT examinations, much larger doses will result with paediatric patients than with adults. This "one-size-fits-all" adult model underestimates the paediatric CT radiation dose displayed on the console of current CT scanners^[26]. The Alliance for Radiation Safety in Paediatric Imaging^[1], a movement of more than 500000 health care professionals, is working for an increasing awareness among radiologists and radiographers of the need for a "child size" CT scan technique. It recommends the following steps to prevent excessive dose exposure to paediatric patients: (1) Acquisition of new CT equipment should be supported by validation of the protocol to help ensure that patient doses are "As Low As Reasonably Achievable"; (2) Any increase in dose must be justified by a corresponding improvement in diagnostic information, and where possible, use iodinated contrast medium to perform CT examinations at lower kV values with no loss of diagnostic information^[1].

CT RADIATION DOSE AWARENESS AMONG PATIENTS AND HEALTHCARE PROFESSIONALS

A majority of the hospital protocols involve explanation of CT radiation risk to patient or its carer. Unfortunately, however, physicians themselves are often little more informed than their patients with regards to radiation exposure caused by CT examinations. In a 2004 paper, Lee *et al*^[27] showed that all patients and more than 70% of physicians underestimated the dose from one abdominal CT examination. Many of those questioned did not

realize that CT scans increase the lifetime risk of cancer. They also reported that radiologists are unable to provide accurate estimates of CT dose regardless of their level of experience^[27].

In addition, a 2003 questionnaire-based survey and interview of doctors of all grades, including consultant radiologists, indicated that only 2% of the participants could successfully estimate the relative doses of common diagnostic procedures^[14]. A significant proportion of the interviewees could only answer questions that involved ultrasound, which is non-ionising. The degree of knowledge was inversely proportional to seniority, with consultants scoring less than junior colleagues^[28]. It was revealed in a 2004 survey that 53% of radiologists and 91% of emergency room physicians surveyed did not believe that CT scans increased the lifetime risk of cancer^[27].

ADDRESSING THE PROBLEM

In order to protect paediatric patients from undue exposure to radiation, the FDA has established guidelines to: (1) Improve CT exposure factors in order to reduce unnecessary paediatric patient radiation dose and perform more extensive quality checks to validate the reported dose values; (2) Reduce the number of procedures requiring multiple CT scans; and (3) Utilise alternative, lower dose, radiographic exams wherever possible^[12].

Like the FDA, the “4th Framework European Programme” in paediatric radiology concentrated on developing guidelines for common paediatric CT examinations. A paediatric document was prepared based on the adult CT document, which offers general principles associated with good imaging technique, quality criteria and guidelines on radiation dose to the patient^[29].

In order to facilitate dose adjustment for paediatric patients, some equipment manufacturers have incorporated automatic exposure control (AEC) in their CT scanners. An AEC adjusts dose according to patient size and optimizes radiation dose within a single patient using dynamic tube current^[13].

While CT remains a crucial tool for paediatric diagnosis, physicians, radiographers and health authorities need to work together to reduce the radiation dose to children to as low as reasonably achievable. Semelka *et al*^[30] suggested three ways to reduce radiation. First, reduce the CT-related dose delivered to each patient (partially addressed by the AEC option on the later models of CT scanners). Their second recommendation was to use alternative imaging techniques such as ultrasound and MRI, when practical. The third and most effective way to reduce the population dose from CT is simply to decrease the number of CT studies that are prescribed^[31].

EDUCATION OF RADIOLOGY STAFF

Enhancing understanding of the factors that affect patient doses in CT should be considered the first step in optimization strategies^[16]. Basic training for radiog-

raphers/radiological technologists generally overlooks paediatric CT radiation doses. The IAEA recommends radiographers involved in paediatric CT be specifically educated and trained about paediatric radiation dose^[6]. A 1998 study found that variations of 10%-40% observed in the typical dose between individual scanners were largely due to imaging technique^[32]. A survey of health professionals in Northern Ireland on awareness of the radiation doses imparted during common diagnostic imaging procedures and their long term impact on patients demonstrated a knowledge gap which could be improved with appropriate training^[33]. A 2006 survey in New South Wales, Australia showed the need for continuing education and protocol review, particularly in paediatric CT examinations^[29]. Another study conducted in a large hospital in the United Kingdom assessed the knowledge of primary care and specialist physicians concerning radiation doses and risks. The results revealed an urgent need to improve physicians “understanding of radiation exposure”. Only 27% of doctors attained a 45% pass mark, and only 57% of radiologists and radiology-related subspecialists passed the test^[34].

The need to train radiology personnel, establish protocols, and continuously monitor the performance of CT equipment to control patient CT doses is of utmost importance. Radiologists and other imaging staff must learn that dose adjustment according to size, weight and scanning area plays an important role in radiation dose reduction in CT. Education about high radiation doses during CT examinations can reduce patient exposure and risk with no loss of image quality^[32]. However, reduced-dose protocols for common clinical indications require further investigation.

All of the studies to date suggest the need for improvements in the knowledge and training of imaging professionals about dose in CT examinations, particularly when applied to paediatric patients. To be most effective, this should involve continuing education among all staff involved in radiographic imaging, from radiographers/technologists to referring physicians. Support for this movement has been suggested not just on regional levels, but through large-scale training initiatives in which materials are translated and distributed globally^[6].

CONCLUSION

Over the past two decades CT scanning rates have increased greatly, and this has increased the average radiation dose delivered to paediatric patients. This literature review has found that medical practitioners are not adequately aware of the stochastic effects of CT, or of diagnostic alternatives to CT. Because of the stochastic effects of ionising radiation, dose reduction in CT examinations, especially for paediatric patients, must occur. Dose reduction is being implemented by CT manufacturers, but medical imaging professionals must not rely on this alone. Improvements to CT protocols, referral practices and imaging professionals’ education are needed

to minimise the amount of unnecessary CT dose that is delivered. By undertaking these changes and with continual vigilance, the benefits of CT can be obtained at low radiation dose and the minimum of harmful effects to paediatric patients.

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