

Pediatric radiation exposure risk from Computed Tomography (CT) scan

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Abstract

Computed tomography (CT) is a powerful tool for the accurate and effective diagnosis and treatment of a variety of conditions because it allows high-resolution three-dimensional images to be acquired very quickly. However, as the number of CT procedures performed globally have continued to increase; with growing concerns about patient protection. Currently, no system is in place to track patient doses and the lifetime cumulative dose from medical sources. The widespread use of CT even in developing countries has raised questions regarding the possible threat to public health, especially in children. Although CT scans are very useful clinically, potential cancer risks exist from associated ionizing radiation, in particular for children who are more radiosensitive than adults. Various organizations have recommended measures to minimize unnecessary exposures to radiation through CT scanning. These include the elimination of multiple or medically unnecessary scans, development of patient-specific dosing guidelines, and use of

alternative radiographic methodology wherever possible. efforts should be made toward more active reduction of CT exposure settings in paediatric patients. This review examines the effects of paediatric CT radiation, discusses associated radiation doses, consequent cancer risks particularly in children and practitioner education.

Keywords: Computed Tomography, Radiation Risk, Radiation Dose, Patient Dose Reduction, Children.

Introduction

Computed tomography (CT) is a valuable and essential addition to the array of imaging modalities for children. CT uses x-rays to provide rapid, consistent, and detailed information about virtually any organ system in infants and children. Because x-rays are an integral component for image formation with CT, there is an obligatory radiation exposure during the CT examination. Approximately 62 million CT examinations were performed in the United States in 2006, and the numbers are growing at 10% per annum; 4 million CT scans (approximately 6.5%) were

performed on American children [1]. In Australia between 1996 and 2010, total CT scan numbers have increased 2.8-fold, and paediatric CT scan examinations have had a 2.4-fold increase. Japan, the United States of America and Australia lead the world in the number of CT scanners, with 64, 26 and 18 scanners per million citizens, respectively. Approximately 33% of all paediatric CT examinations are in children aged ten years old or younger, with 17% in children aged five or younger [2]. At these ages, the organs and tissues are intrinsically more sensitive to oncogenic effects of radiation due to the far higher 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. The effective radiation doses received by children are about 50% higher than those received by adults for the same acquisition protocols, due to their smaller body size and related attenuation [3].

CT use can be categorized according to the population of patients (adult or pediatric) and the purpose of imaging (diagnosis in symptomatic patients or screening of asymptomatic patients). CT-based diagnosis in adults is the largest of these categories. The largest increases in CT use, however, have been in the categories of pediatric diagnosis and adult screening. The growth of CT use in children has been driven primarily by the decrease in the time needed to perform a scan — now less than 1 second — largely eliminating the need for anesthesia to prevent the child from moving during image acquisition. The major growth area in CT use for children has been presurgical diagnosis of appendicitis, for which CT appears to be both accurate and cost-effective — though arguably no more so than ultrasonography in most cases [4]

Estimates of the proportion of CT studies that are currently performed in children range between 6% and 11% [5].

The ALARA (as low as reasonably achievable) concept, which was developed in the 1960s by the Atomic Energy Commission (the predecessor of the Nuclear Regulatory Commission) and the Department of Energy, was strongly embraced as a unifying concept for pediatric CT dose reduction efforts [6]. There is no doubt that CT is an extremely important imaging tool for the pediatric population and that it has saved many lives. Clearly, there are limits to lowering radiation dose. Lowering the risk of radiation-induced cancer against the risk of missing the correct diagnosis because of poor image quality has to be put into perspective [7].

Diagnostic Imaging

X-rays are used in radiography, fluoroscopy, angiography, and CT. The dose depends on patient factors (such as age and size), technical factors (equipment settings and procedure length), and equipment model. Three factors have made CT scanning the focus of much of the recent interest in ionizing-radiation exposure from diagnostic imaging. First, CT scanning provides a disproportionately higher amount of radiation exposure from diagnostic imaging. In 2000, Mettler et al reported that CT scanning accounted for 11% of procedures that used ionizing radiation in a large academic radiology department but accounted for 67% of the radiation exposure. Second, indications for CT scanning and the number of CT scans are increasing rapidly [8].

In a more recent study at the same institution, CT scanning accounted for 15% of the procedures and 75% of the dose. Third, CT scanning can be performed by using a wide range of techniques with variable radiation

exposures that produce very similar image quality. With conventional (“plain”) radiographs, an increase in radiation dose makes the image darker, and most individuals will recognize that the film was overexposed. However, changing the amount of radiation for a CT study affects the amount of mottle (or image noise) with little other effects on the appearance of the image. Above a level of diagnostic quality, this decrease in mottle with increasing radiation will have no effect on the diagnostic accuracy of the CT study and may not even be appreciated, but the exposure may have been unnecessarily high, especially in children [9]. Until recently, the same CT-examination parameters were used for children and adults. In fact, a change in these parameters with a resultant reduction in dose, ranging from approximately 50% to 90%, has been shown to be satisfactory for a child’s CT study.

Radiation Doses From CT Scans

Various measures are used to describe the radiation dose delivered by CT scanning, the most relevant being absorbed dose, effective dose, and CT dose index (or CTDI). The absorbed dose is the energy absorbed per unit of mass and is measured in grays (Gy). One gray equals 1 joule of radiation energy absorbed per kilogram. The organ dose (or the distribution of dose in the organ) will largely determine the level of risk to that organ from the radiation. The radiation doses to particular organs from any given CT study depend on a number of factors. The most important are the number of scans, the tube current and scanning time in milliampseconds (mAs), the size of the patient, the axial scan range, the scan pitch (the degree of overlap between adjacent CT slices), the tube voltage in the kilovolt peaks (kVp), and the specific design of the scanner being used [10].

The situation is even clearer for children, who are at greater risk than adults from a given dose of radiation, both because they are inherently more radiosensitive and because they have more remaining years of life during which a radiation-induced cancer could develop. In summary, there is direct evidence from epidemiologic studies that the organ doses corresponding to a common CT study (two or three scans, resulting in a dose in the range of 30 to 90 mSv) result in an increased risk of cancer. The evidence is reasonably convincing for adults and very convincing for children.

The use of CT has been rapidly increasing all over the world during the past two decades, driven by advanced technology and the invention of the multidetector CT (MDCT). 6–11% of all CT examinations in developed countries are performed on children aged from 0 to 15 years [11]. The organ-absorbed doses reported in adult and paediatric patients undergoing single CT examination are considerably lower than the threshold for initiation of a deterministic effect and the estimated effective doses are still within the annual exposure dose from natural background radiation. A retrospective cohort study by Pearce et al [10] did, however, find a significant association between estimated cumulative radiation doses delivered by CT scan to the bone marrow and brain and subsequent increased risk of leukaemia and brain tumours in childhood. General strategies for CT dose reduction in paediatric healthcare include such things as avoiding a CT scan if adequate clinical information can be obtained from ultrasound or MRI, avoiding multiphase examinations and designing CT protocols to minimize exposure time [12]. Nowadays, many professional societies, regulators and manufacturers have been trying innovative new

technologies for reducing radiation dose while maintaining optimal image quality.

Nivelstein et al created the first paediatric MDCT optimizing guideline protocols with scanners from various manufacturers by adjusting tube voltage and CT dose indexes (CTDI_s) based on age or bodyweight category [13]. National surveys from several countries also provide good standards for optimizing scanning protocols with reasonable radiation doses. However, the most important concern is how to balance radiation dose reduction and imaging quality. Several studies have reported on the relationship between optimizing radiation reduction CT protocols and image quality in adults and paediatric patients [14].

Parameters To Reduce CT Radiation Dose

To avoid unnecessary CT examinations, it is first crucial to evaluate whether the ordered CT is justified in every single case. If, after a preliminary review, CT proves to be the appropriate method then, according to Strauss et al., single-phase CT scans are usually all that is needed in children and one long scan results in a lower radiation dose than several regional scans overlapping each other at the scan end and start [15]. In particular, for chronic diseases, imaging modalities that do not require the use of ionizing radiation should be used whenever feasible to keep the cumulative lifetime radiation dose as low as possible. For example, MRI enterography should be considered in inflammatory bowel disease as an alternative diagnostic method.

Effective dose can be estimated from CT acquisitions through simulation data that relate DLP values to organ-specific doses. Then, the weighted average of organ-specific doses times their relative risk of forming cancers provides estimates of effective dose. In clinical CT, images are required to perform a range of tasks, from detection of small features to lesion

characterization. Because of this range of tasks, it is challenging, if not impossible, to determine a fixed set of acquisition parameters that will provide “necessary” image quality. As with all processes at an institution, CT protocols should be reviewed regularly to ensure that image quality and dose are being optimized. This graduated systematic evaluation of dose reductions and image quality tolerance can lead to more dose-conscious CT. It should be stressed that over- and underdosing are medical errors and, therefore, dose reductions and dose increases may be appropriate while trying to optimize CT protocols.

By changing the CT parameters based on the patient’s weight or age, the dose is reduced significantly. However, the radiation dose should only be reduced under the condition that the diagnostic image quality is not sacrificed to ensure appropriate diagnosis.

Tube voltage adjustment

The tube voltage determines the energy distribution of the X-ray beam, so many authors have investigated the effect of tube voltage variation on changing the CT dose. Reid *et al.* (2010) determined the effect of tube voltage reduction on three cylindrical phantoms of an infant, child and adolescent based on the patient circumference to optimize dose reduction for abdominal CT with no change in image quality [16]. So, tube voltage reduction is allowed only on the condition that it does not affect the ability to detect low-visibility structures. A reduction in dose of about 78% in a circular phantom was obtained by Siegel *et al.* (2004) by decreasing the tube voltage from 140 kVp to 80 kVp (at 165 mAs) [17].

Tube current reduction

Adjustments in the tube current are more frequently used to improve management of the radiation dose for children. Frush *et al.* (2002) found that lowering the

current to 67% of the tube current of the original abdominal MDCT scan did not affect the ability to detect high-visibility structures. Even tube current reductions of 33–50% were acceptable for detection of low-visibility structures [18].

The optimum level of tube current and voltage

There are some rules to optimize doses in pediatric CT scans with no loss of diagnostic ability (Vock, 2005). The results of a recent survey conducted in 2008 showed changes in pediatric body MDCT scanning parameters. Now, 98% of radiologists use either a weight-based or an age-based protocol for pediatric CT. The average tube current has decreased to between 31 and 61 mA for all age ranges [19].

Adjusting the pitch

With the advent of helical CT, scanning techniques became more sophisticated. In addition to tube current and voltage, pitch is a selectable parameter (Paterson *et al.*, 2001) By increasing the pitch from 1.0 to 1.5, Paterson *et al.* (2001) decreased the radiation dose by 33% [20].

Shielding of superficial organs

The superficial tissues in the scan range, that are sensitive to radiation e.g. mammary glands, thyroid gland and lenses of the eye, can be protected with bismuth shields. The aim is to filter off the low energies of the beam that would otherwise absorb into the patient's tissues. Lead shields can be used outside the scan range for protecting e.g. thyroid gland, mammary gland for girls and testes for boys.

Super-resolution technique

In pediatric patients, image resolution is of notable importance. Resolution is mainly dependent on the focal spot size and the pixel size of the detector. Resolution can be improved by the super-resolution technique. Here, two or more medical images that are

translated, rotated and scaled against each other within at least the subpixel dimension are combined to resolve structures smaller than a single-detector pixel. These high-resolution images can help to reduce the total radiation time during diagnosis and therapy because image quality is improved.

Role of pediatric health care professionals and radiologist

Pediatric health care professionals have an important role in the use of CT for children. The health care professional ultimately decides whether a CT examination is necessary. The health care professional should also be able to discuss these risks in a manner that is informative and understandable to patients and families. CT has an increasingly recognized role as the first, if not only, imaging examination for a wide variety of disorders that affect infants and children. A recent

review summarized investigations indicating that CT use has increased substantially over the last 1 to 2 decades, including estimates of at least 10% growth per year [18]. The use of CT for common problems such as trauma (closed head injury, skeletal evaluation including cervical spine assessment, and blunt abdominal trauma), appendicitis, and renal calculi has increased the frequency of CT examinations in adult and pediatric populations.

For children, the situation may also be critical if scanning parameters are not adapted to their smaller size and increased radiation risk: the risk-benefit ratio may then no longer favour CT, if the cumulative doses delivered in the course of management are not monitored to keep it as low as reasonably achievable. The application of CT for young patients, patients with favourable prognosis and for frequent follow-up

examinations will increase the radiation risk to the individual and the population [21].

Conclusions

The widespread use of CT represents probably the single most important advance in diagnostic radiology. However, as compared with plain-film radiography, CT involves much higher doses of radiation, resulting in a marked increase in radiation exposure in the population. Continuous research and innovation will lead to even more and better dose-saving tools. Therefore, it is important to stay informed and to keep current with the newest technology to offer the best available service with the lowest radiation burden to our patients. New image enhancement methods improving the image reconstruction process offer the potential for significant dose savings at matched image quality. Radiologists must continually think about reducing exposure as low as reasonably achievable (ALARA), by using exposure settings customized for children. All physicians who request paediatric CT should continually assess its appropriateness on a case-by-case basis. When used prudently, CT is a valuable imaging modality for both children and adults.

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