Optimal Utilization of Pediatric Computed Tomography to Minimize Radiation Exposure: What the Clinician Must Know

NATASHA GUPTA AND LALENDRA UPRETI

From Department of Radiology and Imaging, University College of Medical Sciences and Guru Teg Bahadur Hospital, Dilshad Garden, Delhi, India.

Correspondence to: Dr Natasha Gupta, Specialist, Department of Radiology and Imaging, University College of Medical Sciences and Guru Teg Bahadur Hospital, Dilshad Garden, Delhi, India. drnatashagupta@gmail.com

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The number of computed tomography (CT) scans being done for children all over the world is on the rise ever since the advent of Multi-Detector CT (MDCT). However, CT is a potential source of harmful ionizing radiation, and children are more susceptible to its adverse effects. It is essential for the pediatrician as well as the radiologist to be aware of some important principles and guidelines, by following which, radiation exposure to the child can be minimized to the bare essential. It is important to have knowledge of the valid and justifiable indications of CT for the child, the correct technique of performing the scan, and the new technological innovations now available on modern scanners that help to minimize radiation dose.

Keywords: *Adverse-effect, Imaging, Radiation dose*.

Radiological investigations have established themselves as an important ancillary aid to the pediatrician in reaching a diagnosis, and in follow-up of a known disease process. The clinician relies heavily on various imaging tools in his day-to-day practice, and most prescriptions often include one or more imaging investigations. There has been a surge in the options available for this purpose. Modern imaging comprises a myriad of investigations. While the pediatrician is not expected to possess deep knowledge pertaining to all modalities, the awareness and necessity of minimizing radiation exposure to the patient is a responsibility which all clinicians must be willing to share with the radiologist.

Plain *X*-rays and special radiological investigations were the main source of radiation a few decades ago; presently computed tomography (CT) scan accounts for most of radiation burden being imposed upon the pediatric patient. The number of CT scans being done worldwide has significantly increased in the last decade, and is still on the rise. As per recent data, the number of scans has increased globally by about 700-800% since the advent of Multidetector CT (MDCT), with an annual growth rate of 10% [1]. It is estimated that of the total number of CT scans, more than 10% are performed in pediatric patients [2]. Although CT studies comprise only 15% of the total imaging studies involving use of ionizing radiation, they contribute up to 70% of the total radiation dose received from medical imaging [3]. The request for CT scans for common problems in pediatric patients as head injury, abdominal trauma and acute abdominal conditions as appendicitis is responsible for the rising trend in pediatric CT. One of the main reasons for this rising trend is that in many settings, CT scan provides a rapid and accurate diagnosis, there by facilitating timely management. Negative test results lead to avoidance of unnecessary surgical exploration and reduce hospital stay. With the advent of MDCT, it is possible to obtain excellent high resolution images in all planes in a very short time span. Reduced scanning time has virtually eliminated the need for sedation and anesthesia in children [4]. For the radiologist, this results in increased confidence regarding the diagnosis apart from increasing the throughput of the patient in a busy radiology department. Other factors which also play a role for increased CT usage include relatively lower cost, wider availability, overcautious use by the clinician in the era of consumer litigations, undue pressure exerted by affording parents to perform high-end investigations for their wards, and financial incentives offered to the prescribing physicians.

Although the utility of CT scan in the management of various pathological processes is clearly established, concern against its injudicious and indiscriminate use is increasing and increasingly being voiced in the scientific literature and lay media due to attendant radiation hazards [5]. Use of CT scan results in a marked increase in the radiation dose to the patient. A standard CT scan of the head gives an effective radiation dose of about 4 mSv, which is equivalent to the dose from 200 *X*-rays of the chest. CT abdomen produces a dose of about 5 mSv, equivalent to 250 chest *X*-rays [3]. The radiation concerns are significantly more for the pediatric population, as this group is particularly vulnerable to harmful effects of the radiation (***Box* 1**), mainly due to rapidly dividing cells in their growing bodies which are more radio-sensitive, and also due to longer life expectancy of the child, which may allow potential oncogenic radiation effects to manifest themselves at a later date [1,6]. Another relevant issue is the tendency to use adult CT protocols in pediatric CT. This undesirable practice results in a much higher dose as compared to using the technical parameters which are customized for the young patients according to their body size. It also needs to be emphasized that radiation exposure is cumulative over the lifetime of the child, and repeated scanning results in a greater lifetime risk, especially for carcinogenesis [5,6].

The radiology community recognized and acknowledged the importance of these issues, and responded by launching a global campaign for right-sizing the radiation parameters and using dedicated pediatric CT protocols. This initiative, aptly named 'Image Gently Campaign' was jointly started by several societies in 2008, including the Society of Pediatric Radiology and American College of Radiology, with the goal to highlight the importance of pediatric radiation dose reduction with focus on CT scanning, by holding various awareness and education programs [5]. The campaign essentially emphasizes the concept of 'ALARA' as being central to the practice of pediatric radiology. This acronym, which stands for 'As Low As Reasonably Achievable' is essential to be understood as well as adopted by all professionals involved in pediatric care. The goal is to avoid or optimize radiation exposure to the child. The benefits of a properly executed and clinically justified CT examination should always outweigh the risk. In clear words, it is the responsibility of the clinician, who is ordering the CT, to ensure that the examination is actually indicated and justified, and that of the radiologist to check that radiation dose is minimized by using correct techniques and factors [2].

BOX 1 ADVERSE EFFECTS OF IONIZING RADIATION

Dose independent effects
- Carcinogenesis
- Genetic effects

Dose dependent effects
- Hair loss
- Skin changes
- Radiation sickness
- Diarrhea
- Cataract
- Sterility
- IUGR / Fetal demise

IUGR: Intrauterine growth retardation

DOSE REDUCTION IN PEDIATRIC CT

Dose reduction revolves around the following three main strategies: (*i*) justification; (*ii*) selection of protocols and appropriate technical parameters; and (*iii*) use of technological innovations.

Justification: Few important principles must be followed by the referring clinician in order to imbibe the concept of ALARA. The factor of greatest importance is an accurate knowledge of the valid indications of CT and knowledge of alternative imaging modalities, involving lesser or no radiation risk, which may be used in specific clinical situations. CT should be advised only when it is absolutely essential, and the necessary results will not be achieved with the other modalities involving lower risk. For the purpose of objective selection of the most suitable radiological study in a clinical condition, it is advisable to follow the 'ACR Appropriateness Criteria and Practice Guidelines'. These evidence-based guidelines are reviewed and updated by a multidisciplinary expert panel every two years [7]. Following are some clinical scenarios where there is potential for eliminating or scaling down the radiation burden:

- Cranial ultrasound should be preferred for evaluation of intracranial pathologies till the time the fontanellar window is available. It can detect the presence of an abnormality in a significant number of cases. When ultrasound is unable to answer the clinical question, further evaluation is to be done by using MRI [7]. CT is not recommended as the primary investigative modality in non-traumatic intracranial pathology in children.
- For a neonate presenting with seizures, transfontenellar ultrasound of the cranium is the first imaging modality of choice. In case of unsatisfactory results, MRI brain without contrast is the next preferred modality [7]. MRI is optimal for evaluation of changes of Hypoxic ischemic encephalopathy and congenital malformations of the brain. CT is not indicated as the first modality, and is only to be performed in scenarios where MRI is not available.
- For a pediatric patient presenting with seizures, MRI without contrast is the preferred investigative modality [7].

- Non-contrast CT of head is the primary study for emergent evaluation of acute intracranial injury in children. However, CT is to be used selectively in cases of head trauma, where clinically indicated, and not indiscriminately in every child who presents with trauma. Various clinical guidelines like PECARN rule [8] and CATCH rule [9], are also available for this purpose. The PECARN pediatric head injury/ Trauma algorithm comprises of clinical prediction rules, which help to identify children with very low risk of clinically important injury following blunt head trauma, who would not require neuroimaging, and in whom CT would be unnecessary. As per this study [8], prediction rules have been identified and validated, which classify children into low risk group, where routine CT can be eliminated from the management protocol. The prediction rules for children below 2 years of age comprise normal mental status, no scalp hematoma or hematoma in frontal region, no loss of consciousness or loss of consciousness less than 5 seconds, non-severe injury mechanism, no palpable skull fracture and acting normally according to parents. For children aged 2 years or more, the prediction rules are normal mental status, no loss of consciousness, no vomiting, non severe injury mechanism, no signs of basilar skull fracture and no severe headache. The CATCH rule is a clinical decision rule for use of CT in children with minor head injury. It identifies children at two levels of risk- those with high and medium risk factors, and helps to predict the need for neurological intervention and requirement for CT scanning [9].
- For imaging of spinal trauma in children aged 14 years or less, *X*-ray of the spine is the imaging modality of choice. For cervical spinal trauma, three views are routinely recommended- AP, lateral and open mouth, and for thoracic and lumbar spine, two views- AP and lateral are required. MRI is the investigation of choice for evaluation of suspected spinal cord injury, cord compression and ligamentous integrity.
- As acute and recurrent abdominal pain in children is often due to non-organic causes, imaging is not required in most cases if there are no clinical signs of involvement of abdominal viscera. In most cases where imaging is required, ultrasonography (USG) should suffice to rule out most organic causes involving solid abdominal viscera. For specific evaluation of right lower quadrant pain with suspected appendicitis in a child below 14 years of age, USG abdomen with graded compression is the imaging modality of choice for initial evaluation, while in an adult patient with the same complaints, CT abdomen with intravenous contrast administration is the preferred investigative modality [7].
- Imaging modalities are usually not helpful for diagnosis of intestinal pathologies such as Celiac disease and inflammatory bowel disease. If these conditions are suspected, endoscopy studies should be preferred, which also provide opportunity for biopsy and histopathological diagnosis. Non-availability of endoscopy should not be the reason to perform CT scan; the patient should rather be referred to another center. If serial or follow-up imaging is required for diagnosis or monitoring of small bowel diseases (e.g. Crohn's disease, intestinal tuberculosis), MR enterography should be preferred over CT abdomen.
- MRI / MR Cholangio–pancreaticography should be considered for evaluation of hepatobiliary and pancreatic lesions in place of CT scan. If CT has been used as an initial diagnostic modality, USG is best suited for follow-up of the disease.
- For imaging of chest pathology in children, *X*-ray Chest is an important initial modality, which may act as a screening tool to detect positive findings, or even provide the diagnosis in some conditions like pleural effusion, pneumothorax and chest wall fractures. However, plain *X*-ray has a low sensitivity, may fail to provide specific diagnosis or indicate the true extent and severity of pathology, as in cases of lung mass, mediastinal mass and congenital anomalies. CT Chest may be performed either with contrast or without contrast. CT Chest with contrast is indicated in children in conditions like recurrent or antibiotic resistant pneumonia, pneumonia with immuno-compromised status, mediastinal mass and lung mass. Low dose CT is indicated every 2 years for monitoring patients with bronchiectasis and small airways disease [10]. Ultrasound of the chest or axilla is indicated as an initial study for evaluating adenopathy, palpable chest wall lesions, pleural effusion or thickening, and patency of thoracic vasculature. Lung ultrasound can also be used for image guided biopsy for thoracic lesions accessible on the ultrasound, in place of the routinely used CT guided biopsy for thoracic mass lesions [12].

It is always advisable that the ordering clinician and the radiologist must have a meaningful discussion with intent to follow the ALARA principle in each and every case.

Selection of protocols and appropriate technical parameters: The radiologist has an even greater and unavoidable responsibility when it comes to radiation dose reduction. Apart from the consideration of alternative non-radiation modalities and consulting the Appropriateness criteria, other essential principles are also to be followed by radiology professionals; some of these can undoubtedly be checked and emphasized upon by the clinicians while referring their patients for imaging.

1. Before imaging the child, his/her radiation history needs to be reviewed in order to avoid cumulative radiation dose.

2. Adult CT parameters are not to be applied to the child as such, rather have to be adjusted based on child size, region scanned and organ scanned, in order to reduce the dose to the child.

3. The highest quality images which involve administration of very high radiation are not always required for making the diagnosis. In many situations, relatively lower resolutions scans may also suffice for the correct diagnosis and treatment initiation. Thus, for every clinical situation, the required image quality may be decided and accordingly, imaging factors can be modified. Low dose head CT protocol (with low tube current) has been documented to produce diagnostically acceptable image quality in evaluation of ventricular volume and shunt patency in children with hydrocephalus, at the same time reducing radiation dose by upto 63% [12].

4. Non-contrast scan prior to contrast-enhanced scan and Multiphasic studies *i.e*. in the arterial, venous and delayed phases etc., should be resorted to only when there is an absolute necessity. In most clinical situations, a single phase scan covering the entire region of interest at one time can suffice for diagnosis. In examinations like perfusion studies, where one anatomical region or lesion is repeatedly scanned to assess its vascular perfusion, there is significant increase in the organ dose and such studies are best avoided in pediatric patients. Most CT overdose accidents reported in literature are known to have occurred during multiphasic studies [6].

5. Many technical parameters in the CT equipment such as *X*-ray beam energy, tube current, gantry rotation time, pitch, slice thickness and scan length have a direct effect on patient radiation dose and can be modified or selected by the operator. Selection of correct parameters is the responsibility of all radiology personnel involved in CT data acquisition of the child [5,6]. The radiology community has been constantly reviewing and child-sizing the CT protocols factoring in the benefits of the advancements in the CT technology.

6. Radiation personnel should be familiar with the display of dose descriptors on CT equipment. They should make a note of the dose after each examination, and take necessary steps if the dose is unreasonably high.

Use of technological innovations: The newer CT equipments provide several advanced technical innovations, which serve to reduce radiation dose to the basic minimum. These include some hardware *X*-ray beam filters, software filters, automatic selection of beam energy and tube current by the equipment based on body size, tube current adjustment in the cranio-caudal as well circumferential directions as per the thickness of body parts to ensure uniform exposure and image quality, and newer algorithms for image reconstruction which are able to generate better image quality with low dose CT images [5,6].

In conclusion, everyone concerned with pediatric patient-care must realize that the child is not a miniature adult and faces a much greater lifetime risk when exposed to radiation. The ALARA principle should be clearly understood and applied consciously and conscientiously while ordering and performing a CT scan. Radiation exposure should be justified and minimized using every possible means available. Fortunately, the modern imaging armamentarium and technological innovations give us a lot of choice and latitude to achieve desirable results while minimizing the risk. We owe it to our children to be aware of these beneficial tools.

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