

ARTICLE

Practical advices for optimal CT scanner dose in children

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Abstract – Radiation protection and dose optimisation in computerized tomography (CT) for pediatric patients are of utmost importance because of the potential risk of cancer induction by exposure to ionizing radiation. A review of available technical features in modern CT machines aiming at reducing and/or optimizing patient dose was performed. Practical advices to operators were listed according to dose-related technical solutions studied to decrease the doses and to practically implement dose optimisation.

Keywords: CT / patient dose optimisation / radiation protection / pediatric imaging

1 Introduction

Doubts exist on the possible increase in the number of cancers (brain cancers, leukaemia and others) following computerized tomography (CT) irradiation of children (Brenner *et al.*, 2001; Pearce *et al.*, 2012; Kritsaneepaiboon *et al.*, 2012; Mathews *et al.*, 2013; Miglioretti *et al.*, 2013; Meulepas *et al.*, 2019; Shao *et al.*, 2020).

Final results of the European EPI-CT epidemiologic survey in about one million children are pending while details of the methodology (Bosch de Basea *et al.*, 2015) and cohort profile (Bernier *et al.*, 2019) have already been published.

In view of these recent publications and of the known sensitivity to radiation of children, a very cautious approach has to be taken for pediatric CT examinations. Furthermore, the longer life expectancy of children gives them a greater probability to develop a cancer which is an age related process. Moreover the smaller amount of fat that separate organs from each other in children contributes to a larger absorbed dose for the same technical parameters and displayed CT dose index (CTDIvol) in comparison to adults. Indeed the principles of radiological protection of the International Commission of Radiological Protection have to be enforced in children (ICRP, 2007):

- all CT examinations must be justified (Sodhi *et al.*, 2015);
- all CT examinations, whether performed in a children hospital, in a general hospital or in a private practice, must be optimized and the parameters scaled to the individual child size (Strauss *et al.*, 2010; Mannudeep, 2016) to obtain a quality sufficient to allow the precise diagnosis;
- the principle of dose limitation does not apply to patients.

Therefore the optimal CT scanner dose is entirely in the hands of the radiological team (radiologist, radiographer,

medical physicist, application engineer etc...) who must choose the optimized parameters for the lowest possible dose to achieve an appropriate diagnosis for each child. It is worth recalling that medical exposures are intentional exposures and that each CT scanner examination must be justified, *i.e.*, *a priori* useful in the following sense: “*A useful investigation is one in which the result – positive or negative – will alter management (of the patient) or add confidence to the clinician’s diagnosis*” (Radiation Protection 118, 2000).

Thus this paper reviews CT scanner parameters and protocols that must be used for optimal CT dose in children. This paper addresses:

- 1 How to decrease CT doses?
- 2 How to practically implement dose optimization?

2 How to decrease CT doses?

Various technical possibilities are available in modern CT machines to reduce patient dose in CT pediatric examinations.

2.1 Fixed tube current (technique charts)

Due to the normalized nature of CT data which ensures that the image always appears properly exposed, CT users are not technically compelled to decrease the tube-current-time product (mAs) for small patients, which may result in excess radiation dose for them.

As with radiographic and fluoroscopic imaging, the operator should be provided with appropriate guidelines for mAs selection as a function of patient size. These are often referred to as technical charts. In CT, the tube current exposure time and tube potential can be altered to give the appropriate exposure to the patient.

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Once users have standardized the tube potential (kV) according to patient weight, and gantry rotation time (s) is set for a given clinical application, the manner in which mA should be adjusted as a function of patient size should be related to the overall attenuation, or thickness, of the anatomy of interest as opposed to patient weight.

2.2 Tube current (mA) modulation

Wide variations in patient absorption occur both with projection angle and anatomic region and are not considered when using a fixed tube current.

The projection with the most noise primarily determines the noise of the final image. Hence, data acquired through body parts having less attenuation can be acquired with substantially less radiation without impairing the final image quality ([Radiation Technology Skills UP Series, 2019](#)).

- Angular (x,y) mA modulation

Angular (x,y) mA modulation deals with the variation in X-ray attenuation around the patient by varying the mA as the X-ray tube rotates around the patient (e.g., in the Antero Posterior versus Lateral direction).

- Longitudinal (z) mA modulation

Longitudinal (z) mA modulation deals with the varying attenuation of the patient among anatomic regions by varying the mA along the z-axis of the patient (e.g., shoulders versus the abdomen).

- Angular and longitudinal (x,y,z) mA modulation

Angular and longitudinal (x,y,z) mA modulation combines the previous two methods to vary the mA both during rotation and along the z-axis of the patient.

2.3 Automatic exposure control (AEC)

For CT systems it is technologically possible to adjust the X-ray tube current in real time in response to variations in X-ray intensity at the detector. These methods of adapting the tube current to patient attenuation, known generically as automatic exposure control (AEC), are analogous to phototiming in general radiography and have demonstrated reductions in dose of about 20–40% when image quality is appropriately specified ([Martin and Sookpeng, 2016](#)). Among all these techniques, the major issue is the definition of the image quality which differs depending on CT manufacturers:

- GE Healthcare uses a concept known as the Noise Index;
- Canon (formerly Toshiba) allows two ways to prescribe image quality in their Sure Exposure AEC algorithm: Standard Deviation and Image Quality Level;
- Philips Medical System uses a Reference Image from a satisfactory patient exam (Reference Case) stored in the system;
- Siemens Healthineers uses a Quality Reference mAs to define the effective mAs (=mAs/pitch) required to produce a specific image quality in an 80 kg patient (20 kg for pediatric cases) for a given protocol.

It is important to know how the scanner operates in order to fully understand how to set the mA modulation system ([Martin and Sookpeng, 2016](#)).

2.4 Adjusting kV based on patient size

The principle behind the benefit of lower kV is that in many CT exams involving the use of iodinated contrast media, the superior enhancement of iodine at lower tube potentials improves the visualisation of hypervascular or hypovascular pathologies.

Despite the increased noise level, the quality of images of small sized patients is better than that obtained with higher tube potential, for the same radiation dose (if mA is increased) or much lower.

Some manufacturers offer an assistance for choosing kV based on the radiographic view ([Li et al., 2017](#)).

2.5 Dose and Pitch relationship

Pitch in the multidetector, spiral CT era is defined as table travel per rotation divided by beam collimation.

A pitch equal to 1 means neither overlap nor gap between slices. A pitch > 1 results in a lower radiation dose (and lower sampling). A pitch < 1 results in an increased dose (and overlap of anatomy).

It is worth knowing that, through an automatic proportional increasing of tube current when pitch increases, some CT brands can provide an increased radiation dose values for smaller pitch selections in order to avoid any image quality impairment.

2.6 Detector configuration, slice thickness and collimation

The detector configuration should be determined on the basis of the type of study performed. For routine acquisitions, without the need for thin-section 3-D imaging, there is no need for extremely thin effective detector thicknesses.

In such cases, if thick-section 5-mm images in the axial, coronal, and sagittal planes are sufficient for radiologist review, the effective detector thickness can be widened to 1.25 or 1.5 mm (rather than 0.75 or 0.5 mm), keeping a similar image quality.

However, if thin-section multiplanar reconstructions (MPRs) or high-resolution 3-D images (with increased spatial resolution in the z-axis) are required, a thin effective detector thickness (0.5–0.75 mm) may be necessary, although there is an associated dose penalty.

2.7 Adaptive collimation

In spiral CT, an extra half-rotation of the gantry before and after each scan is routinely done, fully irradiating the detector throughout, even though only part of the acquired data is necessary for image reconstruction. As a result, the wide cone beam exposes tissue that will never be part of reconstructed images.

The adaptive collimation, a technology based on precise, fast, and independent movement of both collimator blades, limits this over-ranging.

The pre-patient collimator asymmetrically opens and closes at the beginning and end of each spiral scan, temporarily blocking those parts of the X-ray beam that are not used for image reconstruction. As a result, only the targeted tissue is irradiated, since adjacent organs at risk are protected.

By using adaptive section collimation, a substantial dose reduction of up to 10% can be achieved for cardiac and chest. For scan ranges smaller than 12 cm such dose reduction can reach 40%. ([Deak et al., 2009](#)).

2.8 Spectral imaging

Spectral imaging is a way to visualize tissue composition. Dual energy imaging allows a reduction in radiation dose by eliminating the need for true non-contrast imaging and reducing the need for repeat exams. Lower energy images can be used to salvage bad CT angiograms, do low-contrast-low-dose exams and increase conspicuity of lesions among other things.

The two dual-energy CT postprocessing techniques that best exploit the advantages of dual-energy CT in children are the material-decomposition images (which include virtual nonenhanced, iodine, perfused lung blood volume, lung vessel, automated bone removal, and renal stone characterization images) and virtual monoenergetic images ([Siegel and Ramirez-Giralodo, 2019](#)).

2.9 Artificial Intelligence (AI)

Although AI is only at the beginning of its full potential, it has potential for many applications especially in oncology in tumour diagnosis (early detection, flagging of abnormal findings, differentiation between benign and malignant tumours, vessel involvement, tumour staging...) ([Daldrup-Link, 2019](#)).

Machine learning has the potential to vastly advance medical imaging, particularly computerized tomography (CT) scanning, by reducing radiation exposure and improving image quality ([Rensselaer Polytechnic Institute, 2019](#)).

It will help in adapting and choosing in the most appropriate way exposure parameters and protocols according to diagnostic objectives that doctors are seeking for.

2.10 Organ sparing options

Organ sparing refers to selective reduction of radiation exposure of dose-sensitive anatomical regions such as female breasts, eye lenses, and thyroid.

Unfortunately, protection shields give rise to artefacts that may prevent their use in specific cases ([Liao et al., 2019](#)).

Alternatively, organ dose modulation systems are organ sparing options that allow to reduce or completely switch off tube current during the rotation phase in which the concerned anatomical regions are most directly exposed to radiation, making a dose reduction of individual anatomical regions possible ([Kim et al., 2017](#)).

2.11 Reconstruction algorithms-Iterative reconstruction (IR)

Model-based iterative reconstruction refers to iterative algorithms used to reconstruct 2D and 3D images. In CT an image must be reconstructed from projections of an object. Iterative reconstruction techniques are a better alternative to the common filtered back projection (FBP) method, which directly calculates the image from raw data in a single reconstruction step.

Iterative reconstruction techniques have demonstrated the potential for improving image quality thus allowing a reduction in radiation dose ([Khawaja et al., 2014; Brand et al., 2018](#)).

The first generation used only image correction in addition to image data reconstruction (image space) and allowed up to 40% gain in dose.

The most widely used second generation uses raw data reconstruction as well as image data reconstruction and image correction using system noise statistics in an iterative way (image and raw data space) allowing for very fast reconstruction and up to 60–70% decrease in dose.

So far, the third generation of iterative reconstruction takes minutes as compared to seconds in other IR and consequently is not used in routine practice. It uses the system noise statistics and a mathematical model of the scanner allowing for extremely low doses, comparable to conventional X-ray doses.

Metal artefact algorithm may also help in avoiding unnecessary repeated exams.

Artificial intelligence will potentially further increase the performance of reconstruction methods ([Willemink and Noël, 2019](#)).

2.12 Diagnostic Reference Levels (DRL)

Although DRL do not decrease dose by themselves, they are an interesting tool for optimization. The need to establish national DRLs as well as local DRLs is highlighted in many recent publications ([Radiation Protection 185, 2018; Roch et al., 2018](#)).

Local DRLs are defined as the third quartile value of a set of dosimetric and morphologic data from local patients for defined CT procedures and for defined patient weight range. It would make more sense to define DRL for specific clinical indications of CT procedures ([Radiation Protection 185, 2018; Granata et al., 2019](#)).

National DRLs are based on the 3rd quartile of the distribution from all local medians ([Journal officiel de la république française, 2019](#)).

European DRLs are based on the distribution of national DRLs.

There are many challenges in defining pediatric DRLs: categorizing according to weight rather than age is better but more difficult to achieve.

3 How to practically implement dose optimization?

As a general rule, dose reduction in CT is based on the following principles, valid for each procedure:

All technical parameters of the scan must be adapted ideally to the patient body mass index, if not to the weight and failing that to the patient age, to the organ and to the volume of the organ to be examined, its natural contrast, the size of the lesion, and the indication of the examination.

3.1 Concerning the equipment

- When buying a CT scanner, take the dosimetry criterion described above into account along with the other criteria (cost, ergonomics, throughput, etc...). This should contribute to progressively get rid of the machines that require the largest amounts of dose.
- Have preventive maintenances and quality control tests done, to ensure conformity and performance stability of the machine.
- Make sure the complete dose data of Radiation Dose Structured Report (RDSR) are sent to a dose server – Dose Archiving and Communication System (DACS) – allowing dose traceability, analysis of dose characteristics, assessment of local DRLs for the whole pediatric population thus contributing to the optimisation through temporal analysis of data as well as the required local DRLs that are usually based on a limited set of patients' data.

3.2 Concerning CT protocols

- Position the patient carefully, check that he/she is at the isocenter of the scanner, that the arms are correctly positioned in order to avoid beam hardening artefacts and dose increase if mA modulation is used, that he/she is quiet enough and will not move during the examination. Incorrect positioning may result in significant (up to 25%) dose increase ([Raman et al., 2013](#); [Zacharias et al., 2013](#)).
- Prefer a Postero Anterior radiographic view using the lowest possible kV and mA and adapt as much as possible the field of view to the patient body size.
- Use the smallest possible scan range that is compatible with the scan request. Limit the scanned volume (field of view, number of slices) to what is just necessary to answer the clinical questions justifying the procedure ([Raman et al., 2013](#); [Zacharias et al., 2013](#))
- Choose the lowest kV compatible with the necessary image quality according to patient weight. For the same field of view, dose to patient increases with tension to the power of 2.5. In practice, the kV used for pediatric CT are between 70 and 120; 70 to 80 kV being used for less than 30 kg patients, 100 kV for patients until 60 kg, 120 kV being used for adult sized children. For thorax CT it is never useful to use more than 100 kV.
- Lower the dose by decreasing current mA and/or rotation time within limits that are compatible with the image quality criteria (Signal to Noise ratio for instance). The dose delivered to the patient is directly proportional to mAs, and an overexposure (mAs in excess) can be totally overlooked. The mAs can be decreased for smaller morphotype with no significant change of the image

quality. Surveys have shown that CT parameters are not adapted enough to body built of patients.

- Be careful when selecting thin slices (< 1 mm) because dose is automatically increased when collimation decreases to these levels.
- Do not use gantry tilt especially for head CT: the helical mode allows for multiplanar reconstructions (MPR) that show images in the coronal plane while avoiding exposure of the lens of the eyes.
- Both collimation (function of size and number of detector arrays) and reconstructed slice thickness must be chosen at the time of acquisition. Acquisition parameters must be chosen in function of the desired reconstruction slice thickness in order to obtain the required image quality.
- Use the manufacturer's pediatric protocols, age or weight classified, they can help choosing the best parameters considering the child's morphotype. Be aware that these protocols still have to be adapted as a function of the clinical indication.
- Use automatic current modulation systems (mA modulation) since they allow for dose reduction. These techniques must be used in addition to a previous optimization of the protocols. Quality indices (noise index in the image, reference mAs or reference image according to different manufacturers) are used to maintain a constant image quality.
- Shields can be used to protect sensitive organs. Bismuth shields are available commercially: breast shields for using during the thorax examination of young females, thyroid shields, etc... They reduce the absorbed dose by a factor of 2 but create artefacts in the image. Their use is optimized by putting foam between the surface of the skin and the shielding. Their use is not recommended when x-y mA modulation is used, and they must be put in place after the radiogram has been done (risk of overexposure). Alternatively, organ dose modulation can be used to spare organs at risk.
- Do not use lead garments to protect radiosensitive organs (thyroid, pelvis) because they might negatively interfere with mA modulation and resulting in a fault sense of protection ([Marsh and Silosky, 2019](#)).

4 Conclusion

Medical exposures constitute a priority in radiological protection and all efforts need to be made to control the growth of the doses due to diagnostic examination with ionizing radiation especially for CT ([Bourguignon et al., 2017](#)). The most important issues in paediatric imaging are to get images of good quality for diagnosis and to avoid repeating the examination.

We have investigated in this paper all possible ways to optimize doses in pediatric CT. Methods reviewed in this manuscript are useful for the optimisation process in order to get a diagnostic image quality with the lowest patient exposure.

To achieve that in practice, a voluntary attitude of radiologists is necessary to really optimize the technical parameters of the examinations.

Certainly the assessment of DRLs for each CT equipment and in each institution constitutes a simple way to control the efficacy of the optimization.

It is important to create a core team for patient dose management consisting of radiologists, medical physicists, technicians as recommended by the new EURATOM directive in order to evaluate the optimisation process.

Training of the operators on patient radiation protection issues is of utmost importance including training on how to use the CT scanners safely and how to use the available dose/image quality methods.

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