Journal of Research in Medical and Dental Science
2018, Volume 6, Issue 5, Page No: 104-114

Available Online at: www.jrmds.in
eISSN No. 2347-2367: pISSN No. 2347-2545

Addressing as Low as Reasonably Achievable (ALARA) in Pediatric Computed Tomography (CT) Procedures

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ABSTRACT

During past three decades, there has been a remarkable increase in the number of patients undergoing computed tomography (CT) procedures. Although CT is a valuable diagnostic tool, its use involves some potential health effects, especially increasing the risk of radiation induced carcinogenesis. Therefore, it is necessary that the patients 'dose to be kept as low as reasonably achievable (ALARA) and all radiation dose optimization strategies to be applied. The increasing use of CT in the past decades, reports of a significant fraction of patients undergoing multiple CT examinations, as well as the risk of radiation health effects has created a global concern among the scientific and media literatures. Paralleling this, many dose optimization strategies has been developed that needed to be addressed, particularly in pediatric patients. In this review, we have addressed these strategies with focus on pediatric patients to achieve lower doses.

Key words: Computed tomography, Radiation risk, Dose optimization, Pediatrics

HOW TO CITE THIS ARTICLE: Vahid Karami, Mehrdad Gholami*, Sajjad Lorestani, Addressing as low as reasonably achievable (ALARA) in pediatric computed tomography (CT) procedures, J Res Med Dent Sci, 2018, 6 (5):104-114

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Received: 08/08/2018
Accepted: 03/09/2018

INTRODUCTION

Computed tomography (CT) has since introduction in the 1970s proved to be able to bring the invaluable clinically benefits in medicine [1-3]. The advent and using of CT has fundamentally improved medical imaging [3,4]. During three past decades, the number of patients undergoing CT procedures has steadily continued to increase. From 1980 to 1990, CT usage has increased by a factor of 5 [5], as well as, between 1998 to 2008, by a factor of 7 [6]. In 2011, 85 million CTs were conducted in the United States of America (USA), including as many as 5% to 11% in children [7]. The diagnostic sensitivity of CT is 10 times more than those from conventional radiography and is comparable with magnetic resonance imaging (MRI) [1,8]. CT is also performed in several seconds and can reduce the need for sedation or anesthesia, particularly in pediatric patients [1,6,8]. Hence, CT has become a user-friendly diagnostic modality, for both the patients and physicians [3,9].

In spite of the immediate benefits of CT, its use involves some potential health risks [2,7,10,11]. CT exposes patients to much more radiation dose compared to those from conventional radiography and is almost enough to become a health issue [12,13]. CT is accounted for 11% of all radiological procedures; however it is responsible for 67% of the population collective dose [2,14]. The increasing risk of radiation induced carcinogenesis has been concerned [15]. The international commission on radiological protection (ICRP) stated that: "the absorbed dose to tissue from CT can often approach or exceed the levels known to increase the probability of cancer" [16]. According to Brenner and Hall [3], 2% of cancers in the USA are comes from CTs performed in this country [3]. Moreover, De Gonzalez et al. [17] estimated that 29,000 future cancers may be attributable to the CT examinations performed in the USA in 2007, so that 4350 of these cancers are allocated to pediatric patients. Such similar findings have been reported in the literatures [8,10,18-20].

Although it is necessary that the radiation dose to all patients to be kept as low as reasonably achievable (ALARA), however, pediatric patients merit particular attention from the radiation protection point of view. The high mitotic division rate of pediatric cells [13], the greater post-exposure life expectancy [13,21,22] and the smaller body size of pediatric patients [23] make them particularly radiosensitive. Several literatures report that the radio sensitivity of pediatric patients to be 10 times more than those from middle-aged adults [3,21,24-28]. Moreover, most CT departments currently use of pre-programmed CT protocols and does not consider the specific protocols to the age, weight, body size, and composition [6]. The use of this pre-programmed protocols resulted in pediatrics received much more radiation dose than needed for a given study [6,22].

The increasing use of CT in the past decades [6,7], reports of the significant fraction of patients undergoing multiple CT examinations [2,29], as well as the increasing risk of radiation induced cancer [7,8,10,17-19,30] has created a global health concern, not only in the scientific publications, but also in the media and public literatures. Looking on the some popular newspapers such as "New York Times" and "Newsweek", the cogitable phrases, in term of CT risks, such as "we are giving ourselves cancer" [31], "we are silently irradiating ourselves to death" [31] and "death rays" [32] are notable. Despite these statements has certainly overstatement of the CT risks, but it reflects some potential concerns among the public that needed to be considered. There are many dose optimization strategies that can be applied to achieve lower doses, without decreasing patients care. Therefore, in this review we aimed to address these strategies with focus on pediatric patients.

As low as reasonably achievable (ALARA)

As low as reasonably achievable (ALARA) is a fundamental safety concept intended to radiation dose optimization [33]. It means making every practical and reasonable attempt to decrease the radiation exposure to the patients and personals as low as possible, social and economic considerations taken into account [34]. The ALARA come from a best conservative estimate of dose-response known as linear no threshold (LNT). This hypothesis maintains that the relationship between the dose and its response is extremely linear with no threshold, suggests any radiation dose may be accompanying with a response or risk [35]. Much focus has been placed on the letters ALA (as low as) and it has created a competition situation between the institutions and CT manufacturers to achieve lower doses. However, concentration on and the definition of the letters RA (reasonably achievable) remains poor [36] and it may needed to be more clarification. The RA refers to all practical methods in which there is a reasonable balance between the risk and benefit [36]. For example, in CT of the large and obese patients, increasing the dose may be consistent with RA [37]. When discussing ALARA in medical imaging, keeping the radiation exposure as low as possible, associate with obtaining optimum image quality is of particular importance [38]. The concept of ALARA has been the focus of many scientific societies such as the society for pediatric radiology [39].

Addressing ALARA in CT

According to Brenner [40], in general, there is three ways to protect the patient (pediatrics and adults) from undue exposure to radiation during CT: 1-reducing the number of unnecessary CT examinations by referring physicians, 2-considering alternative imaging modalities that involve non-ionizing radiation, such as ultrasonography (US) and MRI, where possible and appropriate, and 3-radiation dose optimization per CT examination. In other category, CT radiation dose optimization strategies could be divided into general, specific and future strategies [37]. Dose reduction strategies have successful outcomes if a perfect clinical decision rule includes all of appropriate criteria related to actual dose reduction to be task. In this decision rule, the most important step is the first step, in which the referring physician should checking the necessity of imaging and decide to perform it or not. Physicians should notify that approximately 40% of pediatric CTs are unnecessary and can be deletion without decreasing patient's care [41]. Before ordering any CT examination, the referring physician should check the necessity of ordering that CT and ask yourself: do I need this CT at this time? Does this CT have address the clinical question? If imaging is not necessary, the physician should consider other diagnostic approaches and if so, in the first line it should consider radiation-free imaging modalities such as US and MRI, whenever possible and appropriate. Pediatrics are the best candidate to be imaging by the US [13,41], especially for abdominopelvic evaluations [13]. Similarly, MRI has an excellent accuracy in pediatrics [41]. Appendicitis may be the surge for the use of abdominal CT in pediatric patients [6]. As an alternative method, US can first to be use and if it was positive, the appendectomy can be performed; however, if it was negative, CT will be performed. This procedure can reduce CT usage by about 30% [42]. Moreover, CT can be replaced with MRI for variety of assessments such as the brain [43], the lumbar spine [44] and acute appendicitis in children [45]. Consultation with the radiologist can also help to select the best imaging modality [46]. The conventional radiography is the next option that the physician should consider to prescribe. However some issues such as unavailability and economic considerations make the MRI and US challenging to be considered before ordering conventional radiography. After checking this entire, if CT imaging is necessary, the radiation dose optimization strategies should be applied. Both the physicians and medical imaging technologists (MIT) are responsible at this stage. These strategies have been discussed in the follow.

Tube voltage selection (TVS)

The patients received dose, image noise and contrast are particularly influenced by variation in the tube voltage or kilo voltage peak (kVp) [47-50]. With other parameters constant, the patient dose would be decrease and the image contrast would be increase, when low tube voltages to be applied [47,51-59]. Unlike tube current, the relationship between tube voltage and patient dose is nonlinear [33]. Reducing the tube voltage by 16.5% could reduce patient dose by 40% [60]. According to Funama et al. [58] and Nakayama et al. [61], in abdominal

CT, decreasing the tube voltage from 120 to 90 is achievable without significantly decreasing the image quality, when the patient weight to bellower than 80 kg. However, it is necessary the tube voltage to be selected in the appropriate range, otherwise the diagnostic image quality may be sacrifice, especially due to introduction of beam hardening artifact in low tube voltages [51]. The influence of low tube voltages on image quality is less obvious in pediatrics than in adult patients. This is due to less attenuation coefficient of the pediatric tissues that allow low tube voltages to be use without significantly increase image noise [37]. Therefore, low tube voltages is more effective in pediatrics than in adults, especially for high contrast structures and for iodine enhanced procedures [37,51]. For example, the tube voltage of 60, instead of preprogrammed tube voltage of 120 may be enough to address the clinical problem in high contrast structures such as the chest [62]. Note that for soft tissue evaluations, particularly in obese pediatric patients, there is limitations for the use of lower tube voltages and therefore increasing the tube voltage [51] or tube current [37] may be necessary to offset the potential lose in image quality. The GE healthcare, recommended the tube voltage of 80-100 for pediatric CT [63]. However, selection of optimal tube voltage needs to be discussion between referring physicians and medical physicists.

Automated tube voltage selection (ATVS) with tube current modulation (TCM) is an alternative technology in which the scanner would measure the attenuation of the scanned body region based on the scanogram and select one of the tube voltages of 70, 80, 100, 120 and 140 to optimize patient dose and image quality [51,64]. This technology can particularly reduce patient dose while optimizing contrast-to-noise ratio (CNR) or image quality [64]. The effectiveness of this technology has been demonstrated in several adult CT studies [65-68], however, there are limited data on pediatric studies [64]. Therefore, more studies are necessary to be performed on pediatric patients.

Tube current modulation (TCM)

Tube current or milliampere (mA) is proportional to the number of emitted photons. Decreasing the tube current with other parameter constants, results in lower radiation doses to the patients [51]. The smaller body size of pediatric patients makes it possible the low tube currents to be applied [47]. However, the image noise would be increase and the trade-off between image noise and patient dose should be considered, especially for low-contrast structures such as the abdomen [48]. Unlike conventional radiography, over-exposing the patient is not obvious from CT images; namely if high exposure parameters to be use, all images are seen appropriate [37,69]. Therefore, MITs may do not adjust exposure parameters as a function of patients' body size and consequently, pediatrics and small body size patients received more radiation dose than needed [69]. It is suggested that reduction the patient diameter per 3.5 cm will reduce the absorption by 50% [41]. Therefore, the mAs can be reduced in pediatric patients to lower doses, accordingly. In abdominal CT, the radiation dose reduction of 70% has been reported follow adjusting the exposure parameters according to patient body size [70]. However, for brain CT, adjusting exposure parameters according to patient’s age is shown to be more effective than weight and/or body size [37]. It is suggested that for brain CT in newborn patients, reducing the tube current by a factor of 2 to 2.5 is achievable compared to the adult patients [71]. Tube current modulation (TCM) is an alternative dose optimization technology; however it is not disponible in old scanners. TCM is identified as one of the most effective dose optimization technologies [47]. It needed the MITs to provide desired image quality inputs and then, the tube current is adjust based on patient body size and cross sectional dimension that is lower for pediatrics than in adults [51]. TCM takes into account variations in the cross sectional dimension of patient body along the longitudinal (z) axis and angular (x and y) planes and therefore, the tube current would be modulated during X-ray tube rotation [47]. The $CTDI_{vol}$ could be reduced by 40%-60% following TCM to be apply [72]. It is necessary to notify that when thin slice thicknesses are required such as high resolution CT (HRCT) and when applying low pitch and short scan time, the scanner would automatically increase the tube current to improve image quality. In this situation, the use of TCM technique may be associated with increasing patient dose [51,62,65,73]. Organ-based-TCM is an alternative dose optimization strategy in which the tube current would be decrease during a 120° rotation of X-ray tube around the anterior portion of the patient and increase in the remaining 240°arc. In this technique, the overall patient dose remains constant. However, radiation dose to the radiosensitive organs located at the anterior aspect of the body such as the lens of the eyes, thyroid gland, breast and gonads would be decrease [74]. In a phantom study, radiation dose reduction of 32% to the lens of the eyes has been reported follow the organ-based-TCM to be used during brain CT [75]. However, increasing the dose to the posterior and lateral organs [76-78] and increasing the image noise are added concerns when organ-based-TCM to be applied [75]. Moreover, the patient should be located at the center of gantry otherwise the anterior patient’s dose would be increase [79].

Iterative reconstruction technique (IRT)

Traditionally, filtered back projection (FBP) technique has been used to reconstruct CT images from raw data [80,81]. This algorithm has restricted dose reduction, since the introduction of image noise and artifacts (especially streak artifacts) with deceasing dose [82,83]. Iterative reconstruction technique (IRT) is a reconstruction algorithm in which image data can be corrected with a set of models to lower image noise [82]. IRT has initially introduced for the use in positron emission tomography (PET) and single photon emission computed tomography (SPECT) since the 1960 [81,84-

87]. Several literatures reports demonstrated that IRT can potentially reduce the radiation dose and improve image quality during CT examinations [74,88-96]. Decreasing the image noise of 20% [75] and CT dose index ($CTDI_{vol}$) of 32%-65% [82] has been reported follow IRT to be use. Based on evaluation of 15,000 CT examinations, Noël et al. [97] demonstrated that IRT has reduced radiation exposure significantly and has potential to be considered for routine use. The main limitation of IRT is the high computational time and load [82,91]. However, with introduction of modified algorithms such as adoptive statistical iterative reconstruction (ASIR), the implementation is within reach [82].

Diagnostic reference levels (DRL)

Evidence suggests that there are significant differences in patient dose for the same type of radiological examination [21]. These variations result in some patients received unnecessarily excessive radiation exposure than needed [98]. In 1996, ICRP has recommended authorized bodies to set and use of DRL as a guide to optimize their protocols [99]. DRLs are the percentile points of the radiologic examination dose distribution [51] and determined through the 3rd quartile of the mean entrance surface dose (ESD) distribution [98]. The main purpose of DRL is minimizing the radiation dose levels without sacrificing image quality. It is necessary for every MIT to be aware of CT radiation dose values and compared them with the established CT DRL levels, especially for pediatric patients. While the patient dose is particularly influenced by variations in the weight-and-body size, most of recommended pediatric CT DRLs are age-specific and so, they are not easy to be applied in clinical practice [51]. The European DRLs for pediatric CT are presented in Table 1 [100].

Table 1: European DRLs for pediatric CT

CT examination	Age (years)	DRL ($CTDI_{vol}$, mGy)
Head	5	38
	15	60
Thorax	5	5.6
	15	6.9
Abdomen	5	5.7
	15	14

Automatic exposure control (AEC)

Adjusting tube current based on patient weight-or-size is an accepted dose optimization strategy in CT [101-104]. MITs could manually adjust the tube current or automatically using automatic exposure control (AEC) [105]. When AEC is to be applied, the tube current would be automatically modulated by taking into account the patient size, shape and body composition based on the scanogram or data gathered from previous rotation, or by combination from both these methods [106]. It needed the MITs to specify a desired image quality in term of image noise or optimal tube current for a reference patient; then the scanner automatically adjusts tube current [60,105]. AEC technology can decrease the patient dose by 20-40% compared to a fixed tube current set up [37]. However, the patient should be positioned at the isocenter of gantry otherwise the radiation dose would be increase [106]. In order to prevent the potential loss in image quality in the larger and obese patients, the radiation dose may needed to be increase [105]; however presence of adipose tissue would result in absorption the small part of the dose before reaching to the internal organs [107,108]. Although the basic principles of AEC are identic, its name and method of use may be different in various CT scanners [105]. Therefore, it is important for every MIT to learn how to work by AEC system to tune the exposure dose for different body parts [70]. Inappropriate use of AEC may be associated with increasing patient's dose [91].

Accept noisier images as long as it does not affecting patient care

Although images at higher dose look better than in lower dose images, however, they expose patients to higher radiation dose [70]. Reducing the radiation dose by 50% may slightly increase inhomogeneity of CT images; however, it does not influence patient diagnosis [41]. Radiologists and referring physicians should learn to accept noisier images whenever possible [47,70]. The patient absorbed dose could be declined by 30% follow accepting 20% image noise [63]. In abdominal CT, reducing the patient dose from 12.6 mGy to 4.2 mGy has been reported without loss of diagnostic image quality [70]. Moreover, it is not necessary the entire of scan field has a desired image quality. Based on clinical question, the radiation dose distribution should be modulated, so that the anatomical regions that are not clinically interest received lower radiation dose compared to the anatomical regions which are clinically interest [91]. Figure 1 presented the influence of accepting image noise on patient dose during abdominal CT.

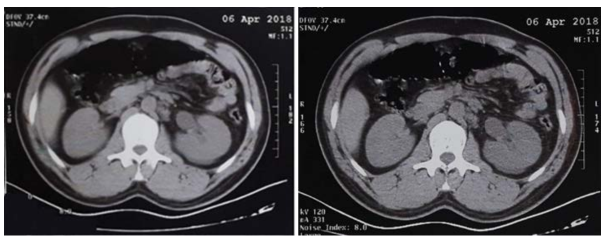

Figure 1: High dose levels may not significantly increase image quality. A) Scan at 120 kVp and 320 mAs, $CTDI_{vol}$ of 17.50 mGy; the dose is unnecessarily high. B) Scan at 100 kVp and 250 mAs, $CTDI_{vol}$ of 10.22 mGy; the dose is lower and adequate for diagnosis. Images originated from the main hospital of Dezful, Iran

Use of indication-specific CT protocols for each body region

It is necessary for every MIT to use of indication-specific CT protocols for each body region, when it was possible and appropriate. For example, for lung nodule follow up or kidney stones, it is not necessary to use of routine or general protocols (i.e. routine chest and abdomen

CT). In these cases, the use of indication-specific CT protocols result in 50% to 75% reduction in radiation dose compared to the routine or general protocols [70].

Shielding

Shielding is one of the fundamental methods used to radiation dose reduction [5,109-111]. Bismuth shields and lead shields are the most common shields used during CT examinations. Bismuth shields serves as an additional filtration, placed on the anterior aspect of the radiosensitive tissues (i.e. the lens of the eyes, breast, thyroid gland and gonad), and intended to reduce radiation exposure from the anterior position of the areas which are clinically interest and should be appear in the image. Since the use of bismuth shield is associated with beam hardening artifacts on the shield-air interface and may decrease image quality, Hohl et al. [112] have suggested and demonstrated that placement a 1 cm cotton as a spacer between the shield and patients can improve image quality by shifting the beam hardening artifact outside the body. The radiation dose reduction of 40% to 67% [113-116] and 30% to 40% [117,118] has been reported following use of bismuth shields during CT of adults and pediatrics, respectively. Note that bismuth shield do not contribute to the attenuation of X-ray beam from posterior and lateral directions, so it can decrease anterior organ dose not actual organ dose. Therefore, some of these reports may be overestimated of the actual organ dose reduction of bismuth shield. Unlike bismuth shields, lead shields intended to reduce radiation exposure from the areas which are not clinically interest and located outside of the radiation field. For example, breast shielding during head and neck CT. According to Beaconsfield et al. [119], the thyroid and breast dose could be reduced by 45% and 76% respectively, following use of lead shields in brain CT. Although the effectiveness of shielding has been highlighted in the literatures, anecdotal evidence and our experience indicated that shielding often forgotten when positioning a CT patient [5,14]. Moreover, the American Association of Physicists in Medicine (AAPM) has recently published a policy statements in which the effectiveness of bismuth shields has been challenged due to wasting some of the radiation, degradation of image quality, unpredictable and potentially undesirable results when combining with AEC [120]. The AAPM recommended considering other technologies such as organ-based and global TCM and IRT, instead of bismuth shields. However, a 2017 systematic review of data from 56 such studies similarly showed until these alternative dose optimization strategies become available in all CT centers, bismuth shielding remains a viable dose reducing strategy [74].

Gantry angulation during brain CT

Brain CT is one of the most frequent CT examinations that contribute to the radiation exposure to the lens of the eyes [14]. The standard protocol for brain CT is starting the scan range from the base of skull to the end of vertex, so removal the eye lens from the scan field. The angulation of gantry has shown to can reduce radiation exposure to the lens of the eyes during routine brain CT (Figure 2). When the gantry is angled, the lens of the eyes remove from the primary radiation field and the dose to the lens is solely due to scattered radiation. According to McLaughlin and Mooney [116], this is an accepted dose optimization strategy in the UK. The radiation dose reduction of 75% [75] to 90% [116] has been reported follow the gantry angulation during brain CT. However, it is not a commonplace practice and frequently ignored during brain CT, especially in emergency departments. Some MITs believe that angulation of gantry would resulted in wasting the time and may decline the optimal lifetime of CT scanner. However, based on discussion with CT engineers, we found that gantry angulation has a negligible effect on the lifetime of CT scanner.

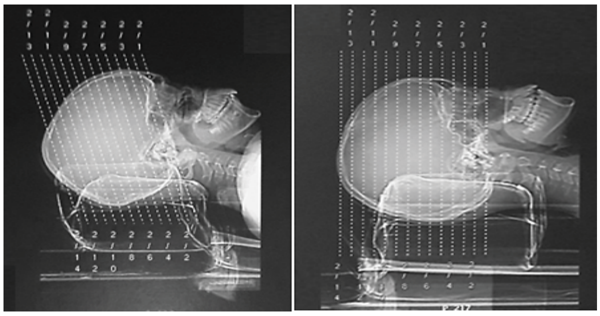

Figure 2: A pediatric brain CT with (A) and without (B) gantry angulation. Removal the lens of the eyes follow 15° gantry angulation. Images originated from the picture archiving and communication system (PACS) of the main hospital of Dezful, Iran

Optimization the scanogram and scan length

Any CT examination is started with a scanogram or scout view, which referred to the extent of irradiated body region or scan length. Optimization the scanogram is one of the important and simplest dose reduction methods that always ignored during CT, especially after implementation of spiral CT scanners in clinical settings [48]. In a retrospective study, Campbell et al. [121] assessed additional exposures beyond the area of diagnostic interest during chest CT and found that 97% and 98% of images had additional exposures at the cranial and caudal regions, respectively. Since most of the radiosensitive tissues are located at the anterior position of the body (i.e. lens of the eyes, thyroid gland, breast and gonad), it is recommended that the scanogram to be performed in the poster-anterior (PA) projection, so locating the X-ray tube under the CT table when the patient position to be supine [66]. According to Mahrooqi et al. [51], this practice can reduce patient dose by more than 30% compared to when the X-ray tube located up to the CT table. For any CT examination, the scan length should be restricting to the area of diagnostic interest, especially for pediatric CT, considering the smaller body size. This rule is true for both the scout view and the rotational scan when there is no value to continuing the scan length [11]. For example, in lung CT, it is not justifiable to including upper half of abdomen or entire thoracic inlet and thyroid gland [121], or in pelvic CT, there is a rarely medical reason for including the testes in the scan field. The start and end points of scout view is pre-programmed in the CT scanners for every CT examination; however, they are not specific to patient's age and body length (Figure 3). Moreover, in patients with multiple CTs of the same region such as the brain, ear and Para nasal sinus, the study can be performing with a singular scanogram.

Figure 3: A scanogram of a 9-year-old pediatric patient underwent chest CT. The scan length is too long; result in unnecessarily radiation exposure to the neck, abdomen and pelvic region. Image originated from the PACS of the main hospital of Dezful, Iran

Pitch ratio

The pitch ratio is defined as the increment of CT table per 360° rotation of X-ray tube, divided into slice thickness or beam collimation that specified to helical CT scanners [47,48,63]. The relationship between the pitch and patient dose is inversely [33]. Higher pitch ratio would result in lower radiation dose [33,47,70]. According to Vade et al. [122], reducing the patient dose by 33% is achievable follow increasing the pitch from 1:1 to 1.5:1. However in some CT scanners, it is not practical to apply very high pitch ratios, since increasing the image noise will be a problem, especially in pediatric patients [37,51]. If very high pitch ratios to be use, the tube current will be increase proportionally [33]. In these situations, IRT may be the method of choice to optimize image quality and patient dose [51].

Gantry speed

One of the main challenges in pediatric CT is noncooperation of patients during data acquisition and so introduction of motion artifact that is the potential source of image unsharpness [51]. In some emergency cases, the pediatric should undergo anesthesia for sedation. Hence, the use of short gantry rotation time (faster gantry rotation speed) may be applied for pediatric CT to suppress these issues [123]. However, it may influence image quality by increasing image noise; therefore increasing the tube current may be needed to improve image quality [48]. Accordingly, before selecting gantry rotation time, the balance between patients' dose and image quality should be taken into account.

Gantry geometry

The patient dose and image noise are influenced by variations in the geometry of CT scanner. With other parameters constant, increasing the distance between X-ray tube and the center of gantry would result in decreasing radiation intensity, so decreasing patient dose and increasing image noise [48]. This increased level of noise usually does not influence patient care. Evidence showed that introduction of 20% noise level may not influence diagnostic image quality, however it can decrease patient dose by nearly 30% [63]. However, this option is depends on the design and configuration of CT scanner.

Filters

The X-ray photons are generated as a polychromatic (multi-energetic) spectrum; meaning that some of the incident photons lay in the low energy levels. These low-energy photons do not play a role in image formation but only absorbed by the patient and increase dose [33,47,48,124]. CT scanners are equipped with filters to absorb these low-energy photons in the incident beam before reaching the patient and thus decreasing the patient dose [48,51,91]. Due to the cross-sectional of human body is oval in shape; attenuation of incident beam is less efficient in the thinner or peripheral regions than in the center [91,125]. Various filters has been evaluated by the literatures, however, the eligibility of bowtie or beam shaping filters has been highlighted. These filters has potentially minimize the patient dose by concentrating the incident X-ray beam in the central regions [47,91]. The radiation doe reduction of 50% has been reported following use of bowtie or beam shaping filters than in flat filters [33,126]. However, the pediatrics-specific bowtie filters may not be commercially available due to bowtie filters are usually specified for the use in adult patients [125]. Note that the effectiveness of bowtie filters is particularly influenced by proper positioning the patient at the center of gantry [127]. This is particularly crucial for pediatric patients, considering their small body size that allows more chance to located off-center of gantry. The pediatric body should place at the center of gantry, otherwise the patient dose would be increased [51,65,91,128,129]. Moreover, off-centering is accompanying with increasing image noise [33]. A phantom study by Li et al. [130] showed that 3 cm and 6 cm off-centering were increased the surface and peripheral phantom dose by 12%-18% and 41%-49%, respectively. Therefore, more care should be taken for positioning the pediatric patients at the isocenter of gantry.

CONCLUSION

In the recent years, the potential danger of CT has been the focus of many scientific and media literatures. CT is associated with a small but significant risk for increasing the lifetime risk of developing cancer, especially in pediatric patients and it may be a public health issue in the next years. However, the benefits of medically indicated CTs are greatly more than the associated health risks. CT radiation dose optimization protocols are necessary to be applied by referring physicians, radiologists, medical physicists, MITs and CT manufacturers, in particular. Follow the guidelines described in this study can significantly reduce patients' dose and the associated health risks.

CONFLICT OF INTEREST

All authors declare that there is no conflict of interest.

REFERENCES

1. Krille L, Zeeb H, Jahnen A, et al. Computed tomographies and cancer risk in children: A literature overview of CT practices, risk estimations and an epidemiologic cohort study proposal. Radiat Environ Biophys 2012; 51:103-11.
2. Mettler Jr FA, Wiest PW, Locken JA, et al. CT scanning: Patterns of use and dose. J Radiat Prot 2000; 20:353-9.
3. Brenner D, Hall E. Computed tomography: An increasing source of radiation exposure. N Engl J Med 2007; 357:2277-84.
4. Smith BJ, Adhami RR. Medical imaging. Computerized tomography. IEEE Potentials 1998; 17:9-12.
5. Voress M. The increasing use of CT and its risks. Radiol Technol 2007; 79:186-90.
6. Shah NB, Platt SL. ALARA: Is there a cause for alarm? Reducing radiation risks from computed tomography scanning in children. Curr Opin Pediatr 2008; 20:243-7.
7. Miglioretti DL, Johnson E, Williams A, et al. The use of computed tomography in pediatrics and the associated radiation exposure and estimated cancer risk. JAMA Pediatr 2013; 167:700-7.
8. Su YP, Niu HW, Chen JB, et al. Radiation dose in the thyroid and the thyroid cancer risk attributable to CT scans for pediatric patients in one general hospital of China. Int J Environ Res Public Health 2014; 11:2793-803.
9. Ogbole G. Radiation dose in paediatric computed tomography: Risks and benefits. Ann Ib Postgrad Med 2010; 8:118-26.
10. Brenner DJ, Elliston CD, Hall EJ, et al. Estimated risks of radiation-induced fatal cancer from pediatric CT. Am J Roentgenol 2001; 176:289-96.
11. Donnelly LF, Emery KH, Brody AS, et al. Minimizing radiation dose for pediatric body applications of single-detector helical CT: Strategies at a large children's hospital. Am J Roentgenol 2001; 176:303-6.
12. Linet MS, Slovis TL, Miller DL, et al. Cancer risks associated with external radiation from diagnostic imaging procedures. CA Cancer J Clin 2012; 62:75-100.
13. Liu D, Khong P. Radiation protection in paediatric computed tomography revisited. Hong Kong J Radiol 2016; 19:166-99.
14. Karami V, Zabihzadeh M. Prevalence of radiosensitive organ shielding in patients undergoing computed tomography examinations: an observational service audit in Ahvaz, Iran. Asian Biomed 2015; 9:771-5.
15. International Atomic Energy Agency. Dosimetry in diagnostic radiology for paediatric patients. Internat Atomic Energy Agency 2013.
16. Rehani MM, Bongartz G, Kalender W, et al. Managing patient dose in computed tomography. Ann ICRP 2000; 30:7-45.
17. De González AB, Mahesh M, Kim KP, et al. Projected cancer risks from computed tomographic scans performed in the United States in 2007. Arch Intern Med 2009; 169:2071-7.
18. Mathews JD, Forsythe AV, Brady Z, et al. Cancer risk in 680,000 people exposed to computed tomography scans in childhood or adolescence: Data linkage study of 11 million Australians. BMJ 2013; 346:1-18.
19. Rice HE, Frush DP, Farmer D, et al. Review of radiation risks from computed tomography: Essentials for the pediatric surgeon. J Pediatr Surg 2007; 42:603-7.
20. Chen JX, Kachniarz B, Gilani S, et al. Risk of malignancy associated with head and neck CT in children: A systematic review. Otolaryngol Head Neck Surg 2014; 151:554-66.
21. Karami V, Zabihzadeh M, Keshtkar M, et al. Evaluation of the entrance surface dose (ESD) and radiation dose to the radiosensitive organs in pediatric pelvic radiography. Int J Pediatr 2017; 5:5013-22.
22. Institute NC. Radiation risks and pediatric computed tomography (CT): A guide for health care providers. NCI Division of Cancer Epidemiology and Genetics Rockville, MD 2008.
23. Almohiy H. Paediatric computed tomography radiation dose: A review of the global dilemma. World J Radiol 2014; 6:1-6.
24. Sun Z, Ng K, Sarji S, et al. Is utilisation of computed tomography justified in clinical practice? Part IV: Applications of paediatric computed tomography. Singapore Med J 2010; 51:457-63.
25. den Harder AM, Willemink MJ, Budde RP, et al. Hybrid and model-based iterative reconstruction techniques for pediatric CT. Am J Roentgenol 2015; 204:645-53.
26. Karami V, Zabihzadeh M, Shams N, et al.

Radioprotection to the gonads in pediatric pelvic radiography: Effectiveness of developed bismuth shield. Int J Pediatr 2017; 5:5153-66.

27. Karami V, Zabihzadeh M, Gholami M, et al. Dose reduction to the thyroid gland in pediatric chest radiography. Int J Pediatr 2016; 4:2183-91.
28. Karami V, Zabihzadeh M, Shams N, et al. Optimization of radiological protection in pediatric patients undergoing common conventional radiological procedures: Effectiveness of increasing the film to focus distance (FFD). Int J Pediatr 2017; 5:4771-82.
29. Sodickson A, Baeyens PF, Andriole KP, et al. Recurrent CT, cumulative radiation exposure, and associated radiation-induced cancer risks from CT of adults. Radiol 2009; 251:175-84.
30. Pearce MS, Salotti JA, Little MP, et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: A retrospective cohort study. Lancet 2012; 380:499-505.
31. www.nytimes.com/2014/01/31/opinion/we-are-giving-ourselves-cancer.html
32. www.newsweek.com/2014/04/11/death-rays-248079.html
33. Zacharias C, Alessio AM, et al. Pediatric CT: Strategies to lower radiation dose. Am J Roentgenol 2013; 200:950-6.
34. Miller DL. The ALARA principle in medical imaging. Philos 1983; 44:595-600.
35. Dowd SB, Tilson ER. Practical radiation protection and applied radiobiology. WB Saunders 1999.
36. Cohen MD. CT radiation dose reduction: Can we do harm by doing good? Pediatr Radiol 2012; 42:397-8.
37. McCollough CH, Primak AN, Braun N, et al. Strategies for reducing radiation dose in CT. Radiol Clin 2009; 47:27-40.
38. Zabihzadeh M, Karami V. Letter to editor: Poor collimation in digital radiology: A growing concern. IJMU-EJOURNAL 2016; 11:29-30.
39. Strauss KJ, Kaste SC. The ALARA (as low as reasonably achievable) concept in pediatric interventional and fluoroscopic imaging: Striving to keep radiation doses as low as possible during fluoroscopy of pediatric patients-A white paper executive summary. Radiol 2006; 240:621-2.
40. Brenner DJ. Slowing the increase in the population dose resulting from CT scans. Radiat Res 2010; 174:809-15.
41. Vock P, Wolf R. Dose optimization and reduction in CT of children. Radiation dose from adult and pediatric multidetector computed tomography: Springer; 2007:223-36.
42. Peña BMG, Cook EF, Mandl KD, et al. Selective imaging strategies for the diagnosis of appendicitis in children. Pediatr 2004; 113:24-8.
43. Deck MD, Henschke C, Lee BC, et al. Computed tomography versus magnetic resonance imaging of the brain a collaborative interinstitutional study. Clin Imaging 1989; 13:2-15.
44. Malfair D, Beall DP. Imaging the degenerative diseases of the lumbar spine. Magn Reson Imaging Clin 2007; 15:221-38.
45. Hörmann M, Paya K, Eibenberger K, et al. MR imaging in children with nonperforated acute appendicitis: Value of unenhanced MR imaging in sonographically selected cases. AJR Am J Roentgenol 1998; 171:467-70.
46. www.iaea.org/sites/default/files/documents/rpop/poster-ct-appropriate-referrals.pdf
47. Alsafi K. Radiation protection in X-ray computed tomography: Literature review. Int J Radiol Imaging Technol 2016; 2:1-5.
48. Kalra MK, Maher MM, Toth TL, et al. Strategies for CT radiation dose optimization. Radiol 2004; 230:619-28.
49. Kim J-E, Newman B. Evaluation of a radiation dose reduction strategy for pediatric chest CT. AJR Am J Roentgenol 2010; 194:1188-93.
50. Yu L, Bruesewitz MR, Thomas KB, et al. Optimal tube potential for radiation dose reduction in pediatric CT: Principles, clinical implementations, and pitfalls. Radiographics 2011; 31:835-48.
51. Al Mahrooqi KMS, Ng CKC, Sun Z, et al. Pediatric computed tomography dose optimization strategies: A literature review. J Med Imaging Radiat Sci 2015; 46:241-9.
52. Huda W, Scalzetti EM, Levin G, et al. Technique factors and image quality as functions of patient weight at abdominal CT. Radiol 2000; 217:430-435.
53. Boone JM, Geraghty EM, Seibert JA, et al. Dose reduction in pediatric CT: A rational approach. Radiol 2003; 228:352-360.
54. Siegel MJ, Schmidt B, Bradley D, et al. Radiation dose and image quality in pediatric CT: Effect of technical factors and phantom size and shape. Radiol 2004; 233:515-22.
55. Cody DD, Moxley DM, Krugh KT, et al. Strategies for formulating appropriate MDCT techniques when imaging the chest, abdomen, and pelvis in pediatric patients. AJR Am J Roentgenol 2004; 182:849-59.
56. Ertl-Wagner BB, Hoffmann R-T, Bruning R, et al. Multi-detector row CT angiography of the brain at various kilo voltage settings. Radiol 2004; 231:528-35.
57. Sigal-Cinqualbre AB, Hennequin R, Abada HT, et al. Low-kilovoltage multi-detector row chest CT in adults: Feasibility and effect on image quality and iodine dose. Radiol 2004; 231:169-74.
58. Funama Y, Awai K, Nakayama Y, et al. Radiation dose reduction without degradation of low-

contrast detectability at abdominal multisection CT with a low–tube voltage technique: Phantom study. Radiol 2005; 237:905-10.

59. Kalva SP, Sahani DV, Hahn PF, et al. Using the K-edge to improve contrast conspicuity and to lower radiation dose with a 16-MDCT: A phantom and human study. Journal of computer assisted tomography 2006; 30:391-7.
60. Zoltowski P. Techniques to lower CT dose. Nepalese J Radiol 2013; 2:55-8.
61. Nakayama Y, Awai K, Funama Y, et al. Abdominal CT with low tube voltage: Preliminary observations about radiation dose, contrast enhancement, image quality, and noise. Radiol 2005; 237:945-51.
62. Nievelstein RA, van Dam IM, van der Molen AJ, et al. Multidetector CT in children: Current concepts and dose reduction strategies. Pediatr Radiol 2010; 40:1324-44.
63. Healthcare G. A guide to ct radiation dose management. Developed in conjunction with Weill Cornell imaging at NewYork–Presbyterian 2018.
64. Siegel MJ, Hildebolt C, Bradley D, et al. Effects of automated kilovoltage selection technology on contrast-enhanced pediatric CT and CT angiography. Radiol 2013; 268:538-47.
65. Yu L, Fletcher JG, Grant KL, et al. Automatic selection of tube potential for radiation dose reduction in vascular and contrast-enhanced abdominopelvic CT. Am J Roentgenol 2013; 201:297-306.
66. Strauss KJ, Goske MJ, Kaste SC, et al. Image gently: Ten steps you can take to optimize image quality and lower CT dose for pediatric patients. Am J Roentgenol 2010; 194:868-73.
67. Winklehner A, Goetti R, Baumueller S, et al. Automated attenuation-based tube potential selection for thoracoabdominal computed tomography angiography: Improved dose effectiveness. Invest Radiol 2011; 46:767-73.
68. Hough DM, Fletcher JG, Grant KL, et al. Lowering kilovoltage to reduce radiation dose in contrast-enhanced abdominal CT: Initial assessment of a prototype automated kilovoltage selection tool. Am J Roentgenol 2012; 199:1070-7.
69. McCollough CH, Bruesewitz MR, Kofler Jr JM, et al. CT dose reduction and dose management tools: Overview of available options. Radiographics 2006; 26:503-12.
70. www.iaea.org/sites/default/files/documents/rpop/poster-ct-radiation-protection.pdf
71. McCollough C, Zink F, Kofler J, et al. Dose optimization in CT: Creation, implementation and clinical acceptance of size-based technique charts. Radiol 2002: Radiological Soc North America 820 Jorie BLVD, Oak Brook, IL 60523 USA.
72. Valentin J. Managing patient dose in multi-detector computed tomography (MDCT). Elsevier 2007.
73. Sorantin E, Weissensteiner S, Hasenburger G, et al. CT in children–dose protection and general considerations when planning a CT in a child. Eur J Radiol. 2013; 82:1043-9.
74. Lawrence S, Seeram E. The current use and effectiveness of bismuth shielding in computed tomography: A systematic review. Radiol Open J 2017; 2:7-16.
75. Nikupaavo U, Kaasalainen T, Reijonen V, et al. Lens dose in routine head CT: Comparison of different optimization methods with anthropomorphic phantoms. AJR Am J Roentgenol 2015; 204:117-23.
76. Matsubara K, Sugai M, Toyoda A, et al. Assessment of an organ-based tube current modulation in thoracic computed tomography. J Appl Clin Med Phys. 2012; 13:148-58.
77. Hoang JK, Yoshizumi TT, Choudhury KR, et al. Organ-based dose current modulation and thyroid shields: Techniques of radiation dose reduction for neck CT. AJR Am J Roentgenol 2012; 198:1132-8.
78. Kim YK, Sung YM, Choi JH, et al. Reduced radiation exposure of the female breast during low-dose chest CT using organ-based tube current modulation and a bismuth shield: Comparison of image quality and radiation dose. AJR Am J Roentgenol 2013; 200:537-44.
79. Lai N, Chen T, Tyan Y, et al. Off-centre effect on dose reduction to anterior surfaces with organ-based tube-current modulation. Radiat Meas 2013; 59:155-9.
80. Shuman WP, FSCBTMR F. Iterative reconstruction in CT: What does it do? How can i use it? Image Wisely 2010; 44:35-7.
81. Beister M, Kolditz D, Kalender WA, et al. Iterative reconstruction methods in X-ray CT. Physica Medica: Eur J Med Phys 2012; 28:94-108.
82. Hara AK, Paden RG, Silva AC, et al. Iterative reconstruction technique for reducing body radiation dose at CT: Feasibility study. Am J Roentgenol 2009; 193:764-71.
83. Padole A, Ali Khawaja RD, Kalra MK, et al. CT radiation dose and iterative reconstruction techniques. Am J Roentgenol 2015; 204:384-92.
84. Lange K, Carson R. EM reconstruction algorithms for emission and transmission tomography. J Comput Assist Tomogr. 1984; 8:306-16.
85. Shepp LA, Vardi Y. Maximum likelihood reconstruction for emission tomography. IEEE Trans Med Imaging 1982; 1:113-22.
86. Qi J, Leahy RM. Iterative reconstruction techniques in emission computed tomography. Phys Med Biol 2006; 51:541.
87. Fessler JA. Penalized weighted least-squares image reconstruction for positron emission tomography. IEEE Trans Med Imaging 1994; 13:290-300.

88. Nuyts J, De Man B, Dupont P, et al. Iterative reconstruction for helical CT: A simulation study. Phys Med Biol 1998; 43:729.
89. Lasio GM, Whiting BR, Williamson JF, et al. Statistical reconstruction for x-ray computed tomography using energy-integrating detectors. Phys Med Biol 2007; 52:2247.
90. Thibault JB, Sauer KD, Bouman CA, et al. A three-dimensional statistical approach to improved image quality for multislice helical CT. Med Phys 2007; 34:4526-44.
91. Trattner S, Pearson GD, Chin C, et al. Standardization and optimization of CT protocols to achieve low dose. J Am Coll Radiol 2014; 11:271-8.
92. Moscariello A, Takx RA, Schoepf UJ, et al. Coronary CT angiography: Image quality, diagnostic accuracy, and potential for radiation dose reduction using a novel iterative image reconstruction technique-comparison with traditional filtered back projection. Eur Radiol 2011; 21:2130.
93. Becce F, Salah YB, Verdun FR, et al. Computed tomography of the cervical spine: Comparison of image quality between a standard-dose and a low-dose protocol using filtered back-projection and iterative reconstruction. Skeletal Radiol 2013; 42:937-45.
94. Yanagawa M, Honda O, Kikuyama A, et al. Pulmonary nodules: Effect of adaptive statistical iterative reconstruction (ASIR) technique on performance of a computer-aided detection (CAD) system-Comparison of performance between different-dose CT scans. Eur J Radiol 2012; 81:2877-86.
95. Baker ME, Dong F, Primak A, et al. Contrast-to-noise ratio and low-contrast object resolution on full-and low-dose MDCT: SAFIRE versus filtered back projection in a low-contrast object phantom and in the liver. Am J Roentgenol 2012; 199:8-18.
96. Schulz B, Beeres M, Bodelle B, et al. Performance of iterative image reconstruction in CT of the paranasal sinuses: A phantom study. Am J Neuroradiol 2013; 34:1072-6.
97. Noël PB, Renger B, Fiebich M, et al. Does iterative reconstruction lower CT radiation dose: evaluation of 15,000 examinations. PloS one 2013; 8:811-41.
98. Toossi MTB, Malekzadeh M. Radiation dose to newborns in neonatal intensive care units. Iran J Radiol 2012; 9:145.
99. International Commission on Radiological Protection (ICRP). Radiological protection and safety in medicine. ICRP 1996; 26.
100. www.sirm.org/download/2011
101. Huda W, Bushong SC, Hendee WR, et al. In X-ray computed tomography, technique factors should be selected appropriate to patient size. Med Phys 2001; 28:1543-5.
102. Frush DP. Strategies of dose reduction. Pediatr Radiol 2002; 32:293-7.
103. Huda W, Lieberman KA, Chang J, et al. Patient size and X-ray technique factors in head computed tomography examinations. I. Radiation doses. Med Phys 2004; 31:588-94.
104. Huda W, Lieberman KA, Chang J, et al. Patient size and X-ray technique factors in head computed tomography examinations. II. Image quality. Med Phys 2004; 31:595-601.
105. Singh S, Kalra MK, Thrall JH, et al. Automatic exposure control in CT: Applications and limitations. J Am Col Radiol 2011; 8:446-9.
106. Gudjonsdottir J, Svensson J, Campling S, et al. Efficient use of automatic exposure control systems in computed tomography requires correct patient positioning. Acta Radiologica 2009; 50:1035-41.
107. Kalender WA, Wolf H, Suess C, et al. Dose reduction in CT by anatomically adapted tube current modulation. II. Phantom measurements. Med Phys 1999; 26:2248-53.
108. Schmidt R, Kalender W. A fast voxel-based Monte Carlo method for scanner-and patient-specific dose calculations in computed tomography. Physica Medica 2002; 18:43-54.
109. Curtis JR. Computed tomography shielding methods: A literature review. Radiol Technol 2010; 81:428-36.
110. Karami V, Zabihzadeh M, Gholami M, et al. Gonad shielding for patients undergoing conventional radiological examinations: Is There cause for concern? Jentashapir J Health Res 2016; 7.
111. Karami V, Zabihzadeh M, Gilavand A, et al. Survey of the use of X-ray beam collimator and shielding tools during infant chest radiography. Int J Pediatr 2016; 4:1637-42.
112. Hohl C, Wildberger J, Süß C, et al. Radiation dose reduction to breast and thyroid during MDCT: Effectiveness of an in-plane bismuth shield. Acta Radiologica 2006; 47:562-7.
113. Hein E, Rogalla P, Klingebiel R, et al. Low-dose CT of the paranasal sinuses with eye lens protection: Effect on image quality and radiation dose. Eur Radiol 2002; 12:1693-6.
114. Hopper KD. Orbital, thyroid, and breast superficial radiation shielding for patients undergoing diagnostic CT. Seminars in Ultrasound, CT and MRI. Elsevier 2002.
115. Hopper KD, Neuman JD, King SH, et al. Radioprotection to the eye during CT scanning. Am J Neuroradiol 2001; 22:1194-8.
116. McLaughlin D, Mooney R. Dose reduction to radiosensitive tissues in CT. Do commercially available shields meet the users' needs? Clin Radiol 2004; 59:446-50.
117. Fricke BL, Donnelly LF, Frush DP, et al. In-plane bismuth breast shields for pediatric CT: Effects

on radiation dose and image quality using experimental and clinical data. Am J Roentgenol 2003; 180:407-11.

118. Perisinakis K, Raissaki M, Tzedakis A, et al. Reduction of eye lens radiation dose by orbital bismuth shielding in pediatric patients undergoing CT of the head: A Monte Carlo study. Med Phys 2005; 32:1024-30.
119. Beaconsfield T, Nicholson R, Thornton A, et al. Would thyroid and breast shielding be beneficial in CT of the head? Eur Radiol 1998; 8:664-7.
120. citeseerx.ist.psu.edu/viewdoc/download;jsessionid=83F7695031532942696C6F93C256AF39?doi=10.1.1.231.4997&rep=rep1&type=pdf
121. Campbell J, Kalra MK, Rizzo S, et al. Scanning beyond anatomic limits of the thorax in chest CT: Findings, radiation dose, and automatic tube current modulation. Am J Roentgenol 2005; 185:1525-30.
122. Vade A, Demos TC, Olson MC, et al. Evaluation of image quality using 1:1 pitch and 1.5:1 pitch helical CT in children: A comparative study. Pediatr Radiol 1996; 26:891.
123. Fukuda A, Lin PJP, Matsubara K, et al. Measurement of gantry rotation time in modern ct. J Appl Clin Med Phys 2014; 15:303-8.
124. Karami V, Zabihzadeh M. Review on the radiation protection in diagnostic radiology. Tehran Univ Med J 2016; 74:457-66.
125. Costello JE, Cecava ND, Tucker JE, et al. CT radiation dose: Current controversies and dose reduction strategies. Am J Roentgenol 2013; 201:1283-90.
126. Toth TL. Dose reduction opportunities for CT scanners. Pediatr Radiol 2002; 32:261-7.
127. Callahan MJ. CT dose reduction in practice. Pediatr Radiol 2011; 41:488.
128. Brisse HJ, Robilliard M, Savignoni A, et al. Assessment of organ absorbed doses and estimation of effective doses from pediatric anthropomorphic phantom measurements for multi-detector row CT with and without automatic exposure control. Health Phys 2009; 97:303-14.
129. Kalra MK, Maher MM, Kamath RS, et al. Sixteen–detector row CT of abdomen and pelvis: Study for optimization of Z-axis modulation technique performed in 153 patients. Radiol 2004; 233:241-9.
130. Li J, Udayasankar UK, Toth TL, et al. Automatic patient centering for MDCT: Effect on radiation dose. Am J Roentgenol 2007; 188:547-52.