Review article

Computed Tomography Dose Reduction in Children: Review Paper

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Received on 05.11.2019, accepted for publication on 21.01.2020, (Doi : dx.doi.org/10.5455/mjhs.2020.02.014)

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Abstract

Background:
Increasing the needs of Computed Tomography (CT) for children is quietly augmented over the last decades, although it's one of the most important modalities in diagnostic finalization. However, it carries a higher risk for the patient in term of radiation dose and cancer risk due to higher sensitivity to radiation than the adult.

Aim:
This study was conducted to review the multiple methods of dose reduction technique as presented by different authors where the different scanning protocols, machine and types of the studies were presented

Methods:
Here, more studies and books were selected, where they are carefully summarized and outlined into different categories for which the result stated that; the most frequent examination done in the CT department is head, neck, and sinuses in which where taken as an example of dose reduction methods.

Results:
The use of the most modern technical advances was recommended in order to optimize the dose level, comfortable, constants (anesthesia if required) position and using low number of phases as possible according to the pathology of interest (low phases with better visualizations), scanning with thin collimation and view thicker as possible, increasing pitch, automatic exposure control, only the area of interest should be examined, with low tube voltage and using of tube current modulation system can give better result of dose reduction and there were multiple methods presented here.

Conclusion:
Where is most important for radiologist, technicians, and the person who conduct such studies to increase their knowledge in radiation protection, technical advances and how to interpret the different CT protocols.

Keywords:
Radiation, Children, Dose Reduction, computed tomography.

الملخص

خلفية:
ازدادت الحاجة الى التصوير المقطعي (CT) للأطفال بشكل ملحوظ خلال العقود الماضية؛ وعلى الرغم من أنها واحدة من أهم الطرائق لوضع اللمسات الأخيرة على التشخيص، لكنها تحمل الكثير من المخاطر على المريض من حيث جرعة الإشعاع ومخاطر السرطان بسبب الحساسية العالية للإشعاع مقارنة بالبالغين.

هدف الدراسة:
تهدف الدراسة الحالية لمراجعة الطرق المتعددة لتقنية تخفيض الجرعة كما قدمها كثير من الباحثين والمؤلفين، حيث تم استعراض بروتوكولات المسح المختلفة، وآلة المسح المستخدمة، ونوع الدراسات التي تم تطبيقها.

طريقة البحث:
تطرقنا في المنهجية الى الكثير من الدراسات والكتب، حيث تم تلخيصها وترتيبها بعناية في فئات مختلفة كما هو موضح في النتائج. والفحص الأكثر شيوعًا الذي تم إجراؤه في قسم التصوير المقطعي المحوسب شمل الرأس والرقبة والجيوب الأنفية، حيث تم أخذ مثال على طرق تخفيض الجرعة.

النتائج:
توصي الدراسة باستخدام أحدث التطورات التقنية من أجل تحسين وضع الجرعة، وتوفير الراحة، والثبات (التخدير إذا لزم الأمر)، واستخدام عدد قليل من المراحل قدر الإمكان وفقًا لمتطلبات علم الأمراض الذي يهتم بعدد المراحل القليل مع تصورات أفضل)، والتصوير المتوازي الرقيق، ورؤية أكثر سمكا بقدر الإمكان، وزيادة درجة الاهتزاز، والتحكم التلقائي في التعرض الاشعاعي، ويجب فحص مجال الاهتمام فقط، مع الجهد المنخفض للأنبوب واستخدام نظام تعديل جهد تيار الأنبوب، والذي يمكن أن يعطي نتيجة أفضل لتخفيض الجرعة، حيث عرضنا أكثر من طريقة ضمن هذه الورقة البحثية.

الخلاصة :
من المهم بالنسبة لأخصائيين الأشعة والفنيين والشخص الذي يجري مثل هذه الدراسات السعي لزيادة معرفتهم في الحماية من الإشعاع والتقدم التقني وكيفية تفسير البروتوكولات المختلفة.

Introduction:

A variety of doses has been reported for computed tomography investigations of the same area. Such variations caused by using different scan procedures as well as different dose units. Increasing the values of CT in diagnosis of a majority of body disease in case of CT brain, chest abdomen and neck in addition to the bony structure of the body in both cold and urgent cases, leads to increasing the use of CT over other routine x-ray and MRI examination. Therefore, with increasing the number of scans needs for such case where contrast scan additional to the routine axial scan could resulting for more radiation exposure dose due to multi and high doses scans. Thus, dose reduction technique allows for acceptable image quality and lower radiation doses [1].

Many researches of minimizing radiation exposure during CT scans concluded the possibilities of using decreased dose in imaging of high contrast as in case of lung scans with same image performances and no any loss of information effecting the diagnosis[2]. Still not yet clear if low dose protocols could be used in areas of low contrast CT studies as in cases of intracranial brain constructions. In similar cases of child brain abnormalities, a reduction of 'standard' image considerations due to lower dose protocols could be occurred and possible in such CT investigations [3].

Image technicalities.

Its main aim must be to gain a high-quality image performance rather than only optimizing a protocol with a decreased radiation exposure to the child. In addition to implementation of ALARA principle with good image quality. Inappropriately, up to now no stablished intensities of CT noise descriptions have been believed adequate for investigative dedications, particularly in children.

Minimum stages and collimation:

avoidance of multistage and dependence of pre-contrast imaging is important; If further characterization of a lesion by multiple pre- and post-CM phases is indicated, these scans should be kept to a minimum, and a low dose technique often will suffice [4, 5]. Furthermore, other imaging modalities such as US or MRI should be used if possible. On other hand; Small children need thin collimation, but this will increase the image noise and as small children usually lack visceral fatty tissue, less noise can be tolerated than in adolescents and adults. Therefore, the choice of collimation depends on the clinical question and size of the patient and should balance the necessary z-axis resolution, gain in three-dimensional (3-D) reformatting possibilities, noise level and low radiation dose level. The higher noise level usually can be solved by using the "scan thin view thick" approach while interpreting the images. Also using small FOV as possible that gives higher spatial resolution, as the pixel size decreases with smaller FOV.

Pitch:

An increase in the playing field outcomes in a shorter scan time and (in some scanner types) in a dose reduction for the patient. But this is not the best option in MDCT; this is explained by the negative dose effects of the so-called over-ranging which will be exaggerated by increasing the pitch. Furthermore, the spatial resolution will decrease by increasing the pitch. In those scanner types in which effective mAs is used, an increase in pitch will result in an increase in the tube current. Therefore, it is usually more dose efficient to keep the pitch as low as possible (<1) and if needed manually decrease the tube current, in order to achieve a similar tube current/pitch ratio (effective mAs) as would be the case with a higher pitch.

Tube Power (voltage - kVp):

According to the reduced size of children, lower voltage with maintaining the image quality is required. In most children a tube voltage of 80–100 kVp will suffice, especially in children with a body weight <45 kg. Adolescents, a tube voltage of 100 kVp for the thorax and 120 kVp for the abdomen is usually sufficient. However, the scanner-related parameters, such as, scanner geometry, tube filtration, detector design and efficiency, sometimes negatively influence the image quality with lower tube voltages, for instance by inducing artifacts. Recent studies with phantoms suggest that the optimal tube voltage in children may be even lower (approximately 60 kVp), at least for some indications.

Current of the Tube (mA):

decreasing the tube current will directly decrease the dose. But increasing the noise is a major drawback, but so the adapted selection of noise is acceptable [6]. Although several studies in phantoms have shown that the mA can be halved for each 3.5- to 4-cm reduction in body diameter (half value layer, HVL), in clinical practice a less stringent HVL of 4–6 cm is used in children. This is because small children usually lack large amounts of visceral fatty tissue and, therefore, less image noise is desirable. Based on the aforementioned, several body size or weight-based pediatric CT protocols have been suggested [7, 8, 5 , 9].

Tube spinning:

Majority of recent MDCT scanner models with a tube rotation times of 0.3 -to- 0.5 seconds giving a shorter investigation time. This is beneficial to children by reduction in movement and respiration artifacts. Nevertheless, minding that a shorter spins period can produce a reduced number of profiles that will be used in image rebuilding, concerning the increase of the noise image. Then a spinning time of 0.5 seconds is the option of choice for image quality. Concerning the procedures of radioactive dose modulation, approximately all recent MDCT scanners are now fitted out with some type of programmed exposure control (AEC) or Automatic Tube Current Modulation (ATCM) system. Such a systems are acting as a dynamic tube current controller during the process of scanning then adjustable and modified to the body building constructed geometry. By this way, an improved image performances and quality can be gained because of the decreasing of constant noise level and radiation exposure. Variation in models is conceivable for axial horizontal plane (XY-modulation as well as angular), or joined systems [10].

The procedure and settings of various models are different [10,11]. Some medical systems recommended using the old good quality images as quality control for new investigations. By using ATCM methods, a drop of radiation exposure received by individual patient is commonly achievable [12,13]. Depending on operators the dose will optimized. For example, if ATCM is used in the upper body the tube current will rise in the shoulder and liver area to keep a constant noise level.

Exposure Lessening in Head and PNS CT of Kids:

A report by Brenner et al., (2001) estimated the mortality risk for cancers as (0.18% and 0.07%) for pediatric CT abdominal and head CT respectively, which is 10-fold huger than for adult individuals (14). Their findings strongly recommended dropping the CT dosage exposure for children to the lower possible level, and not applying the same CT protocols of adults for the youngsters' population, as was a common trend at that time [15] While the CT image excellence and quality mainly dis-

tinguished X-ray fluency dependent; accordingly, pediatrics CT method factors should be reduced compared to those of adults, due to the fewer X-ray attenuation by smaller bodies of children. Consequently, similar scan performances and quality must be provided even with lower dose methodology. Furthermore, CT energy values for pediatrics are always less than for grown person [16]. Cranial CT is the investigations of high frequency in children. Around 30% of neonate's bone marrow is located in the skull, while only about 10% in adults. The marrow-absorbed high radiation exposure even more than the chest or abdomen [17]. Chan, et al., (1999) demonstrated the possibility of using lower tube current for a pediatric brain CT scan with the same image performances and quality [18]. No change in image performances recorded for seven anatomical regions with low dose image procedure. Maximum antero-posterior diameter (MAPD) was used by Wong, et al., (2001) as a respectable principle for tube current assortment to measure child head diameters [19]. Boone et al., (2003) recommended using CT system charts which depends on the body size and circumference of the child with reduced dose scanning protocols [20]. All measured statistics were taken via phantom chambers with different thicknesses. An exponential relation among X-ray diminution versus patient diameters leads to a significant dose drop in the smallest body sizes as kids [20]. Diagnostic reference levels (DRL) could be useful for modification of dose to age agreement. Such alike surveys in Europe are now in hand [21] [22]; [23].
In case of CT brain of pediatric, extra dose exposure lessening practice could be held for some signs and indications as hydrocephalus assessment [12]: a standard dose procedure is used for 'higher dose' suggestions: trauma, encephalopathy, seizure, congenital anomalies and acute neurologic deficit. Low dose CT is highly recommended even for 10-15 yrs old patient.

Dose adaptation & Lessening of CT Skull and Neck Area:

In a CT study of skull phantom done by (24) with 120 kV tube voltages, six set of investigations were done with 50 percent of mAs reduction every time. Similar research also handled with 28-fold dose reduction for coronal scan, and other of 60 volunteers in a same way subdivided to six groups each of them undergone coronal CT as for the phantom. 30 patients were scanned with lower mAs; same procedure was followed also for the phantom. The gained CT scan results were of high-quality image performances in diagnostic point of view for the lowest dose procedures. Some latest researches agreed with the finding of the earlier ones concerning the excellent and diagnostic clearness results of the low dose CT protocols [25], [26]; [27]; [28]. Conversely a modern CT system can provide an outstanding diagnosable image quality with low dose levels [27], [21]. Also mentioned, the effect of high contrast in sinus CT could allow the use of low dose protocol easily. The only challenging point is the comparison between various CT scanners because they are not suppling extra dose descriptors as CTDI or effective dose. Then, straightly comparing mAs values alone, crosswise studies with different scanners, has restrictions [29]. Also Tack et al., (2003) calculated the effective dose of these earlier described low-dose CT studies of the sinuses [1].
At eight different sinus nasal anatomical locations in mucosal deformities study, weighty divergence comments reported by three different reviewers, while the image result outcome by different dose levels showed no significant variances. This could be explained, observational dissimilarities concomitant with the reduction in dose levels, although they concluded and decided that low dose MDCT should be deliberated as routine procedure for the evaluation and assessment of chronic sinusitis. the Pediatrics Academy of USA on (2001)

recommends replacing the routine use of sinusitis imaging in case of not improved patients or/and deteriorates during treatment in addition to the event of recurrent illness (due to lack of sensitivity). CT use is almost limited to children who have very tenacious or recurrent sinus infections, not reactive to medical managing and whereby surgical procedure is considered, and for those of acute sinusitis. CT exams provide a much well detailed scan of the anatomy of sinus, which will be useful guide of surgical treatment. Aforementioned studies already presented the imprecision of radiographic diagnosis of children sinusitis in comparison to CT exams. More than 70% of the results were not in agreement with each other in around 40% of normal radiographs patients, there were signs of pathology showed on CT scans and vice versa.

While in 35% of suspicious abnormality in radiographs the CT results were normal. [30]. Another weakness of sinus radiograph is the huge variability in the interpretation and clarification between radiologists [31]. The use of sedation was often essential in youngsters to accomplish a good quality CT exam.

Many other organs could be visualized at the same time of CT sinuses as middle ear, mastoids and adenoids. Using and performing this technique of CT the whole ear, nose and throat section could be displayed in one inspection, which is impossible in radiographic exam. A weakness in sinusitis imaging is the high prevalence of soft tissue variations. [32]; [33]. Recently the Use of the tube current modulation systems in CT has been publicized for dose reduction purposes. Will significantly reduce the dose by 20-60% [34].

Cone Beam CT in the Head and Neck area: This is a new modality which is provide a dose reduction procedure and 3 dimensional images for bones of head and neck areas, also found to be very useful for follow up of cochlear implantations [35]. Other studies were used for evaluation of lung parenchyma, and lung cancer surveying programs using a significantly reduced dose protocols[36].

Interpretations of the literature:

Contemporary research indicates that (CT) procedures are a major cause of radiation exposure for patients when conducted repeatedly in the course of healthcare treatments and therapies, especially for those with chronic health conditions [37]. Demonstrative organ absorbed doses in CT are significantly lower than threshold doses for the instruction of deterministic effects. However, extended exposure following the advent of helical, fluoroscopic and multi-slice techniques exposes patients to the same levels of radiation repeatedly within different procedures, thereby significantly increasing their overall levels of radiation exposure, [38]. Furthermore, the use of CT scanning has also increased through new applications including cardiac CT, CT colonography, angiography and urology [39]. The increased frequency in the use of CT investigations from 4% to 15% of procedures along with the rise in the diagnostic radiation dose received by patients from 40% to 75 has led to a statistically important increase in malignance occurrence related to scanning [14], [39], [40], [37].

According to Dougeni et al., (2012) most physicians underestimate the exposure risk for patients, as evidenced by the increased use of CT scans on children and the limited implementation of exposure parameters considering the clinical question under investigation and the patients' size [39]. Hence, dose reduction in pediatric CT scanning demands significant attention to prevent high-risk radiation exposure among children [40]. Alarmingly, only 43% of image departments acknowledge having adjusted CT parameters for children [41]. Furthermore, the reasons for conducting pediatric CT scans sometimes fail to confirm their necessity. According to Donnelly (2005), unnecessary pediatric CT scans are a public health

problem in America [41].

In their study, Hollingsworth et al., (2003) discovered that 11–26% of CT examinations of children younger than nine years of age were done using more than 150mA, while 20–25% of radiologists did not adequately understand the specific parameters for the helical CT scans of the body they oversaw [42]. Ironically, pediatricians have limited power to effectively manage the levels of radiation exposure their patients receive when undergoing CT scans since it remains the role of the radiologists conducting the scan [43]. Consequently, pediatricians mainly focus on educating the patient's family on the potential dangers of CT scanning and limit recommending its use until an absolute necessity [43].

Bischoff et al., (2009) argue that radiation doses of 6.4–27.8mSv are adequate for spiral CT angiography image acquisition [44]. However, the international Prospective Multicenter Study on Radiation Dose estimates of Cardiac CT Angiography I maintains the optimal median dose-length-product as 885mGy. cm, with an effective radiation dose of 12mSv.

The technical considerations in radiation dose management generally focus on optimizing the trade-offs between noise, artefacts, scanning speed and contrast [45]. There are several factors worth considering when determining dose reduction measures during CT scans in paediatric care. According to Yu et al., (2011), the process depends on the size of the patient and the diagnostic task being conducted. The main limitations are the scanner speed and the power limits of the CT scanner [45]. In their study, critically evaluated the use of automatic exposure control and optimal tube potential in improving image quality and reducing the radiation dose in pediatric CT examinations. They argue that low tube potential improves contrast enhancement and reduces radiation exposure for children, even though their use increases noise output during the process [5], [45]. One effective strategy for reducing the radiation dose in pediatric CT scanning involves hybrid interactive reconstruction. Singh et al., (2009) compared the effectiveness of hybrid interactive reconstruction and the conventional filtered back projection and determined that hybrid interactive reconstruction such as hybrid adaptive statistical iterative reconstruction (ASIR) reduced the radiation dose significantly without adversely affect the quality of the images or diagnostic confidence when analyzed.

Similarly, Lee et al., (2012) compared radiation dose reduction among pediatric patients undergoing chest CT scans when using ASIR and filtered back projection. They found that the CT dose index decreased by 60.3% from 18.73 to 7.43 mGy, the dose-length product decreased by 56.2% from 307.42 to 134.51mGy x cm and the effective dose decreased by 55.2% from 4.12 to 1.84 mSv compared to the filtered back projection results [46].

Contrastingly, Lee et al., (2012) analyzed the effectiveness of a kilo-voltage (Kvp)-lowering strategy in mitigating dose reduction on chest CT scans for children, where Kvp was reduced from 120 to 80 for children below 15 kg and reduced to 100 for children 15–60 kg at a reduced mA rating of 65–55 mA. The CT dose index, dose-length product and effective dose reduced by 73%, 75% and 73%, respectively, for children below 15 kg. The measures declined by 45%, 44% and 48%, respectively, for children 15–60 kg [46].

Another innovative strategy for radiation dose reduction in pediatric CT scanning is model-based iterative reconstruction (MBIR). According to GE Healthcare (2012), MBIR is superior to both filtered back projection and ASIR due to its capacity to develop multiple iterations using multiple models. Unlike filtered back projection, MBIR analyses the x-ray beam in three different ways: at its focal spot, as it passes through the body and at the level of the x-ray detector. It uses these three points to create three-dimensional representa-

tions of the areas scanned using multiple iterations. The MBIR algorithm models two parts of the CT system: the system statistics, including noise and system geometry or optics. Moreover, CT scanning using MBIR can take from 5–40 minutes, depending on the amount of data required and the complexity behind reconstructing an image from the data beam analysis [48]. Hence, the image quality is superior to both ASIR and filtered back projection.

Conclusions:

There was greater challenge meeting us in CT for the babies where the adjustment of protocols to implement the better imaging sequence with low dose to the patient, where it need much knowledge and carful parameter selection in addition to the use of advance technical improvement as mentions can lead to the safe scan with better quality of imaging and diagnosis.

Key points:

• CT is one of sensitive tools for diagnosing many of child's disease, more frequently than other method medical imaging (e.g. Brain CT). so increasing the sensitivity of radiations among baby's lead to increase the cancer risk so dose reduction techniques should be considered.

• Children are more sensitive to radiation than adults they need significant dose reduction (low dose) and separate CT protocols for each part of the baby body. (Low dose CT is highly recommended even for 10-15yrs old patient).

• Small size, with accurate collimations, low mAs as possible, lower Kvp and increasing pitch they consider important in philosophy of dose reductions.

• Using of new technological advances such as effective mAs, ASIR, and automatic tube current modulations ATCM are greatly reduce the amount of received dose by child's body.

• Reducing the number of scans and specifying the dose into its specific area is consider significant in term of radiation induced soft tissue toxicity.

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