Radiation Dose Reduction in Pediatric Chest CT: BMI-based kVp as an Adjunct Method

Poster No.: C-2550
Congress: ECR 2013
Type: Scientific Exhibit
Authors: V. Derderian¹, J. R. Q. W. Siegelman², M. Mahesh³, R. Evers¹, D. A. Bluemke¹, L. R. Folio¹; ¹Bethesda, MD/US, ²New Haven, CT/US, ³Baltimore, MD/US
Keywords: Dosimetric comparison, Radiation safety, Diagnostic procedure, CT, Radioprotection / Radiation dose, Paediatric, Management
DOI: 10.1594/ecr2013/C-2550

Any information contained in this pdf file is automatically generated from digital material submitted to EPOS by third parties in the form of scientific presentations. References to any names, marks, products, or services of third parties or hypertext links to third-party sites or information are provided solely as a convenience to you and do not in any way constitute or imply ECR's endorsement, sponsorship or recommendation of the third party, information, product or service. ECR is not responsible for the content of these pages and does not make any representations regarding the content or accuracy of material in this file.

As per copyright regulations, any unauthorised use of the material or parts thereof as well as commercial reproduction or multiple distribution by any traditional or electronically based reproduction/publication method ist strictly prohibited.

You agree to defend, indemnify, and hold ECR harmless from and against any and all claims, damages, costs, and expenses, including attorneys' fees, arising from or related to your use of these pages.

Please note: Links to movies, ppt slideshows and any other multimedia files are not available in the pdf version of presentations.

www.myESR.org
Introduction:

Machine improvements result in technological advances that can improve image quality without increase in radiation dose. However, many older scanners cannot be retrofit with these technological capabilities and global distribution of these innovations is unlikely. Recent large epidemiologic works demonstrate that children are at increased risk of carcinogenesis from ionizing radiation in general and in particular from CT scanning. At the United States National Institutes of Health, children are enrolled in clinical trials, some of which involve serial exposure to varied levels of radiation exposure and thus may be particularly vulnerable. To address this concern, a multidisciplinary team developed a CT dose reduction strategy adaptable for implementation across multiple vendor platforms. We present our strategy that reduced radiation exposure and dose and appears to be universally applicable across multiple CT vendors, with no capital cost and minimal implementation cost.

Purpose:

Using body mass index (BMI) to determine kVp setting for clinical CT scanning provides a dose reduction method that maintains diagnostic image quality. In addition to automatic exposure control mAs modulation (AEC), the NIH Clinical Center Department of Radiology and Imaging Sciences instituted BMI-based kVp adjustment for chest CT in October 2010. To examine program efficacy, estimated effective radiation dosage (2009-2012) and dose length product (DLP), a metric of radiation exposure, was assessed in a contiguous sample of pediatric patients receiving protocol-indicated annual chest CTs. The radiation dose and exposure were compared at the baseline date (2009) to the most recent scan (2012).
Methods and Materials

Methods:

A multi-disciplinary, inter-institutional radiation dose reduction team was developed in 2009 that included radiologists, radiologic technologists, physicists, administrators and all staff involved in CT workflow (reception, IV team, CT nursing, etc.).

In October of 2010, the first dose reduction trials began with close monitoring to assure no compromise of image quality when lowered to 100 kVp. By December 2010, success at 100 kVp led to further reduction to 80 kVp in smaller children. Initial resistance to use of 80 kVp was diminished in light of continued image quality maintenance and no need for repeated series. Although an age range guide was considered, one of the research populations (Chronic Granulomatous Disease) commonly exhibited growth delays; hence the development of a BMI-based reduction approach including protocols for both 100kVp and 80kVp dose reduction in children.

Two radiologists vetted CT technical protocols as suitable for lower kVp imaging in children; external expertise and experience was sought from several universities and hospital centers to further tailor protocols for our patient populations. The plan was developed with stakeholders, the internal radiology team, and referring clinicians via intranet and quarterly CT newsletters. Internal (radiology staff) and external (Clinical Center) Intranet and newsletter were used to communicate changes, dose risk (CT dose vs. CXR, versus cross-continent flights, etc.), and the availability of new procedures. This communication disseminated the information to a wider audience of clinical staff, further educating hospital providers (and their patients) on the scope of our patient safety efforts. Continuous feedback from department radiologists alerted to monitor quality during the initial dose reduction efforts, in addition to inputs from referring physicians, allowed for assuring maintenance of excellent quality. These measures were piloted by image review with two NIH body radiologists.

Technologists were trained on the effect of lowered kVp on CTDIvol and DLP. They were educated in the BMI calculation, and the intervention: a BMI based kVp reduction method. A simple chart was used to identify the kVp to be selected based on patient BMI (Figure 1). Laminated charts were conspicuously placed in the control room. Each computer generated the patient's clinical requisition sheet with listed current weight and height as well as reminder charts with the BMI/kVp grid (Figure 2). Based on this table, technologists manually adjusted the kVp on existing scanner protocols as an adjunct to AEC. Protocols were adjusted for the intervention to take full advantage of each scanners' unique AEC properties (i.e. each scanner used a reference mAs for the AEC target and none of the scanners utilized a constant image noise model for
exposure control) on four CT models: Siemens Somatom Definition 64, Philips Brilliance 64, GE Lightspeed 8, and Toshiba Aquilion One. During the period of study no unit was de-installed. Routine software upgrades occurred, but no technologic dose lowering solutions (iterative reconstruction, etc.) were applied in these exams.

IRB exemption for retrospective study of radiation dose was obtained. Retrospective chart review was performed on 50 consecutive pediatric clinical trial patients in August-September 2012. Those children with one or more chest CT annually (2009-2012) and available dose summary reports from PACS were selected (n = 14) for analysis in this study. It should be noted that cases with dose reduction applied were not hand selected.

Height and weight data were extracted from patient data/requisition sheets scanned into PACS; dose data was manually extracted from dose reports and then anonymized. Exposure levels (mGy * cm), estimated effective doses (mSv), the presence or absence of repeated series, and the use of AEC were calculated based on BMI and PACS dose summary reports (DLP by phantom size, kVp, scanner) using age and site-specific conversion factors (Thomas, 2008). Data from baseline scans pre (2009) and post (2012) intervention was then compared; data from 2010 and 2011 was not included due to inconsistent kVp application in the implementation phase. Diagnostic quality was defined as no "repeated series, images or exams within 24 hours" and "adequate to be interpreted", with a report without caveat available in the medical record.

Patients:

Pediatric patients were enrolled in clinical trials with diagnoses of Chronic Granulomatous Disease (9), Hyper IgE (Job's) Syndrome (2), X-linked Severe Combined Immunodeficiency (2), and Cystic Fibrosis (1), with increased susceptibility to lung infections. Age at enrollment ranged from 6y1m to 18y8m (17y2m mean, 4y4m standard deviation, 19y0m median), M:F 12:2. Body Mass Index (BMI) at enrollment ranged from 12.4-27.2 (18.6 mean, 4.1 standard deviation, 18.8 median).

Statistics:

For each patient, baseline values (2009) of estimated effective dose, DLP, and weight were compared with post-intervention values (2012) using a two-tailed paired t-test.
Fig. 1: The BMI-kVp chart allows at-a-glance determination of appropriate kVp setting based on patient BMI. A BMI calculation spreadsheet containing this chart is available at each computer and is posted in the control room.

© Radiology and Imaging Sciences, National Institutes of Health, Clinical Center - Bethesda/US
**Fig. 2:** The technologist chart for BMI kVp adjustment is included in each patient demographics/requisition form for each scan. Patient demographic sheets also include height, weight, and age, as well as standard clinical information. These sheets are scanned into PACS along with the dose sheet as part of the patient medical imaging record.

© Radiology and Imaging Sciences, National Institutes of Health, Clinical Center - Bethesda/US
Results

BMI-based kVp adjustment resulted in significantly reduced dose delivery with maintenance of diagnostic image quality; most patients showed # to ½ dose reduction over baseline exams. Baseline kVp was 120 for all exams, while modified kVp ranged from 80 kVp to 120 kVp. All exams (n=28) were of diagnostic quality without repeated series; post intervention, 64% of scans had BMI-indicated kVp reduction applied, compared with no kVp reduction pre-intervention.

To date, our dose reduction strategy has not resulted in a need for a repeat exam or series due to inadequate quality. See Figure 3 and 4 for same patient representative images at various kVp reduction ranges. Demonstration of dose and DLP differences in all patients sampled (n = 14) can be viewed in Figure 5 and 6. All but three patients had lower doses in 2012. With our intervention, approximately half of the children received half of their 2009 dose in 2012, and one third of children received one third of their 2009 dose in 2012 (Figure 5).

Both a statistically significant reduction in DLP (mean difference=93.5, SD=126.8, t=2.76, p=0.0162) and the related derived metric of effective dose (mean difference=1.43, SD=1.96, t=2.73, p=0.0171) was obtained, despite the each of the patient’s statistically significant interval increase in weight (mean difference=7.24, SD=6.78, t=3.99, p=0.0015).

Mean DLP (mGy·cm) based on 32 cm phantom was 285 (2009) and 192 (2012); Mean effective dose (mSv) was 4.208 (2009) and 2.771 (2012). 11 of 14 patients (79%) had lower effective dose in 2012 than baseline, despite expected increase in patient size due to normal growth. Patients whose dose increased (3 of 14) did not have kVp lowering applied; two of these patients had a BMI increase of four points or more. Iterative reconstruction was not applied in any patients in this study.
Fig. 3: Patient 5 Summary (2009): 17y2m male, height 138.6 cm, weight 38.9 kg, BMI 20.2. At 120 kVp: DLP (exposure)= 208mGy*cm, estimated dose=2.912 mSv. Lung window of "Patient 5" scans from 2009-2012 highlight right middle lobe atelectasis/focal consolidation. Note the maintenance in acceptable image quality between the pre-kVp adjustment images on the left (2009, 2010; both at 120 kVp) and post-kVp adjustment images on the right (2011, at 100 kVp, 2012 at 80 kVp).

© Radiology and Imaging Sciences, National Institutes of Health, Clinical Center - Bethesda/US
Fig. 4: Patient 5 Summary (2009): 17y2m male, height 138.6 cm, weight 38.9 kg, BMI 20.2. At 120 kVp: DLP (exposure) = 208mGy*cm, estimated dose = 2.912 mSv. Soft tissue window of "Patient 5" scans from 2009-2012. Note that despite increased image noise at 80 kVp, all tests were of acceptable quality for lung and soft tissue assessment, with no series or scans repeated due to quality compromise.

© Radiology and Imaging Sciences, National Institutes of Health, Clinical Center - Bethesda/US
**Fig. 5:** With our BMI-based kVp lowering intervention, approximately half of the children received half of their 2009 dose in 2012, and one third of children received one third of their 2009 dose in 2012. Of the three children with higher doses, none had kVp lowering applied. Two of the children with higher dose had an increase in BMI of four points or more; one had higher dose due to lack of AEC (machine malfunction).

© Radiology and Imaging Sciences, National Institutes of Health, Clinical Center - Bethesda/US
Fig. 6: Trends in DLP reduction reflect those of dose reduction using our intervention. Approximately half of the children received half of their 2009 DLP in 2012, and one third of children received one third of their 2009 DLP in 2012. Of the three children with higher DLP, none had kVp lowering applied. Two of the children with higher DLP had an increase in BMI of four points or more; one had higher DLP due to lack of AEC (machine malfunction).

© Radiology and Imaging Sciences, National Institutes of Health, Clinical Center - Bethesda/US
**Fig. 7:** An example of two individual patients demonstrating decreased dose over baseline and at three time points. Increased doses in the second time period were in the year of implementation.

© Radiology and Imaging Sciences, National Institutes of Health, Clinical Center - Bethesda/US
Conclusion

Discussion:

Radiation dose from medical diagnostic imaging has increased in recent years (NRCP, 2009), in a large part due to increasing CT exams since the advent of MD (Multi-Detector) CT in the late 1990's (IMV, 2007). Approximately 80 million CT's are done annually (three-fold since 1998) in the US with 7 million performed on children. A recent study on a large population of children demonstrated a three-fold risk in leukemia and brain cancers (Pearce, 2012). The Joint Commission published a Sentinel Event Alert in August 2011 (SEA #47) providing guidance in dose monitoring and reduction techniques and practices (Joint Commission, 2011).

A team approach to reducing radiation dose is paramount (Siegelman, 2012); making changes to technical protocols in isolation could have unintended consequences. Our dose monitoring and reduction team is currently compiling dose data over the last five years at the National Institutes of Health Clinical Center. In addition to verifying dose reduction with efforts such as BMI based kVp, as mentioned above, many other strategies are in various stages of implementation, including reduction of exams from increased diligence in exam protocling. Iterative reconstruction, dual energy, and protocol optimization are being performed with increasing frequency. Additional strategies include appropriateness review with increased communications with ordering physicians and focused assessment of required scan phases to answer clinical questions with appropriate protocol amendments. For example, routine non-contrast passes were eliminated for follow-up in certain metastatic diseases. Another study of BMI based kVp dose reduction is ongoing with pediatric Chest, Abdomen and Pelvis CT scans.

Limitations:

This study was performed on a small sample of patients scanned. Accurate height data may be difficult to obtain in significantly dysmorphic children; standard BMI calculations may not be an appropriate assessment tool. Dose report quality and presence in the PACS was limited in early years due to lack of standardization of automatic sending which resulted in a limitation of sample size. The outcome of "no repeated exams" or "adequate to be interpreted" introduce a potential limitation as it represents a surrogate value for true image quality; no metric was measured for image noise, however, same patient representative images at various kVp (Figure 3, Figure 4) demonstrate that the quality needed to evaluate clinically important information was not compromised.

This technique may be challenging to implement as certain CT units AEC features are tied to an objective standard of image noise. In those cases this technique may not
result in radiation exposure reduction, due to scanner compensation with increased mAs. Inconsistent application of AEC may lower effectiveness when BMI-based kVp adjustment is applied in concert. Consistent application of kVp adjustment is dependent on the technologist "remembering" to adjust the scanner per protocol; this lack of automated application introduces the potential for human error.

Through implementation of this widespread "across-the-board" strategy, the radiology department worked toward increasing technologist and provider dose knowledge base and acceptance of low dose initiatives at the NIH. This quality initiative advanced the ideology of "right dose" in a conspicuous way both within our department, educating technologists and radiologists, as well as to our referring clinicians through asking their input as to whether a lower dose strategy was acceptable to answer their clinical question. We believe our multidisciplinary team and education approach will allow for continued exposure auditing and resultant dose lowering that most sites around the world can implement with minimal cost.

**Conclusion:**

Doses were successfully reduced in our population of pediatric chest CT scans. Tailoring kVp to an objective metric of body habitus offers an additional machine-independent effective dose reduction method that complements AEC. Our multi-disciplinary, inter-institutional team approach allowed for close monitoring of image quality during a staged dose reduction initiative. In our experience, 100 or 80 kVp can offer 1/3 to 1/2 dose reduction, respectively, in chest CT for children, without repeated exams due to quality compromise. This is particularly important in our hospital where children in research trials that are immunocompromised are subject to serial CT scans to rule out or follow infections. Our strategy reduces radiation exposure and dose in an algorithmic, easily disseminated manner which may be universally applicable to CT scanners, providing patient benefits with no capital cost and low implementation cost.
References