Original article

Whole spine CT for evaluation of scoliosis in children: feasibility of sub-milliSievert scanning protocol

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Abstract

Background: Optimization of CT radiation dose is important for children due to their higher risk of radiation-induced adverse effects. Anatomical structures with high inherent contrast, such as bones can be imaged at very low radiation doses by optimizing scan parameters.

Purpose: To assess feasibility of sub-milliSievert whole spine CT scanning protocol for evaluation of scoliosis in children.

Material and Methods: With approval of the ethical board, we performed whole spine CT for evaluation of scoliosis in 22 children (age range, 3–18 years; mean age, 13 years; 13 girls, 9 boys) on a 128-slice dual source multidetector-row CT scanner. Lowest possible quality reference mAs value (image quality factor for xy-z automatic exposure control or xyz-AEC, CARE Dose 4D) was selected on a per patient basis. Remaining parameters were held constant at 3.0:1 pitch, 128 $\times$ 0.6 mm detector collimation, 115.2 mm table feed per gantry rotation, 100 kVp, and 1 and 3 mm reconstructed sections. Average mAs, projected estimated dose savings with AEC, computed tomography dose index volume (CTDI vol), and dose length product (DLP) were recorded. Artifacts were graded on a four-point scale (1, no artifacts; 4, severe artifacts). Ability to identify vertebral and pedicular contours, and measure pedicular width and degree of vertebral rotation was graded on a three-point scale (1, unacceptable; 3, excellent).

Results: All CT examinations were deemed as reliable for identifying vertebral and pedicular contours as well as for measuring pedicular width (5.9 $\pm$ 1.6 mm) and degree of vertebral rotation (28.7 $\pm$ 23.4°). Mean objective image noise and signal to noise ratio (SNR) were 57.5 $\pm$ 21.5 and 4.7 $\pm$ 2.3, respectively. With a mean quality reference mAs of 13, the scanner employed an average actual effective mAs of 10 $\pm$ 3.8 (range, 6–18 mAs) with an estimated radiation dose saving of 43.5 $\pm$ 16.3% with xyz-AEC compared with fixed mAs. The mean CTDI, DLP, and estimated effective doses were 0.4 $\pm$ 0.1 mGy (0.2–0.7 mGy), 21 $\pm$ 10 mGy.cm (8–41 mGy.cm), and 0.3 $\pm$ 0.1 mSv (0.12–0.64 mSv), respectively.

Conclusion: Radiation dose for whole spine CT for evaluation of scoliosis in children can be minimized to less than one-third of a milliSievert while maintaining diagnostic image quality.

Keywords: CT, scoliosis, radiation dose, automatic exposure control

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Reduction of radiation dose from medical imaging is especially important for children who are at higher risk of developing radiation-induced adverse effects. In particular, children who are likely to receive multiple imaging tests due to nature of their ailments or follow-up of their treatments. In recent years, heightened concerns over magnitude and inexplicable variability in radiation doses have led to several studies on ways and means to reduce radiation dose (1–4). The CT industry has stepped up its efforts to enable dose reduction while maintaining image information as well as expanding its clinical applications.

Although earlier multidetector row CT scanners had lower dose efficiency, continued increase in X-ray beam width per gantry rotation coupled with effective strategies to avoid over-beaming of X-ray beam has led to almost 98–99% dose efficiency for the advanced multidetector-row CT scanners (3). Application of different automatic exposure control techniques for automatic adaptation of tube current to maintain constant image quality at lower radiation dose has also resulted in substantial dose savings (2, 4, 5). Published studies also indicate a trend towards personalizing scanning techniques by adjusting automatic exposure control technique and kVp based on specific clinical indication and presence of prior imaging test in order to reduce radiation dose further (5).

In general, situations with high inherent contrast such as lungs and bones can be assessed at very low radiation doses by modifying scanning parameters such as tube potential, tube current, faster and non-overlapping scanning technique, as well as an appropriate reconstruction kernel (6–9). Hence, efforts should be made to optimize radiation dose for appropriately indicated CT examinations. The purpose of our study was to assess feasibility of sub-milliSievert whole spine CT scanning protocol for evaluation of scoliosis in children.

Material and Methods

Ethical considerations

Our regional ethical committee for human research approved this retrospective study of CT examinations performed for routine clinical practice. Need for written informed consent was waived by the ethical committee.

Patients

The Radiology Information System (Sectra IDS7, Sectra, Linkoping, Sweden) was reviewed to identify all 21 children (18 years or younger) who underwent whole spine CT examinations between September 1, 2009 and April 20, 2010. Mean age of these children were 13 years (range, 3–18 years, 13 girls and 8 boys). All patients were referred for known or suspected scoliotic or kyphotic deformities of the spine. Patients with metallic spinal prosthesis were excluded.

Scanning techniques

All patients were scanned on a 128-channel, dual source multidetector-row CT scanner (Siemens Definition Flash, Siemens Medical Solutions, Forchheim, Germany) as per standard of care scanning protocol for whole spine CT for suspected or known spinal deformities in children in supine position, without any external shields.

Scan range for whole spine CT extended from fourth cervical vertebra to coccyx. Scan parameters included 100 kVp, 0.28 s gantry rotation speed, 128*0.6 mm detector configuration (with z-flying focal spot), 38.4 mm beam width, 115.2 mm table feed per gantry rotation, and 3.0:1 pitch (in Flash Spiral scanning mode). The Flash Spiral scanning mode refers to non-overlapping high pitch (>1.5:1) with two X-ray sources.

To minimize radiation dose, lowest allowed quality reference mAs was used on a per patient basis (11 and 14 effective mAs). The effective mAs is defined product of tube current and gantry rotation time divided by pitch factor. Quality reference mAs is a metric of image quality used for applying the combined modulation type of automatic exposure control (CARE Dose 4D, Siemens Medical Solutions). This technique modulates tube current in both x-y axes (different angular positions around the patient) as well as along the scanning direction (longitudinal direction or z-axis) according to patient size in order to achieve desired image quality at lower radiation doses (8, 9). The selected quality reference mAs refers to desired image quality for a reference adult (defined as a 70–80 kg adult) or reference child (defined as a child weighing 20 kg). The technique then estimates patient size from the localizer radiograph and increases or decreases the tube current based on patient size being larger or smaller than the reference patient. If a pre-loaded or pre-saved protocol is selected or built from adult protocol section of the scanner user interface, tube current is modulated with reference adult as the reference image quality target, that is adults smaller than reference adult will be scanned at lower tube current and larger adults will receive higher tube current relative to the reference adult. If much smaller children are scanned with protocols archived in adult section, they are identified as very small adults and consequently will receive much lower tube current. For routine pediatric CT, thus, children are typically scanned with protocol selected from pediatric section of the user interface so that tube current is modulated according to a reference child. For example, if quality reference mAs of 100 is chosen in adult protocol section for smaller subjects (for example, a patient weighing 50 kg), scanning will occur at less than 100 mAs. If scanned within the pediatric protocol group, the same 50 kg patient will be scanned at mAs greater than 100 mAs as the reference child is much smaller at 20 kg. Thus, to minimize radiation dose, we scanned all children with scanning protocol from the adult protocol group.

Furthermore, when this modulation technique is employed, the scanner estimates projected estimated dose saving compared to scanning at fixed tube current. This information is stored as a DICOM image tag within the CT images.

Images were reconstructed using conventional filtered back projection technique at 3-mm section thickness at 3-mm interval. For three-dimensional rendering, 1-mm images were reconstructed at 0.5-mm overlap. A softer reconstruction kernel (B18s) was used for all reconstruction, which reconstructs smoother images as compared to usual soft tissue kernels (B26 to B40) or bone kernels (B50 and higher). For each study, shaded surface display and volume rendered images of the whole spine were obtained.

Radiation dose information

For each CT examination, we hexed the DICOM header information (a feature of our PACS system) to record the average mAs used with the combined modulation technique in each patient. In addition, we also recorded the

DICOM information in the CT images pertaining to the percentage-estimated dose saving with the modulation technique compared to use of fixed tube current technique.

CT dose descriptors such as the CT dose index (CTDI vol), dose length product (DLP), and phantom size were also recorded from the dose information page. Normalized effective doses for all children were determined from DLP using previously described conversion factors for CT imaging of the trunk (children >3 years to <8 years: 0.019, ≥8 years to <15 years: 0.014, ≥15 years, 0.015) (2).

Qualitative assessment of image quality

All quantitative and qualitative assessments of CT examinations were performed on two MP PACS workstation (Sectra PACS IDS7), compliant with the DICOM guidelines. Radiologist (MKK) with 12 years of expertise evaluated the images. Qualitative and quantitative assessments of scoliosis were based on criteria described in prior studies (10). Ease of identifying the contours of vertebral bodies and posterior elements for identifying normal anatomy and anomalous changes was graded on a three-point scale (1, unacceptable; 2, satisfactory; 3, excellent). Ability to measure the pedicular width of the vertex vertebra of the scoliotic curve was also graded on the same scale. In addition, ease of measuring the vertebral rotation angle in the sagittal plane was similarly graded.

Presence of any image artifacts such as helical, beam hardening, or motion was graded on a four-point scale (1, no artifacts; 2, minor artifacts with no effect on interpretation; 3, moderate artifacts with some effect on contour identification of vertebrae; 4, major artifacts causing impaired image interpretation).

Quantitative evaluation

Presence of scoliosis or kyphosis or both was noted for each patient. Vertebral rotation angle of the vertex vertebra in the sagittal plane patients with scoliosis was measured (Fig. 1). In addition, we also measured pedicular width at the level of the vertex vertebra (Fig. 1).

A circular region of interest was drawn in the vertex vertebra to measure mean CT numbers and their standard deviations in each patient (Fig. 1). A large circular region of interest was drawn in the free air outside the patient to measure the standard deviation. Signal to noise ratio (SNR) was estimated as ratio of mean CT numbers in the vertebral body by the standard deviation of the mean CT numbers.

Statistical analysis

Data were analyzed with Microsoft EXCEL (Microsoft Inc., Redmond, WA, USA). Modal scores for subjective evaluation of vertebral contours, pedicular width, and vertebral rotation angle compared to the sagittal plane were obtained. Averages and standard deviations of image noise in vertebrae as well as SNR were calculated. Pearson's correlation tests were performed to determine relationship between patient age, and CTDIvol, and DLP.

Results

Radiation dose

Average applied effective mAs with use of combined modulation technique was 10.0 ± 3.8 mAs (range, 6–18 mAs), resulting in estimated radiation dose savings of 43.5 ± 16.3% (range, 10.5–68.4%) compared to a fixed mAs protocol. There was a moderate correlation coefficient of 0.4 between patient's age and the actual mAs used in our study.

CTDI vol and DLP with the whole spine CT protocol were 0.3 ± 0.1 mGy and 21 ± 10 mGy.cm, respectively, with phantom size of 16 cm. Again a moderate correlation was noted between patient age and CTDI vol ($r^2 = 0.42$) and DLP ($r^2 = 0.57$), respectively. Between the male and female patients, there was no significant difference between CTDI vol ($P = 0.11$) and DLP ($P = 0.28$) although male patients had marginally lower CTDI vol, DLP, and estimated effective dose compared to the female patients (0.3 *vs.* 0.4 mGy, 0.27 *vs.* 0.34 mGy.cm, and 0.27 *vs.* 0.35 mSv, respectively). Average estimated effective doses normalized to patients' age with the CT examinations included in our study were 0.3 ± 0.1 mSv (range, 0.1–0.6 mSv). Total scan time for all examinations was under 1 s with scan length of 55–77.5 cm.

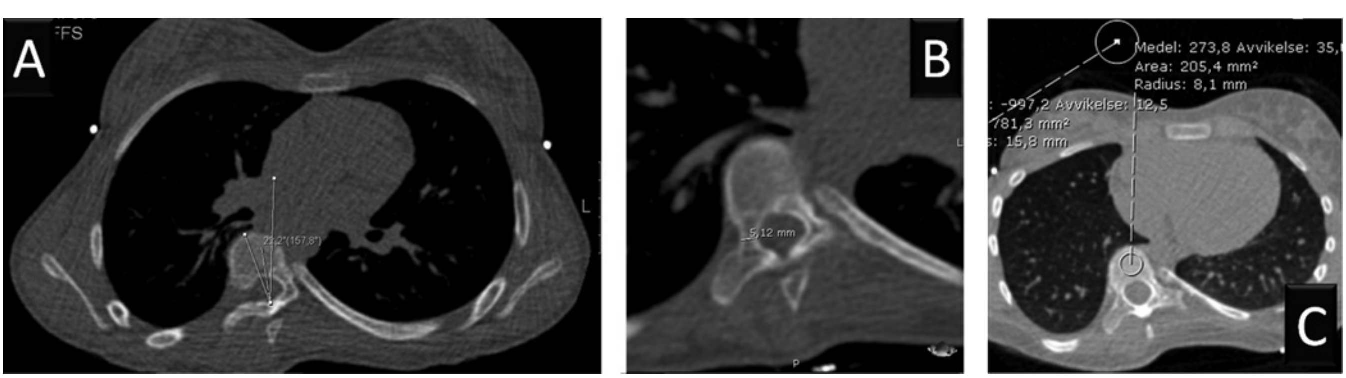

Fig. 1 Technique of measuring the vertebral rotation (a), pedicular width (b) in patients with scoliosis on the PACS workstation. (c) Sites of ROI placement in the vertebral body and air for noise and SNR estimation

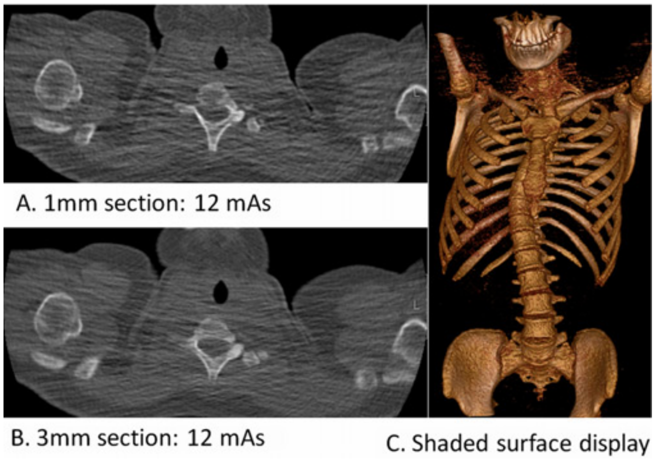

Fig. 2 Transverse CT images at 1 mm (a) and 3 mm (b) section thickness and shaded surface display (SSD) of entire spine (c) from a low radiation dose protocol CT for evaluation of scoliosis in a 14-year-old girl (CTDI vol 0.3 mGy, normalized effective dose 0.22 mSv). Increased noise affected visualization of vertebral contours on thinner images but the 3 mm images were deemed satisfactory for evaluation. Note the effect of beam hardening and low radiation dose on the SSD image as well at the level of the shoulders

Image quality

Excellent delineation of vertebral contours was noted on all studies for assessment of vertebral anomalies. Likewise, ease of measurement of pedicular width and vertebral rotation angle in the sagittal plane was rated as excellent in all CT examinations. No artifacts were seen on any of the studies although disproportionately higher noise was noted in four patients >15 years at the level of shoulders in the cervicothoracic vertebrae due to beam hardening at this level at low radiation dose (Fig. 2). This finding did not affect analysis of vertebral contours or measurement of scoliosis. None of the CT examinations had motion artifacts and no patients were given any sedation prior to CT imaging.

Average image noise in vertebral bodies and air were 57.5 ± 21.5 (range, 29–108) and 22.6 ± 18.9 (range, 13–83). Average SNR was 4.7 ± 2.3 (range, 2–12.1).

Clinical evaluation

Satisfactory clinical interpretation was possible in all patients including identification of vertebral segmentation anomalies and spinal canal defects. Scoliosis of the thoracolumbar spine was noted in 16 out of 22 patients included in our study. Three (3/22) patients had kyphosis of the lumbar spine without associated scoliosis. Three (3/22) patients had no structural or rotational deformity of the spine, of which one patient hypoplastic scapula and hypoplasia of back muscles on the left side (Fig. 3).

In patients with scoliosis, mean vertebral rotation angle of the vertex vertebra was $28.7 \pm 23.3^\circ$ (range, 10–100°). Mean pedicular width at the level of the vertex vertebra was 5.9 ± 1.5 mm (range, 4.6–8.9 mm).

Discussion

Minimization of radiation dose for a given clinical indication or patient age group requires a multipronged approach (5–7, 10, 11). While MR imaging can provide information on the spinal cord and soft tissue abnormalities, it can provide the information on osseous deformities associated with scoliosis. In comparison to radiography, CT scanning provides additional information about extent of rotation of the spine, segmentation defects, and detection of bony spur in diastomatomyelia and associated congenital anomalies of ribs, scapula, and pelvis (10). CT examinations in scoliosis patient are helpful in identifying the cause, guiding surgical planning and eventually postoperative follow-up resulting in multiple scans in the children. Recent studies with use of low-dose digital stereo radiography (EOSImaging Inc., Cambridge, MA, USA) in patients with scoliosis demonstrate efficient 3D reconstructions with the EOS imaging of the spine that provide pertinent morphological information regarding the spinal deformities with much less radiation dose compared to CT imaging (12).

In our study, we used a combination of scanning parameters to minimize radiation dose for children undergoing whole spine CT for evaluation of suspected or known spinal deformities. Compared to prior study performed at 80 kVp (0.37 mSv) for evaluation of scoliosis in children,

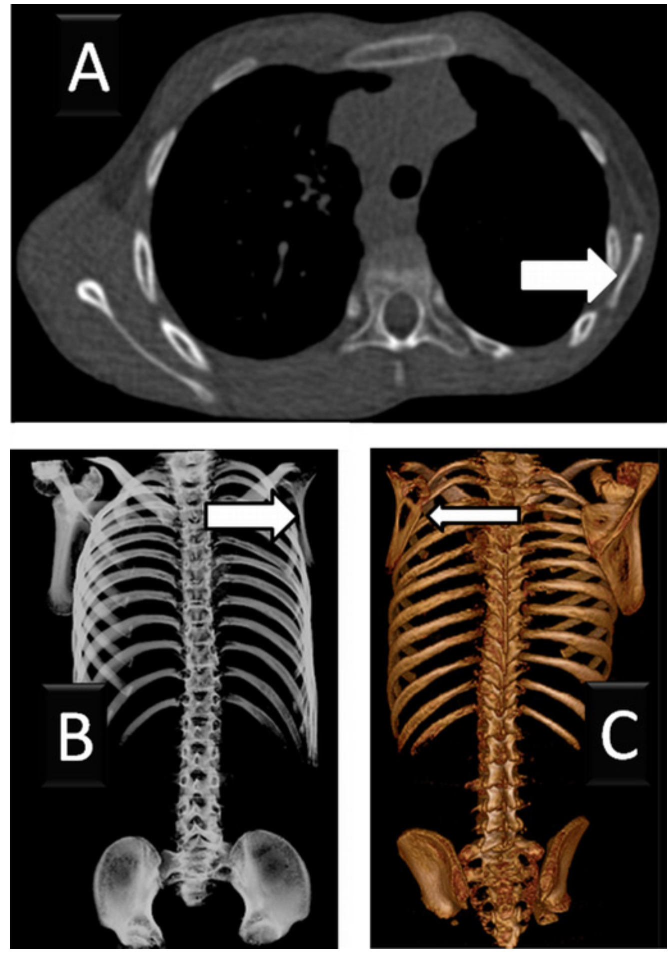

Fig. 3 Transverse CT image (a) and frontal (b) and posterior (c) shaded surface display projections of a 9-year-old boy with amelia of left upper arm referred for evaluation of whole spine (CTDI vol 0.2 mGy, normalized effective dose 0.15 mSv). There were no spinal deformities or defects but patient had severe hypoplasia of left chest wall muscles and the left scapula (arrows)

our radiation doses are probably equal or slightly lower at 100 kVp (0.3 mSv) (11).

Radiation doses with our scanning protocol are also much lower than those reported with localized cervical spine CT examination in adults with automatic exposure control technique and lower kVp (13). Conversely, our doses are about two- to three-fold higher than radiation doses observed with plain radiography of the whole spine reported in a study from the UK (0.14–0.18 mSv) (14), which suggests that more needs to be done in order to match some of the lower dose radiography studies of scoliosis. Use of lower tube potential to 80 kVp and application of recently available iterative reconstruction or noise reduction algorithms may help reduce CT radiation dose further. Likewise, reduction in organ doses can also be accomplished for CT with use of in plane shields over the gonads, breasts, and thyroid.

Our study has numerous clinical implications. First, high pitch (greater than 1.5:1 described in other published reports) and faster table speed scanning used for rapid and motion free coronary imaging can also be applied in non-cardiac indications for dose reduction (2, 10, 11). Such technique can help minimize motion artifacts or need for sedation in uncooperative young children. Second, to minimize radiation dose with combined automatic exposure control technique or Care Dose 4D for children, users must build pediatric scanning protocol from the adult protocol group so that the system employs much lower radiation dose for the children compared to much larger adult reference patient. Also, at 100 kVp, it is possible to reach radiation dose reduction achievable with 80 kVp without risking inadvertent photon starvation, which is basically the decreased amount of photons reaching to the detectors due to higher attenuation or blocking in larger children with suspected or known scoliosis. At the time of this study, iterative reconstruction techniques were not available on our scanner. When these techniques do become available, it is possible that 80 kVp may allow further dose reduction. Users should also reconstruct images with softer filtered back projection kernels compared to the sharper kernels used for routine CT scanning in order to reduce noise in images.

There are limitations in our study. We did not formally assess use of 80 kVp in our study. At the start of the study, we scanned four patients at 80 kVp while retaining other scanner parameters constant and found these studies to be extremely noisy especially at the level of the pelvis and shoulders. Therefore, it was decided to use 100 kVp to image this patient group. Also, we did not compare the effect of stratifying our patient group into different age or size group in order to avoid confusion among different technologists performing CT imaging in these patients. It is possible that image quality in smaller patients may have been acceptable at 80 kVp. Another limitation of our study is the small sample size although given the range of patients from 3 to 18 years included in our study, we do not believe that a larger sample size would have changed the outcome of the study in terms of dose saving and diagnostic acceptability of CT examinations.

A limitation of our study is that high beam pitch and fast table speed used in our study is unique to the CT equipment employed in our study. However, general concepts such as use of lowest possible mAs, lower kVp, high pitch, and automatic exposure control for minimization of radiation dose for structural abnormalities of the spine in children can be applied to other CT equipment as well. Also we did not assess the effect of our scanning protocol on patients who have large orthopedic internal metallic prosthesis. Another limitation of the study was the assessment of images by one radiologist.

An important caveat of our study was that most patients in our study had average body habitus, it is possible that in some very large children, our protocol may not provide acceptable image quality at such low levels of radiation dose. On the other hand, such situation actually underscores the relevance of using combined modulation technique instead of just one fixed lowest possible mAs. Contrary to the fixed mAs, in very large children, the combined modulation technique will increase radiation dose and possibly avoid an inadvertently noisy examination.

In conclusion, radiation dose for whole spine CT for evaluation of scoliosis in children can be minimized to less than one-third of a milliSievert while maintaining diagnostic image quality with high pitch-high speed scanning using combined modulation technique and lower kVp.

Conflict of interest: None.

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