Dose reduction using Cu-filter for full-spine radiographic examination of patients with adolescent idiopathic scoliosis

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Aims and objectives

Adolescent idiopathic scoliosis (AIS) is present in 2%-4% of children aged between 10 and 16 years (Fig. 1 on page 2). It is defined as a lateral (LAT) curvature of the spine greater than 10°, accompanied by vertebral rotation. Although the LAT curvature is the main component, it can also be associated with rotation of the spine and curvatures in different planes (1). AIS is usually first identified by a family member, during school screening or by a paediatric or family physician. Because AIS is usually painless, a fullness or prominence of the back is particularly noted while bending forward. However, as the vertebrae (spinal bones) rotate, the rib cage is affected, which in turn can compromise the heart and lungs (i.e. shortness of breath).

For evaluation of spinal curvature progression, AIS patients have to undergo radiographic full-spine examination at least once every few months. However, a previous report has suggested that exposure to X-rays during childhood and adolescence may increase the risk of breast cancer (2). Therefore, the dose of the full-spine examination should be reduced to prevent from the risk increase. Though some K-edge type filters, which offer selective spectra, have been proposed to reduce the dose of general x-ray imaging, it is noteworthy that the conventional filters with aluminium (Al) and copper (Cu) reduced the dose as efficiently as did the K-edge type filters with negligible additional tube loading (3).

The purpose of the present study was to investigate the effectiveness of a dose reduction method using Cu-filters in full-spine examination.

Images for this section:
Fig. 1: Patients with adolescent idiopathic scoliosis (AIS) surgery is usually indicated for 50° or 40° curves in skeletally immature patients, curves that progress despite bracing, and cause 'unacceptable' (to the patient) deformity.
Methods and materials

Dose measurement

The entrance surface dose (ESD) was measured using a dosimeter (Model 9015, Radcal Co., USA) with an ion chamber (10×5-6, Radcal Co.). Fig. 2 on page 5 shows the measurement geometry we used. The exposure field size was 10 cm × 10 cm. We measured ESDs for non-filter and 0.1-mm, 0.2-mm and 0.3-mm Cu filters (0.1-mm Cu, 0.2-mm Cu, and 0.3-mm Cu), using average exposure conditions of anterior-posterior (AP) (81 kV#20 mAs) and lateral (LAT) (90 kV#50 mAs) images for AIS patients. The formula for calculating the ESD is shown in Fig. 3 on page 5.

Phantom image evaluation

Image acquisition

The full-spine A-P and LAT view images of an anthropomorphic body phantom, Rando Phantom (The Phantom Laboratory, Salem, NY) were obtained by using a computed radiography system (FCR XL-2; Fuji medical systems, Tokyo, Japan) including a imaging plate (Fuji IP Cassette LC 14B2X100002000078; Fuji medical systems, Tokyo, Japan), for non-filter, 0.1-mm Cu, 0.2-mm Cu, and 0.3-mm Cu. The exposure conditions of A-P and LAT images were 81kV 20 mAs and 90 kV 90 mAs, respectively. The mAs value for LAT image was increased from the standard value of 50 mAs, because the lateral width of Rando phantom was larger than that of the standard AIS patient. Other parameters are shown in Fig. 4 on page 6.

Subjective study

Three orthopaedists independently assessed the image qualities of the full-spine A-P and LAT images. Five locations (cervical spine, C4 and C7; thoracic spine, T8 and T12; lumbar spine and L3) for A-P view and six locations (C4, C7, T8, T12, L3 and pelvic bone) for LAT view were graded using a three-point scale: 3 = superior, 2 = suboptimal, 1 = unacceptable (Fig. 5 on page 6). This scale was classified on the basis of the visually observed edge of the bone. Thus 'superior', 'suboptimal' and 'unacceptable' meant 'completely observable', 'partially observable' and 'unobservable', respectively. For each location, the score of each Cu filter was compared with that of non-filter. In addition, the average scores of all locations were compared between no filter, 0.1-mm Cu, 0.2-mm Cu, and 0.3-mm Cu images.
Fig. 2: Exposure doses were measured using an ion chamber. The chamber was placed at 60 cm above the floor to avoid influence from backscatter fractions. All measurements were made at the centre of the X-ray beam with a fixed field size 10 cm × 10 cm.

\[ ESD = \frac{W_{\text{air}}}{e} \times X \times \frac{(\mu_{en}/\rho)_m}{(\mu_{en}/\rho)_{\text{air}}} \times \text{BSF} \times (\text{SCD}/\text{SSD})^2 \]

*ESD*: Total ionizing dose (Gy)
*X*: Exposure dose (C·kg⁻¹)
\[ W_{\text{air}} \]: W value for air = 33.97 (eV)
\[ e = 1.6 \times 10^{-19} \text{ (C)} \]
\[ (\mu_{en}/\rho)_m \]: The mass energy absorption coefficient for material (m²·kg⁻¹)
\[ (\mu_{en}/\rho)_{\text{air}} \]: The mass energy absorption coefficient for air (m²·kg⁻¹)
*BSF*: Back scatter factor
*SCD*: Source chamber distance
*SSD*: Source surface distance

Fig. 3: Calculation formula of entrance surface dose (ESD)
Fig. 3: We measured the entrance surface doses (ESD) for no filter, 0.1-, 0.2- and 0.3-mm Cu filters using average exposure conditions of anterior-posterior (AP) and lateral (LAT) views of AIS patients.

- Computed radiography system: FCR XL-2 (FUJIFILM)
- Imaging plate: CR Cassette (FUJIFILM)
  384 × 868 mm/3.6 kg
- X-ray system: AXIOM Aristos MX/VX (SIEMENS)
- Cu-filters: 0.1-, 0.2- and 0.3-mm
- RANDO phantom (The Phantom Laboratory)
- Ion chamber (10 × 5–6) model 9015 (Radcal)

Radiograph settings
Anterior/posterior view (A–P): 81 kV, 20 mAs
Lateral view (L–R): 90 kV, 50 mAs and 90 mAs
  - Non copper (Cu)-filter (Non filter)
  - Copper (Cu)-filters (0.1-mm Cu, 0.2-mm Cu, and 0.3-mm Cu)
Source detector distance (SDD): 250 cm
Field size: 40 × 90 cm

Fig. 4: Materials and radiographs settings

Fig. 4: Materials and radiographs settings

A-P view
- Cervical spine: C4, C7
- Thoracic spine: T8, T12
- Lumbar spine: L3

LAT view
- Cervical spine: C4, C7
- Thoracic spine: T8, T12
- Lumbar spine: L3
- Pelvic bone

Fig. 5: Locations for subjective evaluation.
Fig. 5: Full-spine images of RANDO taken using no filter: Cu-filters were subjectively assessed by three orthopedists using a 3-point rating scale: superior, suboptimal and unacceptable.
Results

ESD

ESD of A-P views for non-filter was 0.31 mGy, whereas ESDs for 0.1-mm Cu, 0.2-mm Cu and 0.3-mm Cu were 0.16, 0.11 and 0.08 mGy, respectively. ESDs of LAT views for non-filter, 0.1-mm Cu, 0.2-mm Cu and 0.3-mm Cu were 1.67, 0.94, 0.65 and 0.49 mGy, respectively (Fig. 6 on page 8). The dose was remarkably reduced with increase of the thickness of Cu-filter.

Subjective study

For the A-P view, there were small differences in the subjective score between non filter 0.1-mm Cu, 0.2-mm Cu and 0.3-mm Cu. The score for 0.3-mm Cu tended to be lower in the location of the low thoracic and lumbar spine (Fig. 7 on page 9, Fig. 8 on page 9). The LAT view image quality (Fig. 9 on page 10, Fig. 10 on page 10) showed small differences between non filter, 0.1-mm Cu, 0.2-mm Cu, and the 0.3-mm Cu image presented significantly degraded image qualities as shown in Fig. 10 on page 10. The average score of the 0.3-mm Cu-filter image, particularly of the LAT view, was lower than those of the others (Fig. 11 on page 11). The scores of non-filter, 0.1-mm Cu, and 0.2-mm Cu were not statistically significant. As a result, it was indicated that the 0.2-mm Cu-filter could be used with approximately 60% dose reduction, maintaining the image quality of the full spine image for AIS patients.

Images for this section:
Fig. 6: Dose reduction using Cu-filters for full-spine radiography. ESDs associated with no filter, 0.1-, 0.2- and 0.3-mm Cu filters for AP and LAT views were 0.31, 0.16, 0.11 and 0.08 mGy; 1.67, 0.94, 0.65 and 0.49 mGy, respectively.

Fig. 7: A-P images and evaluated scores for non-filter and 0.1-mm Cu.
Fig. 8: A-P view images and evaluated scores for 0.2- and 0.3-mm Cu.

Fig. 8: A-P images and evaluated scores for 0.2- and 0.3-mm Cu.

Fig. 9: LAT view images and evaluated scores for non-filter and 0.1-mm Cu.

Fig. 9: LAT images and evaluated scores for non-filter and 0.1-mm Cu.
**Fig. 10:** LAT images and evaluated scores for 0.2- and 0.3-mm Cu.

**Fig. 11:** Average subjective image quality ratings of orthopedists. Small differences shown in the scores between no filter, 0.1-mm and 0.2-mm Cu-filters (AP: 2.80, 2.80 and 2.73; LAT: 2.78, 2.67 and 2.72, respectively). The 0.3-mm Cu-filter presented significantly degraded image quality (AP: 2.53 and LAT: 2.28). The 0.2-mm Cu-filter could yield satisfactory images with an approximately 60% dose reduction.
Conclusion

The 0.1-mm, 0.2-mm, and 0.3-mm Cu filters offered approximately 50%, 60%, 75% dose reductions, respectively, as compared with non-filter. The visually evaluated image quality scores of 0.1-mm and 0.2-mm Cu filters was comparable with non-filter.

Our findings indicated that the 0.2-mm Cu filter would be useful for dose reduction in the full spine x-ray examination for AIS.

Personal information

References