Spine

SPINE Volume 44, Number 3, pp 203–210
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DIAGNOSTICS

Dose Reduction Protocol for Full Spine X-ray Examination Using Copper Filters in Patients With Adolescent Idiopathic Scoliosis

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Study Design. A prospective case series.

Objective. The aim of this study was to assess a new protocol for full spine X-ray using copper (Cu) filters to reduce radiation exposure in patients with adolescent idiopathic scoliosis (AIS).

Summary of Background Data. Radiation exposure is associated with an increased risk of cancer development in children. To reduce the radiation exposure without compromising the image quality using existing radiographic equipment, a new computed radiography protocol was optimized using a variety of heavy metal filters.

Methods. Study 1: Whole spine radiographs were obtained using a human body phantom, and radiation doses without and with 0.1, 0.2, and 0.3 mm thick Cu filters were compared. Study 2: Patients with AIS who underwent posterior fusion were radiographically evaluated at follow-ups; the X-ray protocols with or without the use of 0.2-mm Cu filters were alternated between consecutive follow-ups. The image quality was independently evaluated using six points in the anterior–posterior (AP) view and seven in the lateral [left–right (LR)] view by three spine surgeons using a three-point grading system.

Results. Study 1: The surface doses while obtaining nonfiltered X-rays in AP and LR views were 0.31 and 0.93 mGy, respectively, whereas those with 0.1-, 0.2-, and 0.3-mm Cu filters were 0.16 and 0.52, 0.11 and 0.36, and 0.08 and 0.27 mGy, respectively.

Study 2: In patients with AIS, the percentage of grade 3 scores (both endplates were identifiable) on AP-view images was 85% with nonfiltered X-rays and 75% with the filtered X-rays. However, there were no significant differences between the two protocols. On LR images, the frequency of grade 3 scores was significantly lower at Th2 and Th12 on filtered images than on nonfiltered ones.

Conclusion. Whole spine radiographs using 0.2-mm Cu filters in patients with AIS could reduce radiation exposure more than 60% while preserving the image quality.

Key words: adolescent idiopathic scoliosis, computed radiography, copper filters, full spine X-ray, radiation exposure.

Level of Evidence: 4

Spine 2019;44:203–210

Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional spinal deformity that presents in 2% to 3% of children. It is defined as a curvature of more than 10° of the spine in the coronal plane accompanied by a rotation of the spine.[1] Treatment of AIS depends on the severity and location of the curve and clinical symptoms. Routine X-ray evaluations are required because the deformity could progress until skeletal maturity is reached.

Patients with AIS with a mild curvature require regular observation and follow-up until they achieve skeletal maturity, whereas those with a greater curvature require bracing or surgical intervention. Repeated radiation exposure due to several follow-up evaluations may increase the risk of cancer. Previous studies reported that radiation exposure during early childhood and adolescence might increase the risk of breast and thyroid cancers.[2,3] Further, publication 73 of the International Commission on Radiological Protection (ICRP) recommends that radiation exposure be limited to levels required to obtain desired images, given the biological deterministic (tissue reactions) and stochastic (cancer and hereditary) effects associated with radiation exposure.[4] The International Atomic Energy Agency (IAEA) has also

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Acknowledgment date: March 19, 2018. First revision date: May 4, 2018. Acceptance date: June 20, 2018.

The legal regulatory status of the device(s)/drug(s) that is/are the subject of this manuscript is not applicable in my country.

No funds were received in support of this work.

No relevant financial activities outside the submitted work.

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DOI: 10.1097/BRS.0000000000002787

established a guidance level, which is the upper limit of the absorbed dose at each X-ray examination.[5] To date, there is no consensus on the reference level for children for full spine X-rays, and the optimal radiation dose required for adequate image quality should be determined to reduce radiation exposure.

Similar to the colored components of visible light, X-rays have a range of energies and form a continuous emission spectrum. Low-energy X-rays (<30 keV) are absorbed by the soft tissues, especially the skin, but are not necessary for obtaining high image quality. Therefore, eliminating these low-energy X-rays using metallic filters will lead to lower exposure without compromising the image quality. Additional metal filters can be made of copper (Cu) or aluminum (Al), which are also used in chest radiography.[6] However, studies on the use of metallic filters in full spine radiography have not been well reported. Thus, the purpose of this study was to investigate a new computed radiography protocol that uses a Cu filter during full spine X-ray examination in patients with AIS to reduce the radiation exposure without compromising the image quality.

MATERIALS AND METHODS

X-ray Imaging System and Filters

Full spine X-ray images were obtained using an X-ray generator system (AXIOM Aristos MX/VS; Siemens, Erlangen, Germany) and a computed radiography system (FCR XL-2; Fujifilm, Tokyo, Japan). An imaging plate with a field size of 384 × 868 mm (FUJI IP Long view cassette type LC; Fujifilm, Tokyo, Japan) was used for acquiring X-ray images. The Cu filters used were built-in type filters implemented in the X-ray system, which were positioned between the X-ray tube and collimator. The filters could be automatically inserted and removed using a switch on the operator console.

Phantom Study

A human-like X-ray phantom (RANDO phantom; Phantom Laboratory, Salem, NY) was used for phantom testing with a tube voltage setting of 80 kV and current–exposure time product of 20 mAs for the anterior–posterior (AP) image; corresponding settings for the lateral [left–right (LR)] image were 90 kV and 50 mAs, respectively. These parameters have been routinely used in our institution for 14 to 17-year-old children. The source–detector distance (SDD) was 240 cm, and the radiation field size was 38 × 85 cm.

According to the IAEA guideline, the entrance surface dose (ESD) is an important factor for evaluating radiation exposure.[5] ESDs were measured using an ion chamber (sensor, 10X5–6; dosimeter, 9015; Radcal, Monrovia, CA) under the aforementioned X-ray conditions and compared between nonfiltered and 0.1, 0.2, and 0.3-mm Cu-filtered X-rays.

Three spine surgeons independently reviewed all phantom images on a 2 mega-pixel monochrome monitor (RadiForce G31; Eizo, Ishikawa, Japan). Both nonfiltered and Cu-filtered (0.1, 0.2, and 0.3 mm) AP and LR images of five vertebrae, including C4, C7, Th8, Th12, and L3, were assessed using a three-point grading system: G1, none of the endplates of the vertebra were identifiable; G2, endplates were identifiable, but bone trabeculae were not identifiable; and G3, both the endplates and bone trabeculae were identifiable.[7] In addition, image quality of the femoral head on LR image was also estimated (Figure 1A–D).

PROSPECTIVE CLINICAL STUDY

Case Selection

This study was approved by the Kanazawa University Hospital Institutional Review Board (No. 1646–1). Informed consent was obtained from all patients. Patients with AIS who underwent posterior instrumented fusion were evaluated in this study. During postoperative X-ray follow-up, Cu-filtered and nonfiltered AP and LR images were alternately obtained in each patient to minimize the radiation exposure during each follow-up.

Patient Image Quality

X-ray examinations were performed using the aforementioned settings of 80 kV and 20 mAs for AP images and 90 kV and 50 mAs for LR images, and the 0.2-mm Cu filter was selected for the clinical study based on the results of the phantom study. AP image quality was evaluated in six vertebrae, including C5, Th2, Th12, L3, apex, upper instrumented vertebra (UIV), and lower instrumented vertebra (LIV), using the three-point grading system.[7] In addition to the above-mentioned points, the first sacral vertebra (S1) and femoral head were also evaluated on LR views.

Inter- and intra-reader reproducibility of the evaluating surgeons was determined; intra-reader reproducibility was assessed twice at an interval of more than 3 months.

Statistical Analysis

Statistical analyses were performed using the GraphPad Prism software version 6 (GraphPad Software, San Diego, CA). The Friedman test along with the post hoc test (Bonferroni test) was used for comparing the visual grading scores for each vertebra among the nonfiltered and 0.1-, 0.2-, and 0.3-mm Cu-filtered phantom images. The Wilcoxon signed rank test was used to compare the visual grade of the 0.2-mm Cu-filtered and nonfiltered images of each vertebra by each reviewer. A P value of less than 0.05 was considered statistically significant. Inter- and intra-reader reproducibility was evaluated using the R software version 3.3.2 (R Core Team, Vienna, Austria). A kappa value of less than 0.20 indicated poor agreement, 0.21 to 0.40 indicated fair agreement, 0.41 to 0.60 indicated moderate agreement, 0.61 to 0.80 indicated good agreement, and more than 0.81 indicated excellent agreement.

RESULTS

Phantom ESD

ESDs for the 0.1-, 0.2-, and 0.3-mm Cu-filtered and nonfiltered X-rays are listed in Figure 2. In all the settings tested,

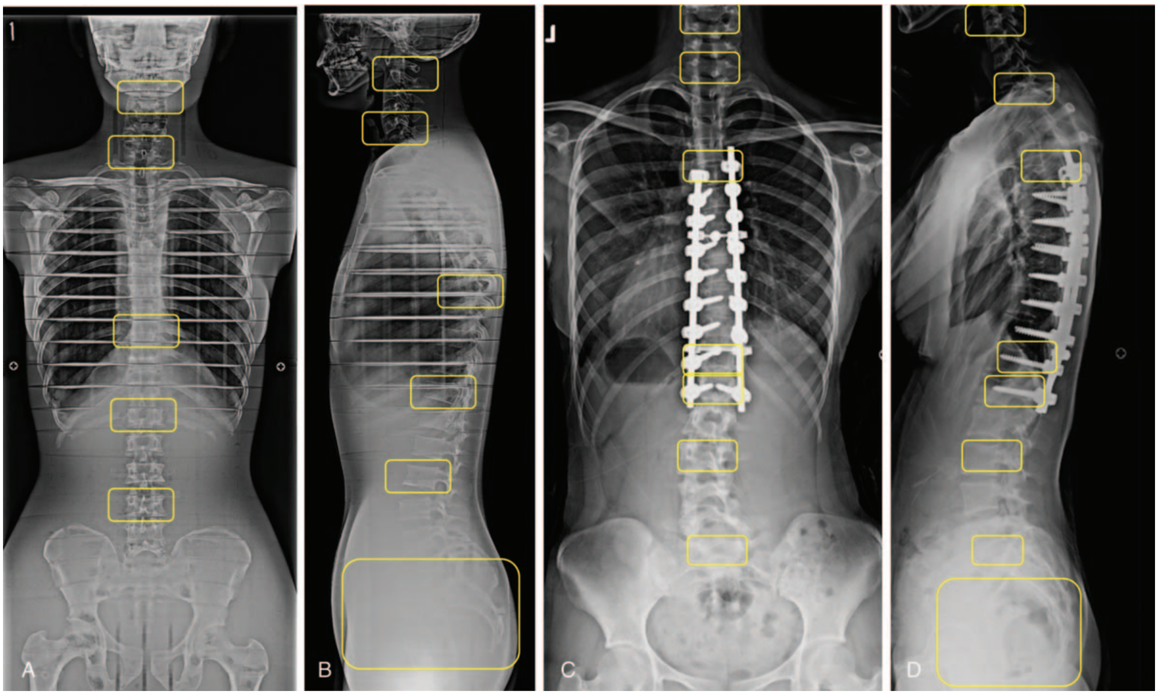

Figure 1. Phantom and patient images. (**A**) Phantom anterior–posterior (AP) image. (**B**) Phantom left–right (LR) image. (**C**) Patient AP image. (**D**) Patient LR image. Image qualities at yellow marks on the X-ray images were visually assessed using the three-point system: G1, none of the vertebral endplates are identifiable; G2, endplates are identifiable, but bone trabeculae are not identifiable; and G3, both the endplates and bone trabeculae are identifiable.

thicker Cu filters resulted in less measurable ESDs. ESDs for AP images (80 kV and 20 mAs) with 0.1-, 0.2-, and 0.3-mm Cu-filtered X-rays were 0.16, 0.11, and 0.08 mGy, respectively, whereas that for the nonfiltered X-ray was 0.31 mGy. ESDs for LR images (90 kV and 50 mAs) with 0.1-, 0.2-, and 0.3-mm Cu-filtered X-rays were 0.52, 0.36, and 0.27, respectively, whereas ESD for nonfiltered X-ray was 0.93 mGy.

Phantom Image Quality

The results of visual image quality assessments for the phantom are summarized in Figures 3A to H and 4. All the vertebrae could be identified (grade 2 or 3) by all readers on AP images. However, image quality of C7 was unacceptable (grade 1) for reader 1 on LR images with a 0.3-mm Cu filter. Image quality of the femoral head with the 0.3-mm Cu filter was not acceptable for any reader. However, there

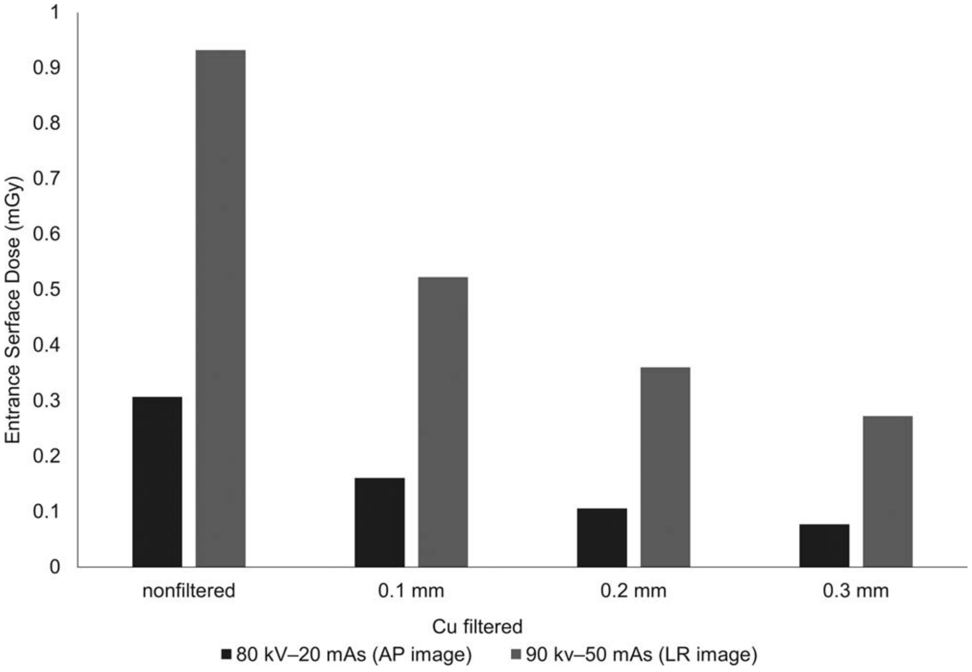

Figure 2. Graph shows the entrance surface doses (ESDs) for 0.1, 0.2, and 0.3 mm copper-filtered and nonfiltered X-ray images.

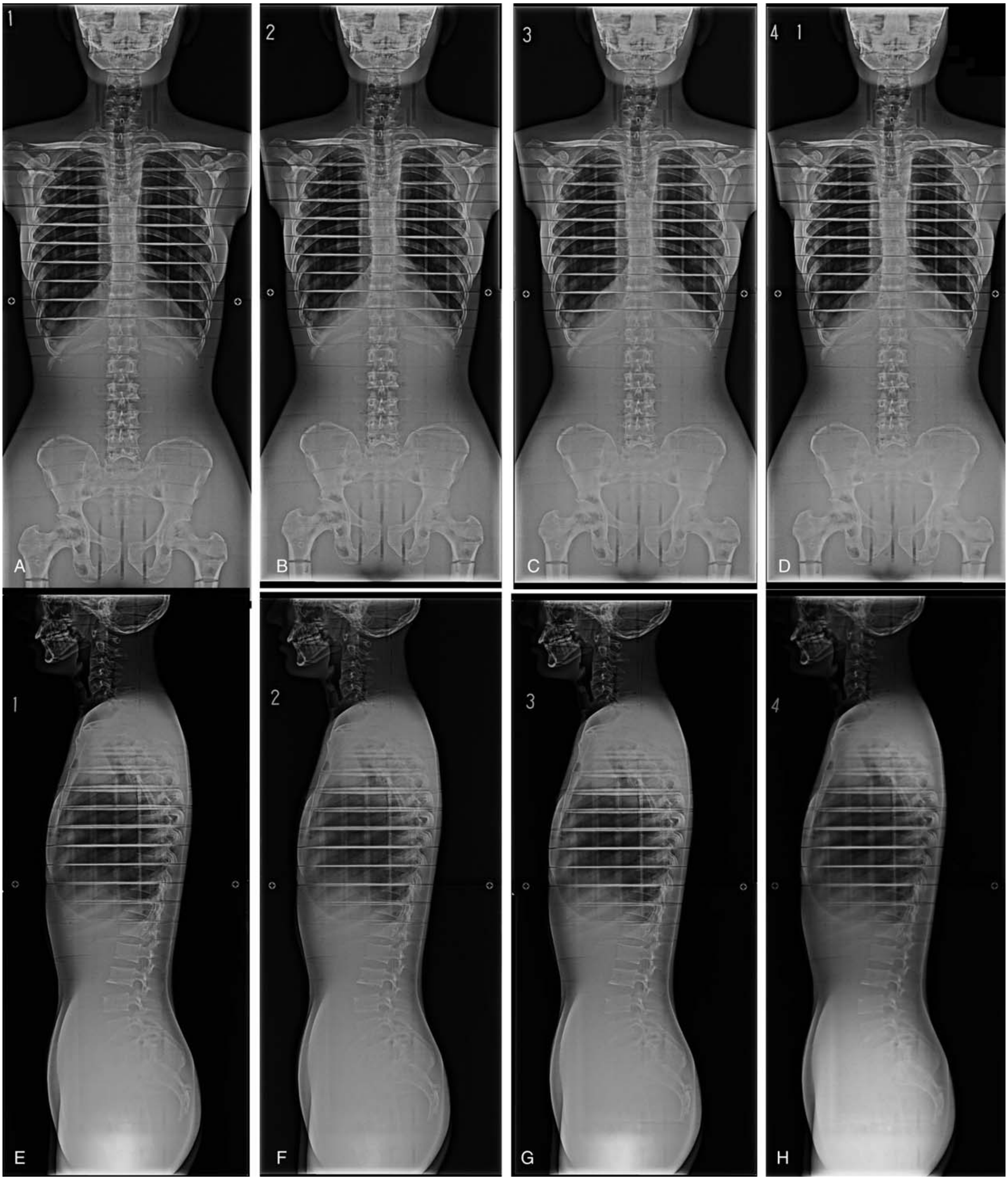

Figure 3. Phantom images. Phantom anterior–posterior (AP) images (**A**) without filter, (**B**) with 0.1-mm copper (Cu) filter, (**C**) with 0.2-mm Cu filter, and (**D**) with 0.3-mm Cu filter. Phantom left–light (LR) images (**E**) without filter, (**F**) with 0.1-mm Cu filter, (**G**) with 0.2-mm Cu filter, and (**H**) with 0.3-mm Cu filter.

were no significant differences among the 0.1-, 0.2-, and 0.3-mm Cu-filtered and nonfiltered groups.

Clinical Image Quality

We included 19 patients with AIS (18 female and 1 male), with a mean age of 14.7 years (range, 11–19 years), in this study. The mean body mass index (BMI) was 18.2 ± 2.4. The results of the clinical image quality assessments are summarized in Figures 5 and 6. Although the use of 0.2-mm Cu filters tended to reduce the frequency of grade 3 scores for each vertebra on AP images scored by all readers, there were no significant differences among all evaluation points. On LR images, the frequency of grade 3 scores showed a similar trend, and there were significant differences in Th2

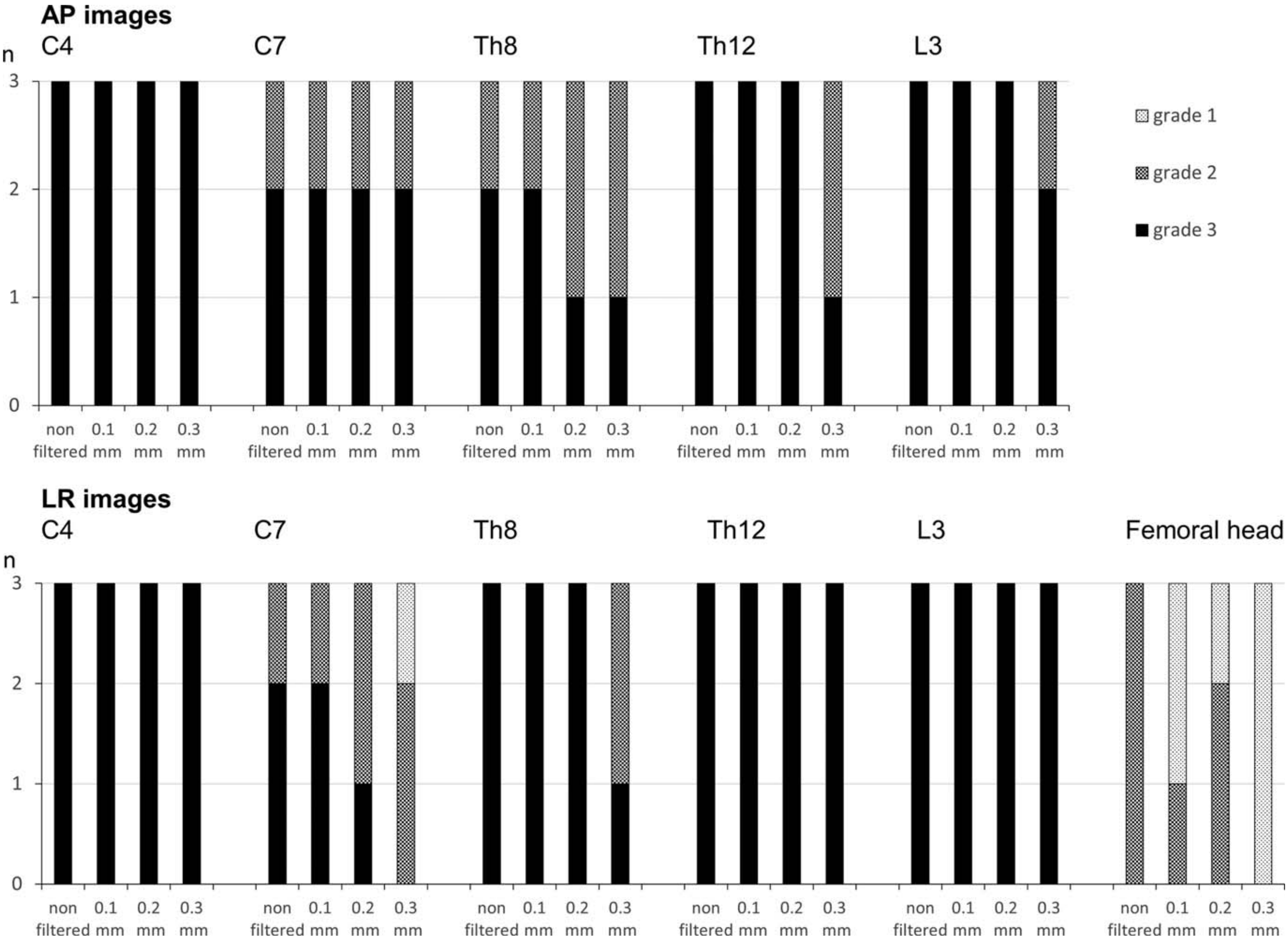

Figure 4. Graphs show visual grade scores for each vertebra on phantom images scored by all the readers. The upper segment is an assessment of anterior–posterior (AP) images, and lower is that of left–right (LR) images. On the basis of the results of the Friedman test with post hoc evaluation, there are no significant differences among nonfiltered and 0.1, 0.2, and 0.3 mm copper-filtered images.

(reader 3, $P < 0.05$) and Th12 (reader 2, $P < 0.05$) scores (Figure 7A–C). The rates of grade 1 judged by readers 1, 2, and 3 were 21.1%, 21.1%, and 26.3% for Th2 and 15.8%, 5.3%, and 15.8% for UIV, respectively, whereas the rate of grade 1 was judged by only reader 2 for nonfiltered images of Th2 (5.3%) and UIV (5.3%).

Kappa values for AP and LR images were 0.56 and 0.66 for inter-reader reproducibility and 0.56 and 0.62 for intra-reader reproducibility, respectively.

DISCUSSION

The X-ray tube system requires an Al filter of at least 2.5 mm thickness to reduce the exposure to harmful low-energy X-rays. Despite this filter, some low-energy components pass through and are absorbed by the patients, which can cause an increase in radiation exposure. The function of an additional filter is to limit the passage of low-energy components while permitting that of middle-to-high energy components that are required for image generation. Thus, the additional filter reduces the radiation exposure while preserving the image quality.

In our phantom study, ESDs were measured according to IAEA guidelines. On AP and LR images, the use of 0.1-, 0.2-, and 0.3-mm Cu filters reduced radiation exposure by more than 40%, 60%, and 70%, respectively. Conversely, the use of thicker filters resulted in poor image quality. Although the 0.3-mm filter efficiently blocked the low-energy components, the resolution of femoral head on LR images using this filter was unacceptable (grade 1) to all the readers.

On the basis of the results of the phantom study, the 0.2-mm Cu filter was selected for use in the prospective clinical study. The results of the clinical study showed that there were only small differences in visual grades between the filtered and nonfiltered groups on AP images, and there were no significant differences among all evaluation points. On the contrary, significant differences were noted on LR images for Th2 by reader 3 and Th12 by reader 2 ($P < 0.05$); however, Th12 results did not include the scores of G1, and all readers accepted the image qualities of Th12. Inter- and intrareader reproducibility were relatively favorable with either moderate or good agreement (kappa value, 0.56–0.66). On the basis of LR images, unacceptable image quality with grade 1 score was noted for Th2 and UIV. However, LR images are clinically used for observing changes in the sagittal spinal alignment and for detecting instrument failures. For their evaluation, the periodical

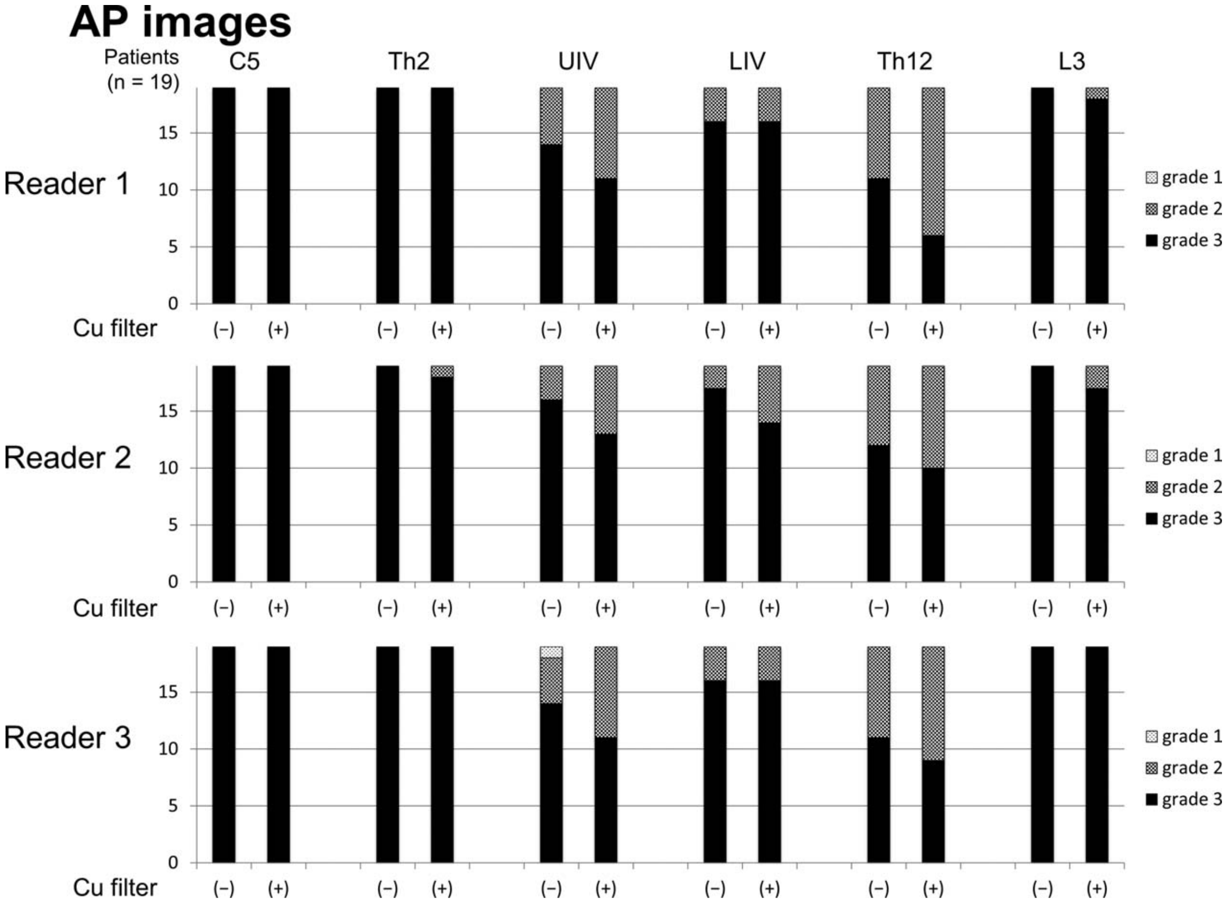

Figure 5. Graphs show scoring frequency in anterior–posterior (AP) images for all three grades in 19 patients. The upper segment corresponds to the assessment by reader 1, middle by reader 2, and lower by reader 3. On the basis of the results of the Wilcoxon signed rank test, there were small differences in visual grades between the filtered and unfiltered groups on AP images. LIV indicates lower instrumented vertebra; UIV, upper instrumented vertebra.

judgment of grade 1 score in Th2 and UIV may not pose serious problems. In addition, it is possible to reduce a high amount of radiation dose using the Cu filters on LR images than AP images, which would be of great value in patients with AIS. Therefore, this protocol is acceptable for use during routine postoperative follow-up X-ray evaluation to reduce the radiation exposure in patients while preserving the image quality.

For image acquisition of X-ray, a certain amount of transmitted X-ray dose is required for acceptable image qualities; thus, it should be nearly equal between cases with and without the Cu filter. According to a previous report, the Cu filter somewhat reduces high-energy radiation, which is required for X-ray transmission through the body.[6] In this study, because we did not change the X-ray settings between the cases with and without the Cu filter, the transmitted dose with the Cu filter was not equal to that with the Cu filter and somewhat less than with the Cu filter. On the basis of this relationship between ESD and the transmitted dose, it is presumed that the dose reduction rate is reduced with the depth from the surface, compared with the ESD reduction of 60%. Therefore, although the dose reduction rate was decreased from 60%, the absorbed doses of organs at less deep positions, including thyroid and mammary glands, were certainly decreased. Therefore, it should be noted that the cancer risk of an organ at a deep position does not necessarily correspond with the ESD reduction.

This study had several limitations. First, our study included a small number of patients. Second, the subjects had a relative low BMI because most were females; therefore, the results may vary in patients with high BMI. Further studies with a larger number of subjects and range of BMI values may be required. Third, filtered and nonfiltered X-ray examinations were not performed on the same day because exposing a patient to radiation twice a day was an ethical concern. Thus, it may have led to a measurement error. However, we analyzed routine postoperative X-ray follow-ups, which would have minimum differences or changes in spine deformity and physical size.

In conclusion, full spine X-ray examinations using 0.2-mm Cu filters in patients with AIS could reduce radiation exposure more than 60% while preserving the image quality. This protocol can be used during postoperative routine follow-ups to reduce the risk of developing cancers due to excessive radiation exposure.

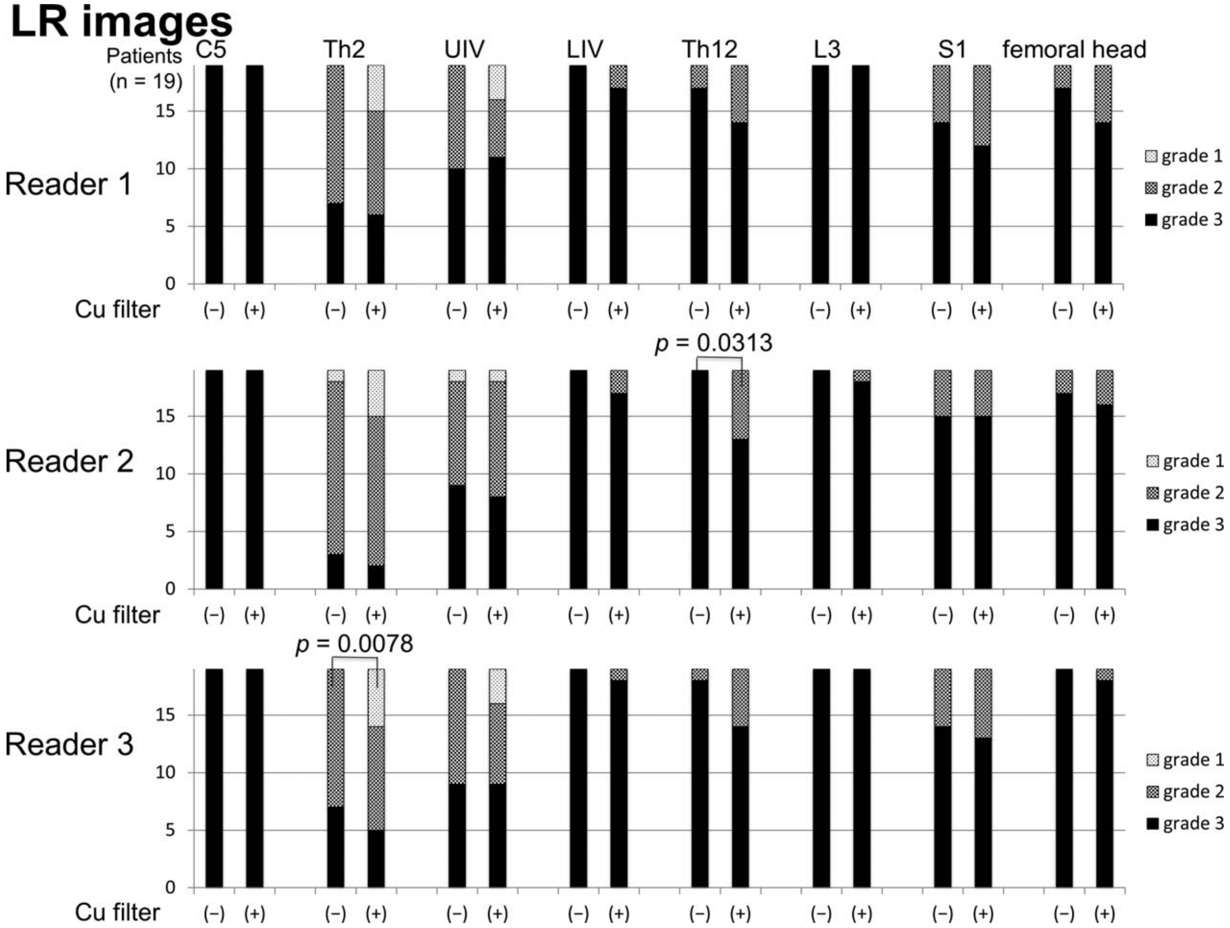

Figure 6. Graphs show scoring frequencies on left−right (LR) images for all three grades in 19 patients. The upper segment corresponds to the assessment by reader 1, middle by reader 2, and lower by reader 3. On the basis of the results of the Wilcoxon signed rank test, significant differences were noted by reader 2 in Th12 on LR images ($P = 0.0313$), and by reader 3 in Th2 on LR images ($P = 0.0078$).

Figure 7. Clinical patient images. (**A**) Anterior−posterior (AP) image without filter. (**B**) Left−right (LR) image without filter. (**C**) AP image with 0.2-mm copper (Cu) filter. (**D**) LR image with 0.2-mm Cu filter.

➢ Key Points

- ☐ We developed a new full spine X-ray protocol using Cu filters to reduce radiation exposure in patients with AIS.
- ☐ We evaluated whole spine radiographs of phantom images and patients with AIS.
- ☐ The Cu filters resulted in >60% reduction in X-ray exposure during whole spine radiography without compromising image quality.

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