Received:
27 June 2017

Revised:
10 September 2017

Accepted:
12 September 2017

<https://doi.org/10.1259/bjr.20170483>

Cite this article as:

Jeon MR, Park HJ, Lee SY, Kang KA, Kim EY, Hong HP, et al. Radiation dose reduction in plain radiography of the full-length lower extremity and full spine. *Br J Radiol* 2017; **90**: 20170483.

FULL PAPER

Radiation dose reduction in plain radiography of the full-length lower extremity and full spine

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Objective: To compare the diagnostic performance of standard- and low-dose radiographs of the full-length lower extremity and spine.

Methods: This study included 223 patients who visited our hospital and received full-length lower extremity standing radiographs and full-spine radiographs. We determined the dose area product (DAP) of each image, and effective doses (ED, mSv) were calculated based on the DAP. Subjective evaluation of the full-length radiographs was based on image quality, which was assessed by bony cortex and trabecula evaluation, and on diagnostic performance, which was assessed by leg length measurement. Subjective evaluation of the full-spine radiographs was based on image quality, which was assessed by viewing the vertebral endplate, pedicle and lateral border of vertebral body, and on diagnostic performance from measurement of Cobb's angle.

Results: For the full-length view and the full-spine view both the mean DAP and ED values of the standard-dose group were significantly higher than those of the low-dose group ($p < 0.05$). Mean scores for subjective values did not significantly differ based on the radiation dosage (p -values, 0.15–0.99). The subjective value scores for the full-length view were 2.94–2.98 in the standard-dose group and 2.91–3.00 in the low-dose group. Of note, both groups had very high scores. Additionally, the diagnostic performance scores between the two groups were also very high (range from 2.92 to 3.00).

Conclusion: Reducing mAs by 50% of the standard dose does not affect the radiograph image quality or its clinical validity.

Advances in knowledge: Radiation dose reduction (50% of the standard dose of mAs) in plain radiography of the full-length lower extremity and full spine do not affect the clinical validity and the image quality.

INTRODUCTION

Digital plain radiographs are used in the evaluation of malalignment of the lower extremities or spine and in evaluating limb length discrepancy of the lower extremities.^{1–4} Evaluation of scoliosis or leg length discrepancy requires the use of radiography, as static factors that are important in the assessment of the condition require upright imaging that cannot be performed with CT or MRI.⁵ Radiographs can be performed quickly, and they are widely available, cost effective and allow for excellent anatomical surveys.^{1–3} Despite these advantages, radiation exposure is an inevitable adverse effect, and as such, diagnostic radiology adheres to the principle of administering radiation doses “as low as reasonably achievable”.^{6,7} For full-length lower extremity standing and full-spine radiographs, this principle is especially important because patients with knee malalignment or scoliosis are often children and young adults, who are often subjected to repeat studies over long treatment periods. Furthermore, radiographic follow-up

examinations are needed more frequently in growing bones than in mature bones, where degeneration usually results in a slow progression of malalignment. Exposure to multiple diagnostic radiographic exams during childhood and adolescence may increase one's risk of malignancy including breast cancer.⁸ Therefore, reduction of radiation exposure is of utmost importance.^{4,9} Kloth et al reported that full-length lower extremity standing radiography using a 33% reduced radiation dose is not inferior to using the standard dose for evaluating knee malalignment.⁹

Thus, the purpose of our study was to compare the diagnostic performance between standard- and low-dose radiographs of the full-length lower extremity and the full spine. To ensure diagnostic quality of the reduced-dose radiographs, the dose reduction was carried out using standardized quality criteria based on common orthopedic assessments necessary for therapeutic decisions and therapy monitoring.

Table 1. Selected cases of our study

	Dose	No. of patients	Sex (M/F)	Age (mean/median)
Full-length lower extremity standing radiography	Standard	54	20/34	52/55
	Low	53	30/23	48/49
Full-spine radiography	Standard	48	9/39	54/63
	Low	53	12/41	52/53
Total	Standard	102	29/73	53/58
	Low	106	42/64	50/52
	Total	208	71/137	51/54

MATERIALS AND METHODS

Case selection

This is retrospective study that was approved by our hospital's institutional ethics review board, and the requirement for informed consent was waived. A total of 223 consecutive patients who visited our hospital between December 2012 and May 2016 and underwent full-length lower extremity standing radiographs and full-spine radiographs were included in this study. Before May 2015, patients received standard-dose radiographs, but after May 2015, patients received low-dose radiographs at half

the standard dose. This was done because many studies recommended dose reduction in daily clinical practice.

We excluded 15 patients who had surgical devices and therefore 208 patients were ultimately included in our study. The 107 full-length lower extremity images consisted of 54 standard-dose radiographs and 53 low-dose radiographs. Additionally, the 101 full-spine cases consisted of 48 standard-dose and 53 low-dose radiographs. There were 137 females and 71 males included in the study (mean age: 81.86 ± 19.6 years, range: 19–85 years). We evaluated the body

Table 2. (a) Full-length lower extremity standing radiography parameters; (b) full-spine radiography parameters

(a) Full-length lower extremity standing radiography parameters									
Dose	mAs				kVp			DAP (Gy.cm ²)	ED (mSv)
	Pelvis	Knee	leg	Average	Pelvis	Knee	Leg		
Standard	50	32	25	35.7	90	85	77	40.73	10.18
Low	25	16	13	18	90	85	77	23.37	5.84
(b) Full-spine radiography parameters									
Dose	mAs		kVp		DAP (Gy.cm ²)		ED (mSv)		
Standard	45		85		46.06		11.51		
Low	23		85		19.69		4.92		

DAP, dose area product; ED, effective dose.

Table 3. BMI, DAP and effective dose according to study type

Study type	Dose	BMI	DAP	Effective dose (mSv) ^a
Full-length view ^b	Standard dose	25.05 (± 3.51)	40.76 (± 3.96)	10.19 (± 0.99)
	Low dose	24.13 (± 3.52)	23.12 (± 4.24)	5.78 (± 1.06)
	<i>p</i> value	0.311	<0.001	<0.001
Full-spine view ^c	Standard dose	22.45 (± 3.59)	46.06 (± 6.69)	11.52 (± 1.67)
	Low dose	24.77 (± 4.86)	19.69 (± 3.24)	4.92 (± 0.81)
	<i>p</i> value	0.053	<0.001	<0.001

BMI, body mass index; DAP dose area product.

Note: Data in parentheses represent standard deviation.

^amSv, milli-Sievert.

^bFull-length view, full length lower extremity standing radiography.

^cFull-spine view, full spine radiography.

Table 4. Interobserver agreement for subjective evaluation and diagnostic performance based on evaluation category

Study type	Categories	κ value	95% confidence interval	p -value
Full-length view ^a	Bony cortex	0.493	-0.107–1.000	<0.001
	Bony trabeculation	0.384	0.056–0.712	<0.001
	Mechanical axis evaluation	0.665	0.665–0.669	<0.001
	Leg length evaluation	0.662	0.043–1.000	<0.001
Full-spine view ^b	Vertebral endplate	0.720	0.571–0.868	<0.001
	Vertebral pedicle	0.686	0.573–0.799	<0.001
	Lateral border of the body	0.704	0.566–0.842	<0.001
	Evaluation of Cobb's angle	0.606	0.335–0.877	<0.001

Note: Interobserver agreement (κ) was characterized as follows: poor ($\kappa < 0.1$), slight ($0.1 \leq \kappa \leq 0.2$), fair ($0.2 < \kappa \leq 0.4$), moderate ($0.4 < \kappa \leq 0.6$), substantial ($0.6 < \kappa \leq 0.8$), and almost perfect ($0.8 < \kappa \leq 1$).

Kappa values are presented with a 95% confidence interval.

^aFull-length view, full length lower extremity standing radiography.

^bFull-spine view, full spine radiography.

mass index (BMI) of each patient group, as obesity can affect image quality. Our study population is summarized in Table 1.

Image acquisition

Both full-length and full-spine views were acquired using a digital flat panel detector and image stitching system consisting of an X-ray tube (E7869X), generator (CMP200DR 80) and digital flat-panel detector ("SDX-4343CS", Samsung, GC80, Korea). Images were taken with the patient facing the X-ray tube and both patella pointing anteriorly. The image receptor format

was 43×35 cm. Three images were stitched at the workstation (SAMSUNG DB-Z400) using the dedicated software, and the combined image was sent to a picture archiving and communications system (PACS) workstation (G3 PACS, Infiniti, Korea). The image voltages and mAs are described in Table 2.

Image analysis

We acquired the dose area product (DAP) of each image from DICOM data through the PACS workstation. Effective doses (ED, mSv) were calculated based on the DAP and body portion

Table 5. Mean scores for subjective evaluation and diagnostic performance

Study type	Categories	Dose	Mean (standard deviation)	p -value
Full-length view ^a	Bony cortex	Standard dose	2.96(± 0.19)/2.98 (± 0.14) ^b	0.569/0.320
		Low dose	2.98 (± 0.14)/3.00 (± 0.00)	
	Bony trabeculation	Standard dose	2.94 (± 0.30)/2.98 (± 0.14)	0.148/0.989
		Low dose	2.91 (± 0.30)/2.98 (± 0.14)	
	Mechanical axis evaluation	Standard dose	2.96 (± 0.27)/2.98(± 0.14)	0.320/0.320
		Low dose	3.00 (± 0.00)/3.00 (± 0.00)	
	Leg length evaluation	Standard dose	2.98 (± 0.14)/2.98 (± 0.14)	0.989/0.320
		Low dose	2.98 (± 0.14)/3.00 (± 0.00)	
Full-spine view ^c	Vertebral endplate	Standard dose	2.81 (± 0.49)/2.85 (± 0.36)	0.091/0.371
		Low dose	2.68 (± 0.51)/2.74 (± 0.49)	
	Vertebral pedicle	Standard dose	2.50 (± 0.67)/2.67 (± 0.47)	0.876/0.218
		Low dose	2.43 (± 0.69)/2.57 (± 0.60)	
	Lateral border of the body	Standard dose	2.65 (± 0.56)/2.73 (± 0.45)	0.491/0.594
		Low dose	2.72 (± 0.57)/3.00 (± 0.50)	
	Evaluation of Cobb's angle	Standard dose	2.92 (± 0.33)/2.90 (± 0.30)	0.517/0.148
		Low dose	2.94 (± 0.30)/2.94 (± 0.30)	

Kappa values are presented with a 95% confidence interval.

^aFull-length view, full length lower extremity standing radiography.

^bReader 1/reader 2.

^cFull-spine view, full spine radiography.

using an effective dose calculator website (<http://veltcamp.blogspot.kr/>).

Subjective evaluation of the full-length view was assessed based on the image quality of the bony cortex and the trabecula and on the diagnostic performance of leg length measurement. The evaluations were performed by two musculoskeletal radiologists with 15 and 8 years of experience, respectively, who were unaware of the clinical information and radiologic reports. First, they evaluated image quality using a subjective, four point scoring system from 0 to 3, as follows: 3 (excellent image quality) = definitely accessible, 2 (good image quality) = $\geq 50\%$ accessible but not defined, 1 (moderate image quality) = $< 50\%$ accessible, 0 (poor image quality) = not accessible.^{9,10} Second, they evaluated whether the mechanical axis of both femurs could be measured and whether both leg lengths could be measured by standard- and low-dose radiography. The mechanical axis was defined as the angle of intersection between the ipsilateral femoral and tibial mechanical axis.^{9,11} Leg length was measured from the top of the femoral head to the center of the distal tibia. To measure leg length, the top of the femoral head and the plafond of the distal tibia should be delineated.^{1,12} Quality was again assessed using the same, above-mentioned subjective scoring system.

Subjective evaluation of the full-spine view was based on image quality of the vertebral endplate, pedicle and lateral border of the vertebral body and on the diagnostic performance of Cobb's angle measurement. These evaluations were also performed by the same musculoskeletal radiologists.^{5,13}

Statistical analysis

We compared the mean values of the BMI, DAP and ED of the standard-dose group to those of the low-dose group using the Student's *t*-test (Table 3). Interobserver agreement for subjective evaluation and diagnostic performance scores was analysed using a κ statistic (Table 4). κ values were interpreted as follows: poor ($\kappa \leq 0.1$), slight ($0.1 < \kappa \leq 0.2$), fair ($0.2 < \kappa \leq 0.4$), moderate ($0.4 < \kappa \leq 0.6$), substantial ($0.6 < \kappa \leq 0.8$) and almost perfect ($0.8 < \kappa \leq 1$).¹⁴ The mean subjective evaluation and diagnostic performance scores between the standard- and low-dose groups were compared using the Student's *t*-test and χ^2 test (Table 5). Statistical analyses were performed using PASW software version 18.0 (IBM, Armonk, NY). *p*-values < 0.05 were considered statistically significant.

RESULTS

A total of 106 patients were scanned using standard-dose radiography, and 102 patients were scanned with low-dose radiography (Table 1). There was no significant difference in the mean BMI values between the standard-dose and low-dose groups (Table 3). For both full-length and full-spine views, the mean DAP and ED values of standard-dose group were significantly higher than those of the low-dose group ($p < 0.05$). The interobserver agreement for subjective evaluation and diagnostic performance according to the categories ranged from fair to substantial (Table 4). Mean scores for subjective values of image quality and diagnostic performance are on Table 5. These values did not significantly differ according to

the dosage of radiation (*p* values, 0.15–0.99). The subjective value scores for the full-length view was 2.94–2.98 in the standard-dose group and 2.91–3.00 in the low-dose group, which were both notably high. The diagnostic performance scores for both views in both groups were also very high, ranging from 2.92 to 3.00. The subjective value scores for the full-spine view were slightly lower than those of the full-length leg view (2.50–2.85, standard dose; 2.43–3.00, low dose), especially in the vertebral pedicle evaluation.

DISCUSSION

The risk of cancer due to radiation exposure is estimated to increase proportionally to the amount of radiation received, reaching around 0.5% at an effective dose of 100 mSv. The risk is higher at a younger age of exposure; however, the risk varies by organ, and females are more susceptible than males.¹⁵ Reduction of radiation exposure in plain radiography is an ongoing challenge that has to be adapted to clinical requirements and technical advances. However, while accomplishing this goal, it is essential to ensure that the clinical quality of the radiographs is not impaired. Therefore, image quality must be continuously tested and controlled using standardized quality criteria.^{9,10} When the patients present themselves for the first time to the examinations

Figure 1. A 17-year-old female with right-sided lock knee. She underwent pre-surgical full-length lower extremity standing radiography [standard dose, (a)], a knee MRI and underwent surgical excision of the synovial plica. Two months later, she underwent follow-up full-length lower extremity standing radiography using the low-dose protocol (b). No significant difference is seen in evaluation of the trabeculae or bony cortex on both examinations. We could measure the mechanical axis and leg length on both examinations.

they need detailed information about bony structure and angles upon the question of the referring physician. However for the reason of follow-up there would be no strong indication to use full dosage again. As we know, when using X-ray to examine the spine or lower extremity, the exposure area is large and includes hematopoietic bone marrow. In many cases, lifelong examination is required. In this regard, many studies have been undertaken with various approaches to reduce doses of radiation. Grieser et al⁵ evaluated exposure dose reduction with DAPs of full-spine images recorded using a digital flat panel detector and an image stitching system in patients with scoliosis. They achieved an exposure dose reduction of 47 to 93%, compared with published values. Measurement of the Cobb and Stagnara angle, lateral deviation and Risser stage was possible in 96% ($n = 50$), 83% ($n = 18$), 100% ($n = 50$) and 100% ($n = 50$) of cases. Kloth et al^{9,10} also attempted dose reduction trials and found no significant inferiorities of diagnostic performance in full-length lower extremity and pelvis radiographs after hip arthroplasty. Our study showed that by lowering the mAs of the low-dose group by 50%, the DAP and effective dose could be reduced by almost 50% when compared to the standard-dose group. There was no statistical inferiority between the standard-dose and low-dose group when assessing subjective image quality and diagnostic performance. The subjective value scores for the full-spine view were slightly lower than those of the full-length leg view (2.50–2.85, standard dose; 2.43–3.00, low dose) (Figures 1 and 2). We think these might results from the fact that full-spine view has many factors that might affect image analysis such as fat, fluid, and air

Figure 2. An 18-year-old male with scoliosis. He underwent standard-dose full-spine radiography (a) and underwent follow-up with low-dose full-spine radiography (b) 6 months later. Measurement of Cobb's angle was possible on both examinations.

in the anterior portion of the spine, compared with the relatively simple surrounding tissue composition of the leg. We controlled for BMI because we thought that it could affect image quality and analysis. Among those enrolled in our study, patients with the highest BMI of 35.49 had the lowest image analysis scores on both standard- and low-dose radiographs, and the images were limited in assessing the bony cortex and trabeculae of the proximal femur (Figure 3).

We think our study results are valuable because there are not many studies that attempted dose reduction by lowering the mAs value as we did. In the future, studies on dose reduction will continue in a variety of ways, including the same way as we did, with dose reduction being applied to patients and young adults who are particularly vulnerable to radiation, as well as patients who need regular follow-up.

Figure 3. A 24-year-old male who had right knee pain. He underwent pre-surgical full-length lower extremity standing radiography [standard dose, (a)], a knee MRI and underwent arthroscopic meniscectomy. Four months later, he underwent follow-up full-length lower extremity standing radiography using the low-dose protocol (b). Both standard- and low-dose radiographs were limited in evaluating the bony cortex and trabeculae. His BMI was 35.49, the highest BMI among all enrolled patients, and he was the only patient receiving the lowest point in image analysis, even at the standard dose. BMI, body mass index.

Limitations of our study were as follows. First, analysis was performed retrospectively. Second, we excluded young patients below 18 years old because our hospital does not use standard-dose radiographs in young patients.

In conclusion, reducing the mAs by 50% of the standard dose does not seem to affect the clinical validity of the image quality for full-length lower extremity standing radiographs and full-spine radiographs.

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