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Evaluation of Gonadal Exposure Dose in Long Bone Plain Radiography for Radiation Protection

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ABSTRACT

Introduction: Long bone examination in standing position, as one of the diagnostic methods in plain radiography, is most commonly used in the field of medical diagnosis, especially leg length discrepancy. However, with regard to this examination, reproductive organs are exposed to radiation as they are placed in the adjacent area to the long bone. Due to the sensitivity of gonads to radiation, their exposure must be kept as minimal as possible to the extent to which proper diagnosis is feasible in order to reduce tumor growth in lower extremity examination. The purpose of this study was to optimize the radiation dose in the long bone examination in standing position.

Material and Methods: This experimental study was conducted to evaluate the radiation exposure dose to a phantom and estimate effective doses and organ-specific doses (i.e., testes and ovaries) among patients using PC-based Monte Carlo program.

Results: A phantom examination in the posterior-anterior (PA) configuration produced a radiation dose nine and three times smaller than those in the anterior-posterior (AP) and AP with shielding configurations, respectively. In a patient study (PA configuration), the testes, ovaries and effective doses were estimated at 15, 1.2, and 2 times smaller than those in the AP configuration, respectively.

Conclusion: This study demonstrated that examinations in the PA configuration produce a smaller radiation dose than those in the AP configuration.

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Introduction

Leg-length discrepancy (LLD) is a difference between the lengths of the legs that is more than 2 cm. It is a common diagnosis that affects at least one out of every 1,000 people [1, 2]. A severe LLD can cause low-back pain [3], standing imbalance [4], and associated running injuries [5]. Leg length inequality could be attributed to various causes, including a broken leg, congenital deformity, osteomyelitis, and dysplasia. The LLD can be diagnosed using patient medical history as well as a physical examination; in addition, it can be confirmed with further imaging studies. Various imaging modalities can be employed to assess the LLD, including computed tomography [6], ultrasound technique [7], micro-dose x-ray and digital radiography [8], and plain radiography as the most frequently used method.

However, in the LLD assessment using plain radiography, sensitive organs, such as gonads can be exposed to radiation. Studies have shown that the radiation may induce harmful effects [9]. The most recent report from the International Commission on Radiological Protection showed that the weighting factor for the gonads as radiosensitive organs was 0.08 [10]. This can explain the potential genetic disorders and malignant transformation caused by radiation exposure. The gonads do not have a threshold dose and they can be affected even by the smallest radiation dose [11].

Various studies have been performed to reduce the gonad radiation dose [12-14]. The effectiveness of gonad shielding, which reduces the radiation dose, has been demonstrated in pelvic examinations. In gonadal shielding, the radiation exposure doses decreased 14 and 7 times for the testes and ovaries, respectively [15]. However, the gonad shielding is used only in pelvic examinations. The shield can be disadvantageous if it is placed on the gonads as the adjacent structures, such as femoral head becomes obscured. With regard to the majority of the cases, the shields have been reported to be poorly placed in the examinations [16, 17].

In this study, the effect of gonad shielding on the examinations of the lower-extremity (i.e., the long bone in standing position) was evaluated. The posterior-anterior (PA) position was proposed for gonad dose reduction, which could overcome the limitations of the gonad shielding without reducing the quality of the

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diagnostic images. Therefore, phantoms and patients were considered for the evaluation of radiation doses.

Materials and Methods

Phantom Study

The study was conducted on a pelvis phantom (Alderson Research Laboratories Inc., USA) consisted of a tissue-equivalent material. The long bone examination in standing position was performed by moving a tube between a start and end points whose scan coverage was determined by the patient height. However, based on the assumption that the scattering was controlled by the same rate for all exposures, the range of the exposure was limited to the pelvic region to measure the dose on the gonads in the phantom. The scans were performed using a GE Definium 8000 system (GE medical systems, Milwaukee), with a CsI/a-Si flat panel detector (FPD) (GE medical systems, Milwaukee). The area of the FPD detector was 40.6 × 40.6cm^2, while the size of the pixel was 143 µm.

All radiographs were obtained at 25 mAs and 76 kVp using a 2.7-mm aluminum (Al) filter and source-to-image-receptor distance of 1.8 m. The surface dose at the location of the gonads was measured with an Unfors dosimeter (Unfors Instrument Incorporated, Billdal, Sweden) and a patient skin dosimeter (PSD) which observed the radiation and prevented radiation overdose.

This instrument consists of four diodes connected to a body of the unit which provides an estimate of the dose only at a single point. The exposure time, average dose rate, and accumulated dose can be recorded and displayed using the unit. Four sensors left an unnoticeably small trace on the image. As it can be conveniently attached to different parts of the body, it is widely used for various purposes. Surface doses in front of the gonads are measured in the AP, AP with shielding, and PA configurations. After the dose was measured regarding the PA configuration, the phantom was placed approximately 30 cm away from the detector. The distance between the tip of the fingers and the detector is 30 cm, which is the average length of the foot.

In the AP configuration, there is no gap between the phantom and the detector, as the hip and ankle can be attached to the detector. The experimental phantom and setup are illustrated in Fig. 1. The surface dose was measured at two parts of the body, two of which are on either side of the gonad (denoted as gonad 1 and gonad 2). The experiments were repeated 20 times under the same conditions to ascertain precision and measure the variation of the surface dose at the location of the gonads.

A total of 182 patients, 73 males and 109 females, with the mean ages of 47 and 53 years, respectively underwent routine long bone AP examinations in standing position. All patients were scanned in standing AP position with arms raised above the chest. The X-ray parameters employed in the analysis were tube voltage of 80 kVp, filtration of 2.7 mm, SID of 1.8m, and anode angle of 12.5°. The mAs was controlled by the automatic exposure control system depending on the patient's body thickness. Two of the AEC chambers were active except for the middle of the three. To calculate the effective dose of the patient, the testes, ovaries, and the effective doses were calculated with the PC-based Monte Carlo program (PCXMC) using the dose area product (DAP) measured for the patients in the AP position only.

Because of the difficulty for obtaining the dose on AP and PA position from one patient due to ethical issues, the DAP measured in the AP position was used to calculate the testes, ovaries, and effective doses in the PA position using the PCXMC. To calculate organ and the effective dose in PCXMC, their tissue weighting factors were used according to ICRP 103 definitions.

Statistical Analysis

The data were analyzed in SPSS software (version 12.0.1). In the phantom study, the obtained average and standard deviation of gonad dose were repeated 20 times and compared regarding the AP, AP with shielding, and PA positions. In addition, the analysis of variance (ANOVA) was performed to determine radiation dose differences within the aforementioned positions. In the patient study, ANOVA was performed to determine differences in the testes, ovaries, and effective doses between the AP and PA positions. P-value less than 0.05 was considered statistically significant.

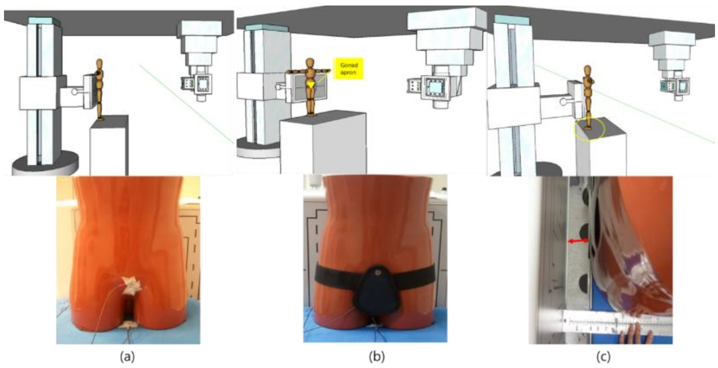

Figure 1. Illustrations of the experimental setup and phantom. (a) AP, (b) AP with shielding, and (c) PA configurations. In the PA configuration, the phantom is placed approximately 30 cm away from the detector due to considering the distance between the foot and detector. In the AP configuration, there is no gap between the phantom and detector as the hip and ankle can be attached to the detector.

Results

Table 1 summarizes the surface doses at the location of the gonads measured with the Unfors PSD in the phantom study. The experimental radiograph images of the phantom at different positions are shown in Fig. 2. The surface dose at the location of the gonads was higher in the AP position than those in the AP with shielding and PA positions by approximately 3.1 and 9.9 times, respectively, depending on the measured location ($P<0.05$).The surface dose at the location of the gonads for the AP with shielding configuration was approximately 3.1 times more than that of the PA configuration ($P<0.05$).

The testes, ovaries, and effective doses of 182 patients in the AP and PA positions are summarized in Table 2. The testes, ovaries, and effective doses in the AP configuration were 15, 1.2, and 2 times higher than those in the PA configuration, respectively ($P<0.05$, Fig. 3).

Table 1. Results obtained at both sides of the gonads surface dose for the phantom using the Unfors PSD showing the dependence on the position.

Position	Gonad 1	Gonad 2
AP (μ Gy)	318±2.6	317±1.7
AP with shielding (μ Gy)	112±1.3	93±0.9
PA (μ Gy)	36±0.2	28±0.3

Table 2. Testes, ovaries, and effective doses in the AP and PA positions using PC-based Monte Carlo program.

Dose	AP	PA
Testes dose (mGy)	1.5±0.9	0.1±0.0
Ovaries dose (mGy)	0.5±0.2	0.4±0.1
Effective dose ICRP 103 (mSv)	0.2±0.1	0.1±0.0

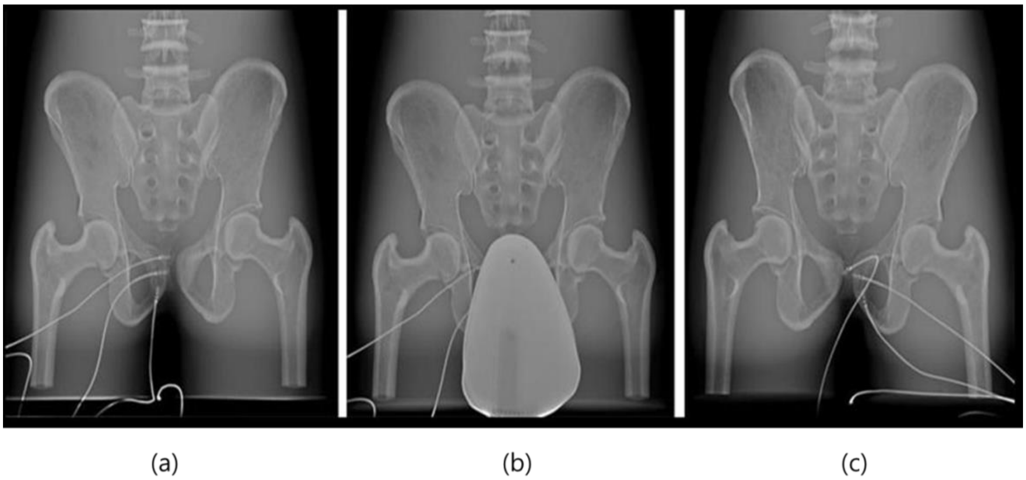

Figure 2. Experimental radiograph images of the phantom for (a) AP, (b) AP with shielding, and (c) PA configurations.

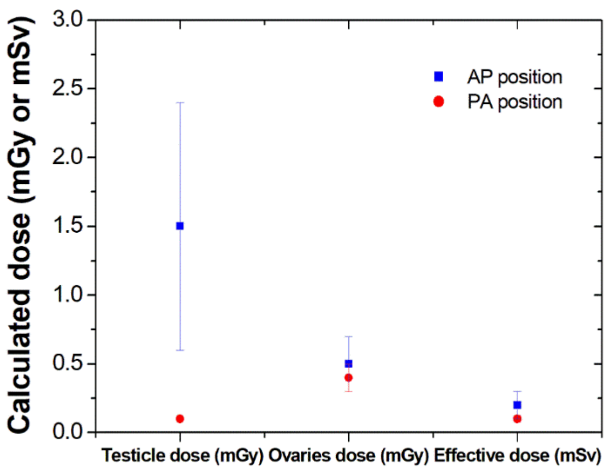

Figure 3. Testes, ovaries, and effective doses using the PC-based Monte Carlo program showing the significant differences between the AP and PA positions.

Discussion

With regard to the results obtained from the phantom study, the radiation dose was the highest in the AP configuration (considered to be the original setting of the method), as the X-ray beam was attenuated as it passes through the body. The gonads are superficial organs; therefore, they are exposed to larger radiation in the AP configuration. The surface dose at the location of the gonads was smaller in the PA position compared to that of AP by approximately 10 times. The gonads in the PA configuration are at a larger distance from the body surface, compared to the AP configuration.

In the spine radiographic imaging, breast dose and effective dose are smaller in PA configuration compared to that of AP [18-20]. The breast, which is sensitive to radiation, is a superficial organ similar to gonads. In addition, the surface dose at the location of the gonads is smaller in the PA configuration than in AP with shielding. This can be explained by a larger attenuation exhibited by radiation within the body compared to the lead material of the shield. Furthermore, the gonad shielding poses problem as the femoral head is covered owing to its close proximity to the gonad in the AP configuration with shielding. Previous studies have reported that low-quality images were obtained by an incorrect shield placement in pelvic examinations [17]. In addition, examinations in the AP configuration with shielding are not convenient as the gonad shielding depends on the patient's size.

According to the findings of the present study, the results reflected the differences in organ location. For the testes, which are superficial organs, the calculated dose was determined by the primary beam. When identical database access points were used to calculate the doses in the AP and PA configurations, the obtained effective dose was higher 1.9 times in the AP configuration than in that of the PA, as the sensitive organ was located in the superficial area.

The obtained results of this study suggested that the PA position can be used to reduce the dose on the gonads in terms of long bone examinations in standing position. This result has been reported in a previous study [21]. However, owing to the length distortion in the PA images, they were not used in clinical practice, which motivated to shield the gonad against radiation using lead materials in order to lower the gonad dose [22]. However, this study demonstrates that the gonad dose in the PA configuration is lower than that in the AP with shielding configuration. This suggests that a clinical agreement between the Department of Radiology and Orthopaedic Surgery is needed to propose how to use the PA images based on a quantitative evaluation of the PA image distortion.

In terms of the distortion images, the distal tibia can be magnified as the patient would be 30 cm away from the detector in the PA configuration. With respect to the center of gravity line in the body [23], the center of the hip joint is in front of the center of gravity line, while the center of the ankle joint is behind it. Therefore, the image magnification depends on the anatomy owing to the differences in distance from the detector to the body. The image in the AP configuration could be magnified significantly more at the femur than at the tibia, as the distance between the femur and detector is larger than that between the tibia and the detector.

Although the tibia image was magnified owing to the distance between the foot and detector, the femur image was not significantly magnified in the PA configuration. In the existing AP position, a localizer method was used to correct the length distortion attributed to the magnification. If the PA position is used by a localizer method, the length distortion could be predictable. In addition, it can be applied to follow-up patients who already have information on the length and alignment of the long bone, which can contribute to lower radiation dose among these patients. However, for effective clinical applications, further studies on the quantitative evaluation of the PA image distortion are required.

In the study of the phantom, the pelvic region was only exposed to radiation by assuming that the scattering effect was random at all positions because it evaluated the tendency of gonad dose reliance on positions. However, in the patient case, due to the influence of the scatter effect, the different gonadal dose could arise.

Conclusion

Long bone examinations in standing position with PA configuration can minimize the patient exposure to radiation dose. The radiation dose was lower in the PA compared to the AP configuration with shielding. This allows for the reduction of costs attributed to the shielding. Therefore, these findings demonstrated that long bone examination in the standing position with PA configuration could efficiently reduce gonadal exposure dose and effective doses.

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