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Optimization of Organ Dose and Reduction of Radiation Exposure in Portable X-ray Imaging of Neonates: Utilizing the ALARA-GR Program

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ABSTRACT

Portable X-ray imaging is vital for neonates, especially those with very low birth weight (VLBW), in neonatal intensive care units (NICUs), but improper collimation and variations in incubator structures can lead to increased radiation exposure and compromised image quality. This study aimed to evaluate the impact of collimation settings on neonatal organ doses using the ALARA-GR program to optimize radiation exposure and raise awareness among radiologic technologists. Simulations were conducted for neonates undergoing chest and abdominal X-rays with standard dose conditions (60 kVp, 1.25 mAs) and two different field sizes: a properly collimated field (5×7 inches) and a larger, uncollimated field (8×10 inches). Results showed that gender-based differences in organ doses were minimal, but female neonates received significantly higher doses in the uterus, ovaries, and bladder compared to male neonates. Increasing the field size from 5×7 inches to 8×10 inches resulted in substantial increases in organ doses, with doses in critical organs such as the uterus, prostate, testes, and bladder rising by factors of 9, 10, and 12, respectively. The study concluded that expanding the exposure field increased organ doses by 2.4 times for chest X-rays and 1.9 times for abdominal X-rays. Proper collimation significantly reduced radiation exposure, highlighting the importance of standardized collimation training to improve neonatal radiographic safety and minimize unnecessary radiation exposure in NICUs.

Keywords: *Neonatal Patients, Very low birth weight, incubator, portable X-ray, ALARA-GR program*

1. INTRODUCTION

Portable X-ray imaging of neonates within incubators is commonly performed with the detector placed on a tray beneath the incubator. This setup helps maintain the neonate's respiratory stability and temperature while preventing various complications, making incubators an optimal choice [1]. However, this approach has disadvantages. Previous studies have shown that differences in structural parameters of the incubator, such as Source-to-Image Distance (SID) and Object-to-Image Distance (OID), can significantly impact the absorbed organ dose in neonates [2]. Furthermore, the mattress situated between the neonate and the tray of incubator can degrade X-ray image quality [3, 4]. Research has demonstrated that placing the X-ray detector on the tray under the mattress has a 6–15% attenuation effect and that removing such structural components can improve the Contrast-to-Noise Ratio (CNR) by over 21% [5].

Neonates requiring intensive medical care are often admitted to neonatal intensive care units (NICUs), where those born with Very Low Birth Weight (VLBW, <1500 g) are exposed to frequent radiographic examinations. Primary reasons for X-ray imaging in neonates include central venous line (CVL) insertion, nasogastric (NG) tube placement, peripherally inserted central catheter (PICC) line placement, gastrointestinal evaluations, and respiratory function assessments [6-7]. One study reported that 88 neonates underwent a total of 306 radiographic examinations [8], while another study found that VLBW neonates underwent an average of 10.6 (ranging from 0 to 95) radiographic examinations during hospitalization [9].

Due to structural constraints of incubators, accurate positioning and proper collimation optimized to a neonate's body size are challenging, leading to unnecessary radiation exposure [8]. Inadequate collimation increases scatter radiation, posing Although reducing the number of radiographic examinations is crucial, optimizing collimation to minimize unnecessary radiation exposure is equally important. Therefore, this study aimed to assess the impact of collimation settings on neonatal organ doses using the ALARA-GR (As Low As Reasonably Achievable- General Radiography) program and to promote awareness among radiologic technologists.

2. MATERIAL AND METHOD

The Korea Disease Control and Prevention Agency (KDCA) developed the ALARA-GR program to optimize radiation exposure by calculating patient dose according to age, gender, and many other factors in general radiographic examinations [14]. Based on Monte Carlo N-Particle (MCNP) simulations, the ALARA-GR program allows users to input various parameters, including examination type, tube voltage (kVp), tube current (mAs), filtration thickness, focus-to-skin distance, gender, and age, to assess radiation effective dose.

For this study, dose evaluations were conducted using the ALARA-GR program (Figure 1). A total of eight evaluations were performed, setting a patient age of 0 years, height of 48 cm, weight of 3 kg, and both male and female genders. Examinations included chest and abdominal X-rays. The standard dose conditions were set at 60 kVp and 1.25 mAs. Two field sizes were analyzed: a properly collimated field of 5×7 inches and a larger field of 8×10 inches, which included unnecessary exposure regions.

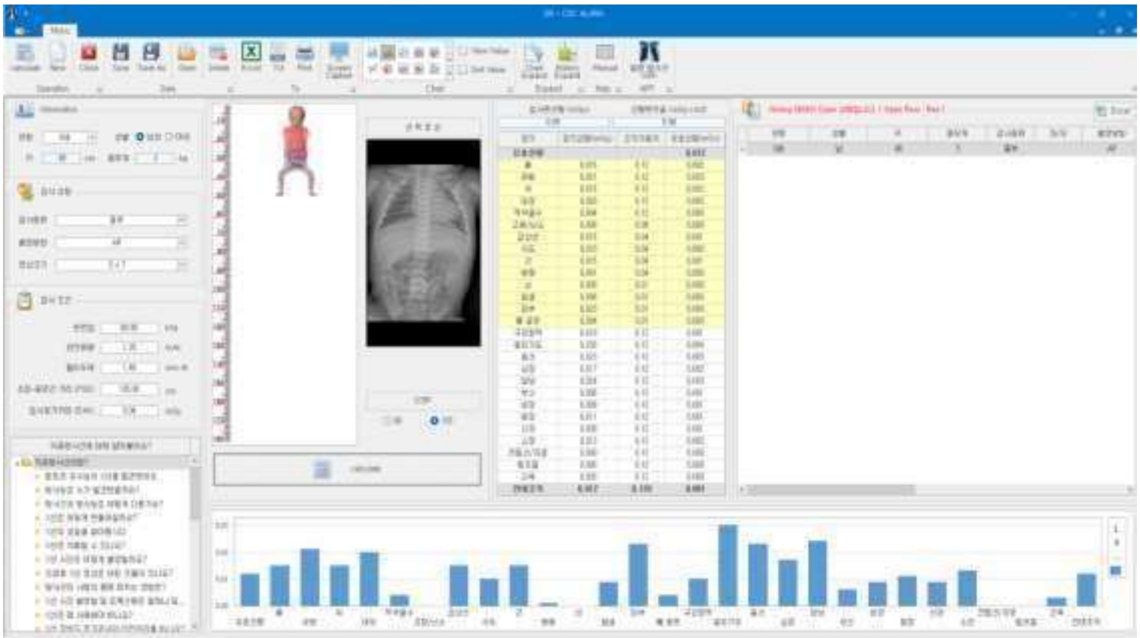

Figure 1. Organ dose assessment interface in neonatal X-ray imaging using the ALARA-GR program

3. RESULT

This study found that under identical examination conditions, gender-based differences in absorbed organ dose were within ± 10% for both chest and abdominal X-rays. However, in chest X-rays, absorbed doses in the uteri and ovaries of female neonates were more than four times higher than those in male neonates. The observed dose on bladder was also approximately twice as high in female neonates. For abdominal X-rays, the absorbed dose in the prostate of male neonates was more than twice that in female neonates.

When the field size was increased from 5×7 inches to 8×10 inches while maintaining identical examination conditions, chest X-ray results showed dose increases in various organs, including salivary glands (1.4×), small intestine (1.8×), large intestine (1.4×), uterus/prostate (9×), testes (10×), bladder (12×), skin (1.5×), bone surface (1.8×), red bone marrow (1.5×), and muscle (1.7×) (Figure 2). Similarly, for abdominal X-rays, dose increases were observed in the esophagus (1.7×), thymus (6×), lungs (4×), heart (8×), skin (1.6×), bone surface, red bone marrow, and muscle (each 1.5×).

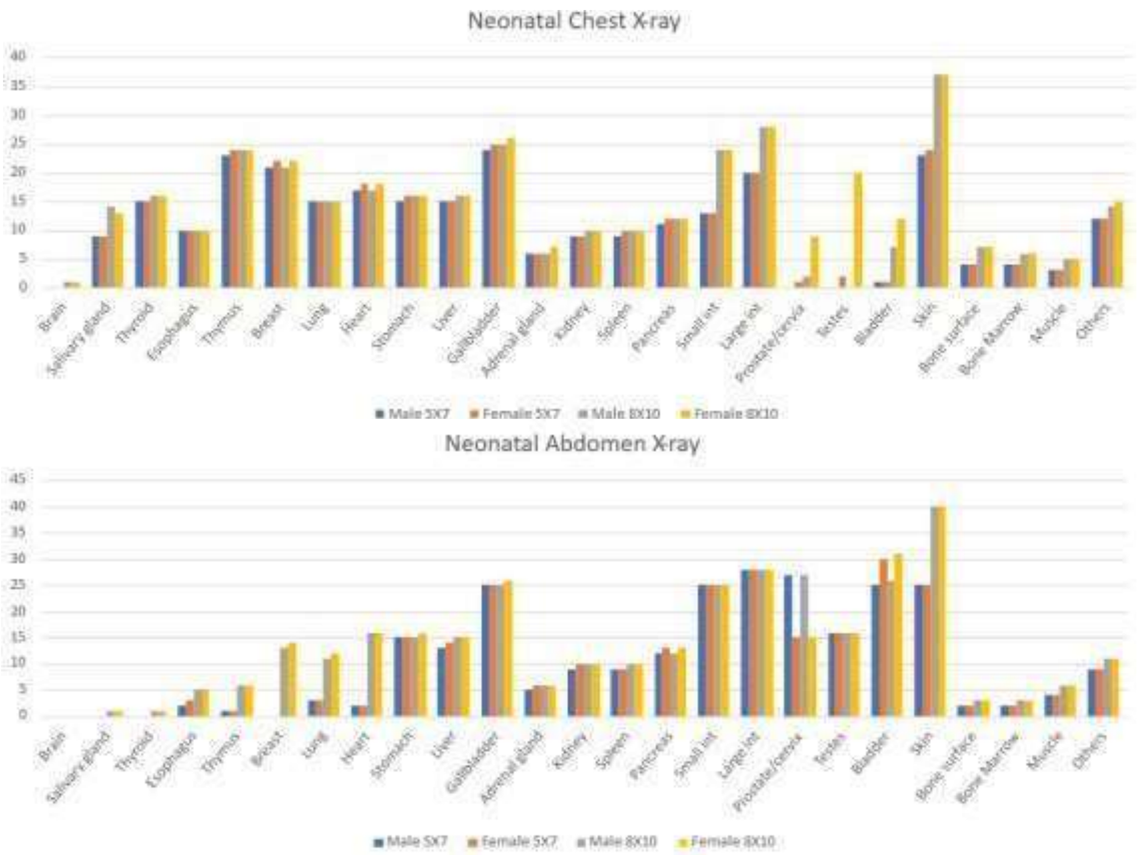

Figure 2. Organ dose evaluation results for neonatal X-ray imaging using the ALARA-GR program. Chest and abdominal X-rays were performed by field size and gender (μGy).

4. DISCUSSION

Increasing the field size from 5×7 inches to 8×10 inches led to an average increase in organ dose of 2.4 times for chest X-rays and 1.9 times for abdominal X-rays. Efforts to minimize unnecessary organ dose should begin with proper collimation to limit the exposure area [15]. One study found that over 99.75% of pediatric intensive care unit radiographic images included excessive anatomical exposure, resulting in unnecessary radiation doses [16]. Another study reported that only 55% of neonatal chest X-ray images exclusively contained the thoracic region, while 45% included additional non-thoracic areas [17]. Furthermore, in chest X-rays, 85% included the entire abdomen and 45% included the cervical region, while in abdominal X-rays, 62% included the femur and 31% exposed the male reproductive organs [18]. The presence of an acrylic canopy on the incubator can make tight collimation adjustments challenging. However, proper patient positioning and restricting the collimation field to the patient's body size can reduce both primary radiation dose to the neonate and secondary radiation exposure to surrounding patients and medical staff.

Previous studies have reported that entrance skin doses for neonatal radiographic examinations range from 36 to 74 μGy, depending on exposure conditions [19-22]. These values are below the International Electrotechnical Commission safety threshold of 80 μGy [19]. However, cumulative radiation dose increases as imaging frequency increases due to medical necessity. While reducing the number of X-ray examinations is crucial, optimizing collimation to decrease radiation dose is equally important. This study found that reducing the field size from 8×10 inches to 5×7 inches decreased radiation dose by an average of 30% in both chest and abdominal X-rays.

A previous study found no significant correlation between radiologic technologists' experience and collimation accuracy [10]. Without proper education, maintaining optimal collimation remains challenging regardless of radiologic technologists' experience. To enhance collimation quality, tailored training programs and quality control measures for radiologic technologists are essential. Standardized protocols for exposure field adjustments can improve consistency in radiographic practice [23]. Implementation of radiation safety programs in NICUs has been shown to improve awareness among medical staff and reduce unnecessary radiographic examinations. One study has demonstrated a reduction in general X-ray examinations per neonatal admission from 4.2 to 2.4 over five years following program implementation [24]. Increasing awareness of radiation safety can reduce radiation exposure for both neonates and healthcare providers.

5. CONCLUSION

This study highlights the critical impact of collimation settings on neonatal organ doses in portable X-ray imaging, emphasizing the necessity of radiation dose optimization. Using the ALARA-GR program, we demonstrated that expanding the exposure field significantly increases organ doses, with some organs experiencing up to a 12-fold increase in radiation exposure. Proper collimation was shown to effectively reduce unnecessary radiation, underscoring the importance of standardized training for radiologic technologists. Given the heightened radiosensitivity of neonates and their frequent exposure to diagnostic imaging, implementing rigorous collimation protocols and radiation safety programs in NICUs is essential. These measures can enhance awareness among healthcare providers, minimize unnecessary radiation exposure, and ultimately improve the safety of neonatal radiographic procedures.

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