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Reduced radiation dose and improved image quality using a mini mobile digital imaging system in a neonatal intensive care unit

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ABSTRACT

This study was aimed to assess the radiation dose and image quality of a mini-mobile digital imaging (mini-DI) system for neonatal chest radiography and compared to conventional digital radiography (DR). A total of 64 neonates were examined and anatomical landmarks were assessed. The entrance surface dose of mini DI and conventional DR was 26.64 ± 0.15 μGy and 49.11 ± 1.46 μGy, respectively ($p < 0.001$). The mean SNR values for mini-DI and DR were 233.2 ± 5.1 and 31.6 ± 1.2, and 10% MTF values were 131 and 161 μm. A newly developed mini-DI is capable of preserving the diagnostic information with dose reduction in neonates under intensive care.

1. Introduction

Several studies have evaluated the risks associated with radiation exposure during radiographic examinations, such as computed tomography (CT) and digital radiography (DR) scans, in pediatric [1] and middle-age [2] subjects. These showed that an important factor in radiation-induced risk is the age at which exposure takes place, and fetuses and neonates are the most sensitive. Therefore, the age at the time of radiation exposure is critical in the determination of radiation risk.

During fetal development and early childhood, intense tissue proliferation and differentiation take place, and proliferating cells are more likely to develop into cancer [3]. Especially, the smaller body of premature infants places all organs within the useful beam, resulting in a higher effective dose per radiograph than may be the case with older children and adults. Therefore, radiation doses for neonatal X-ray examinations should be minimized.

The World Health Organization (WHO) reported that preterm birth rates are increasing in most countries for which reliable data are available [4]. Preterm birth is one of the most important single conditions in the global burden of disease analysis given the high mortality and the considerable risk of lifelong impairment [5]. In a neonatal intensive care unit (NICU), DR is frequently used in preterm neonates together with bedside chest radiography, because premature infants are born with immature organs, and frequently have complications of severe illness, such as respiratory distress syndrome and patent ductus arteriosus. Therefore, premature neonates are required to undergo a large number of radiographic examinations depending on the birth weight of the infant, gestational age and medical problems [6]. Moreover, repeated follow-up chest X-ray examinations are required to reduce the mortality rate of prematurity after tube and catheter placement and monitoring of health status [7]. In terms of radiation dose safety, reduction of the radiation dose to neonates is an important issue. The guidelines of the European Union (EU) [8] and American College of Radiologists (ACR) [9,10] suggest that the mean entrance surface exposure (ESE) should range from 0.05 to 0.3 mGy per exposure in newborns, infants and children. However, few studies have addressed radiation dose reduction for neonates, including preterm neonates.

In recent years, many DR systems, including mobile digital imaging systems, have been developed for radiographic examinations in operating rooms, emergency rooms and NICUs. Recent advances in DR

Abbreviations: ACR, American college of radiologists; ALARA, As Low as Reasonable Achievable; CNR, contrast-to-noise ratio; CT, computed tomography; CV, coefficient of variance; DR, digital radiography; ESD, entrance surface dose; EU, European union; ICRP, International Commission on Radiological Protection; LNT, linear-no-threshold; mini-DI, mini-mobile digital imaging system; MTF, modulation transferring function; NICU, neonatal intensive care unit; NRPB, National Radiological Protection Board; SDD, source-to-detector distance; SNR, signal-to-noise ratio; SOD, source-to-object distance; TFT, thin film transistor; TLD, thermoluminescent dosimeter.

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Fig. 1. Photograph of the mini digital imaging system. The system comprises an X-ray source, flat panel detector, and image viewer including an imaging processing module.

technology have resulted in smaller and lighter systems that are more mobile, and flat-panel detectors are now used [11–14]. Flat-panel detectors typically offer a detective quantum efficiency twofold that of film-screen systems. DR systems with flat-panel detectors exhibit superior imaging performance at a lower radiation dose in clinical radiography due to their relatively high detective quantum efficiency, depending on the detector sensitivity [15–17]. The improved detective quantum efficiency enables dose reduction while maintaining image quality [18, 19]. Recently, we developed a mini mobile digital imaging (mini-DI) system with a flat-panel detector [17]. The imaging system has a number of advantages including small size, absence of spatial distortion, enhanced stability and wider dynamic range. We hypothesized that the system could be used for chest imaging to reduce radiation dose and improve image quality.

Therefore, the aim of this study was to examine the feasibility of chest imaging using our mini-DI system and evaluate the radiation dose received by neonates during radiographic examinations.

2. Materials and methods

2.1. Mini-mobile digital imaging system

A mini-DI system (MX-DRF0815, meteor®, NanoFocusRay Co. Ltd., Jeonju, Korea) with a complementary metal-oxide-semiconductor (CMOS) flat-panel detector was used in this study. The flat-panel detector is based on a high-resolution CMOS sensor-based flat panel with a 2352 × 2944 matrix and pixel size of 49.5 μm. The X-ray source generates 40–80 kVp and 0.25 mA with a focal spot size of 0.033 mm. Also, the source was used pulsed X-ray mode to reduce patient's radiation dose instead of continuous X-ray mode. The dimensions of the mini-DI system are 324 mm (width) × 470 mm (depth) × 690 mm (height), and the maximum field of view (FOV) is 112 mm (width) × 140 mm (height). The mini-DI system weighed 23 kg and an external interface was designed for portability. The system offers both a radiographic imaging mode and a fluoroscopic imaging mode. The fluoroscopy mode is two options as 2 × 2 binned fluoroscopy mode (at 30 frames per second, fps) and 4 × 4 binned low-dose fluoroscopy mode (at 60 fps). The control panel included basic functions such as browsing, viewing, and control of X-rays. The X-ray control function allows the voltage (kVp) and amperage (mA) values to be controlled (Fig. 1).

For comparison, we used a conventional mobile DR (conventional DR; EFX vision, Shimadzu MobileArt, Kyoto, Japan) with a thin-film transistor (TFT) flat-panel detector with a 2800 × 3408 matrix and pixel size of 125 μm. The X-ray generation conditions in the two systems are as follows: tube voltage of 75 kVp and current of 0.09 mAs in mini-DI and voltage of 60 kVp and current of 1.4 mAs in conventional DR. These parameters are optimized for clinical settings. An automatic exposure control system was used for radiation dose reduction while maintaining image quality in both systems. The protocol was used for radiographic examinations of a line phantom (X-ray test pattern type 18, FUNK, Germany) and neonates. Image post-processing techniques were applied for quality control of phantom images and patient scans using both forms of digital imaging equipment. All images processed noise reduction and contrast enhancements.

2.2. Measurements of radiation dose and image quality

The radiation dose was calculated using the method of the International Commission on Radiological Protection (ICRP) [20]. Entrance surface dose (ESD) is the absorbed dose including the contribution from backscatter [21]. The ESD measurement was performed using a dosimeter (RaySafe Xi, Unfors Raysafe, Sweden). To determine the ESD, source-to-detector distances (SDDs) were as follows: 100 cm for conventional DR and 45 cm for mini-DI. The detector angle was fixed at 90° to the direction of radiation beam. The ESD was measured ten times in radiography mode for conventional DR and in pulsed radiography mode for mini-DI.

Image quality was assessed by determining the signal-to-noise ratio (SNR) and spatial resolution [22]. The SNR is the ratio of measured signal to measured system noise and was calculated as the ratio of the value of a lead bar (0.05 mm thick) to the noise. The mean SNR values of six image sets were obtained for each system. The modulation transfer function (MTF) has been used to evaluate the spatial resolution of imaging systems [23], and in this study was measured using a line phantom (X-ray test pattern type 18) to generate MTF curves. The MTF curve was normalized for each system.

2.3. Patient study

This study was approved by the Institutional Review Board (IRB) at our university hospital. The local IRB classified this study as a prospective, non-interventional trial. The study design was explained to the parents, and patients were recruited only when their parents' consent was granted. A total of 64 premature patients in a NICU were admitted

Table 1
Entrance surface dose and image quality.

System	Conventional DR	Mini-DI	*p*-Value[a]
Imaging parameters	60 kVp, 1.4 mAs	75 kVp, 0.09 mAs	–
FOV size	250 × 320 mm	112 × 140 mm	–
ESD (μGy)	49.11 ± 1.46	26.64 ± 0.15	<0.001
SNR [CV, %]	31.6 ± 1.2 [3.8%]	233.2 ± 5.1 [2.2%]	0.002
10% MTF	131 μm	161 μm	0.05

FOV: field of view; ESD: entrance surface dose; SNR: signal-to-noise ratio; CV: coefficient of variation.
SNR and CNR values are presented as means ± SD [CV %].
[a] The difference in ESD, SNR and MTF values between two systems was analyzed by Mann-Whitney *U* test.