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Optimisation of radiation dose and image quality in mobile neonatal chest radiography

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Purpose: To optimise the radiation dose and image quality for chest radiography in the neonatal intensive care unit (NICU) by increasing the mean beam energy.

Methods: Two techniques for the acquisition of NICU AP chest X-ray images were compared for image quality and radiation dose. 73 images were acquired using a standard technique (56 kV, 3.2 mAs and no additional filtration) and 90 images with a new technique (62 kV, 2 mAs and 2 mm Al filtration). The entrance surface air kerma (ESAK) was measured using a phantom and compared between the techniques and against established diagnostic reference levels (DRL). Images were evaluated using seven image quality criteria independently by three radiologists. Images quality and radiation dose were compared statistically between the standard and new techniques.

Results: The maximum ESAK for the new technique was 40.20 μGy, 43.7% of the ESAK of the standard technique. Statistical evaluation demonstrated no significant differences in image quality between the two acquisition techniques.

Conclusions: Based on the techniques and acquisition factors investigated within this study, it is possible to lower the radiation dose without any significant effects on image quality by adding filtration (2 mm Al) and increasing the tube potential. Such steps are relatively simple to undertake and as such, other departments should consider testing and implementing this dose reduction strategy within clinical practice where appropriate.

Introduction

Radiography is the most common imaging method used to monitor progress of patients in the neonatal intensive care unit (NICU). Due to the theoretical increased risk for stochastic effects of X ray exposure to these patients, good practice requires planned measures to ensure that imaging procedures are justified and carried out with the minimum radiation dose appropriate to the diagnostic task.[1–5] This process of optimisation requires the balancing of both, radiation dose and image quality. Several researchers have investigated methods for patient dose assessment in radiography,[6–9] while others have focused on the relationship between image quality and radiation dose.[10–12] Studies of the latter kind were considered in the preparation of the *European Guidelines on Quality Criteria for Diagnostic Radiographic Images in Paediatrics* in 1996. This document establishes specific criteria for acceptable image quality of the most common paediatric radiography studies, and proposes reference values for entrance skin dose based on the distribution of doses documented during the European trials which helped produced these guidelines.[13]

The worldwide replacement of screen-film systems by digital image receptors in the mid-nineties unintentionally introduced the risk of a *dose creep*, due to the low noise images produced by overexposed image receptors.[14–16] Effective quality assurance process in modern radiography requires the monitoring of exposure indexes (EI) to verify that image receptors are not underexposed, thus producing noisy images, or overexposed and leading to higher patient radiation dose than necessary. To ultimately verify the level of optimisation in a local centre, comparison of radiation doses against appropriate diagnostic diagnostic reference levels (DRL) is useful and is recommended in professional radiology guidelines and by expert organisations.[17–20]

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The aim of this study was to investigate whether an increase in mean beam energy, from additional filtration and increased tube potential, can maintain image quality but reduce the radiation dose during mobile neonatal chest radiography.

Materials and methods

The Research and Ethics Committee for our School of Medicine approved this study. All X-ray images were acquired using an AMX4 mobile X ray unit (General Electric, Milwaukee, WI, USA) with inherent tube filtration of 0.7 mm Al. This system was subject to regular preventive maintenance and annual quality control (QC). QC tests were performed prior to the study and showed that tube voltage accuracy was within ±2% (between 50 kV and 90 kV). The Half Value Layer at 80 kV was 3.3 mm Al, air kerma per mAs differed from average by up to −7% from 2 mAs to 10 mAs, and a up to 2.4% from 16 mAs to 80 mAs. Coincidence of collimator light and radiation beam at a 1 m source-to-image distance (SID) had a maximum error of 10 mm. All of these parameters were well within the equipment specifications and the QC history of the mobile unit. X ray images were acquired using a Direct View CR-850 reader and CR plates (Carestream, Rochester, NY, USA). Receptor exposure in this reader is indicated by an EI for which the manufacturer suggests a target range between 1800 and 2200.[21] This is a general target range and there were no specific recommendations as to what projections they should apply to. An EI range of 1800–2200 was documented and was routinely used in study site's radiography procedures.

Entrance surface air kerma (ESAK) is one of the dosimetric quantities recommended in the Code of Practice 457 of the International Atomic Energy Agency for Patient Dose Assessment,[22] and in the Report 74 of the International Commission on Radiation Units and Measurements (ICRU).[23] In this study no dosimetry measurements were made on actual patients; ESAK was used as surrogate for the delivered radiation dose, and it was calculated using a phantom following the procedure described in the Practice Code 457, and in the Report 74, according to its definition (Equation (1)):

$$ESAK = [IAK/mAs] \times mAs_{px} \times INV \times B \times TF_{inc} \quad (1)$$

where *IAK* is the incident air kerma measured directly on the beam; *INV* is the inverse-square law correction factor due to the difference between the position at which *IAK* is measured and the point of entrance of the beam to the patient; and *B* is the backscatter factor dependent on the energy and field size of the beam. In this study, *B* was set at 1.1 ± 5%, as calculated by Chapple et al.[6] TF_{inc} is the transmission factor of the incubator (5 mm of acrylic plastic measured by a study researcher). Air kerma was measured with a diode-type dosimeter (Piranha, RTI Electronics, Mölndal, Sweden) calibrated for diagnostic beam energies.

Definition of standard and new techniques

Two different techniques for the acquisition of AP chest X-ray images were defined, one representative of the current examination protocol, labelled as *standard*, and another one with a higher tube potential and additional filtration labelled as *new* technique. Full details of both techniques are shown in Table 1.

The standard technique was defined upon review of established technical procedures and the information available. In these procedures, the chest thickness at the xiphoid process was the defining criterion to select the appropriate radiographic technique. Estimated or measured chest thickness was not recorded, but tube potential and mAs were retrospectively available. The technical factors documented by the radiographer on the admission CXR acquired on the first 109 patients (out of 127 admitted to the NICU in the year prior to this study) showed an average (SD) tube potential of 54 (2.7) kVp. 90% of acquisitions were obtained with tube potentials between 50 and 56 kVp. The average (SD) mAs was 3.2 (0.2). The distribution of the EI (Fig. 1) shows that 57 (52%) of the resultant images were within the manufacturer's suggested target range (1800–2200), 11 (10%) were overexposed with a maximum EI of 2289, 41 (38%) were underexposed, with a minimum EI of 1311. There was some concern amongst the research team regarding the possible high rate of underexposed images and the data were discussed with local radiologists. No concerns were expressed regarding the noise levels on the AP neonatal chest X-ray images for this initial period. Subsequently, for the purposes of this study a target range for the EI was set from 1600 to 2200. This is consistent with the results of a study by Peters and Brennan(15), who found that, using the same CR system, the optimal average EI was significantly lower than the one recommended by the manufacturer. Peters and Brennan further recommended that clinicians determine their own target EI values.[15] Tube potential for the *standard* technique was subsequently recorded at 56 kVp.

Table 1
Technical parameters for the standard and new techniques.

	Technique	
	Standard	New
Tube voltage (kVp)	56	62
Tube current (mAs)	3.2	2.0
Added filtration	None	2 mmAl

Tube potential for the *new* technique was set at 62 kV based on the European Guidelines on Quality Criteria for Paediatric Radiology.[13] A further 2 mm Al of added filtration was used to further reduce radiation dose and to avoid the need for a very low mAs (due to the increased kV). To determine mAs for the *standard* and *new* techniques, uniform acrylic plates 5.7 cm and 8.1 cm thick were exposed using different mAs values with the aim to achieve an EI within the target range. Such attenuators were deemed representative of the range of chest thickness typically expected in the NICU, and are consistent with attenuation phantoms often used as surrogates of patients, including neonates.[12,24] 3.2 mAs and 2.0 mAs were chosen for the *standard* and *new* techniques, respectively. Table 2 shows the EI achieved for each attenuator tested and the associated ESAK values.

The mean (range) weight for patients in the NICU was 1.80 (0.55–5.50) kg. The AP chest thickness estimated for that range of patients was 5 cm–10 cm as determined by senior radiographers working in the NICU. This estimation is reasonably consistent with the approximate relationship for weight to chest thickness of neonates reported by Wraith et al.[25] Following further review and discussion with senior radiographers it was considered that the same kV and mAs (for the standard and new technique) would lead to appropriate EI when applied to the range of patients typically encountered on the NICU.

The main physical difference between the *standard* and *new* techniques was the higher beam energy of the *new* technique, and thus some degree of deterioration of radiographic contrast was expected. A preliminary safety comparison of the techniques was performed using a contrast-detail phantom (CDRAD 2.0, Artinis, Amsterdam, NL). This phantom was imaged under 5.7 cm and 8.1 cm acrylic plates which served as patient attenuators. These additional tests ruled out any substantial differences in image quality before the *new* technique was implemented on patients.

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