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Original paper

Evaluating the effect of reduced entrance surface dose on neonatal chest imaging using subjective image quality evaluation

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ABSTRACT

Introduction: As hospitalized neonates are radiosensitive and often require numerous X-rays, institutions should investigate the optimal beam parameter combinations to deliver diagnostically acceptable quality images at the lowest possible entrance surface dose (ESD). Using a subjective approach, this study evaluated the effect of different beam parameter combinations on image quality.

Methods and materials: Five rabbits simulated the neonatal chest. The ESD was reduced using a variation of voltage, tube current and filtration. Eight radiology registrars, blinded to the dose parameter information, ranked the digital X-ray images of three anatomical regions from best to worst using a variation of the multiple rank order method. T-tests compared the average values, obtained from the scores assigned by each observer to images acquired at different ESDs, for each region. The calculated intraclass correlation coefficient (ICC) assessed observer agreement.

Results: Results showed that a 64% dose reduction was achievable by altering the beam parameters. Large variation among the observers was confirmed by an ICC value <0.5. A 95% confidence interval could not conclude that different ESD values, resulting in a 50–77% dose reduction compared to current practice, would result in different overall observed image quality. This was noted for all three regions indicating that no preference existed towards an image acquired with a specific beam parameter combination.

Conclusions: The large variation in observers' opinion of acceptable image quality emphasizes the importance of subjective image quality evaluation in the clinical environment. The rabbit phantom and multiple rank order method are considered appropriate for these evaluations.

1. Introduction

Neonates, especially those born prematurely, often suffer from respiratory and cardiovascular complications and therefore require intensive care and long periods of hospitalization. Radiographs of neonates who are ill at birth may be taken daily, for the first few weeks after birth, to assess the progress of disease, response to treatment, or, in the case of respiratory illness, to assess the placement of endotracheal tubes and intravenous lines.

X-rays fall into the category of ionizing radiation which has the potential to cause cell damage and are therefore associated with a radiation risk. The focus on paediatric dose reduction has increased over the past decade. This can be attributed to dose optimization campaigns, such as Image Gently® by the Alliance for Radiation Safety in Paediatric Imaging creating awareness, as well as popular media articles informing the public about radiation. A good example is an article in The New York Times published in 2011 titled: "X-rays and Unshielded Infants", underlining bad practice and urging practitioners using ionizing radiation to re-evaluate their imaging protocols [1].

Although the radiation dose associated with general X-ray examinations are very low and the medical benefit largely outweighs the risk, there is always a possibility of stochastic effects such as cancer induction. Therefore, it is important to ensure that the dose from these examinations is kept as low as possible, but at the same time maintain images with adequate quality to fulfil the diagnostic requirements. To aid in achieving this goal, the European Commission and the National Radiological Protection Board recommended dose reference levels for neonatal anteroposterior (AP) chest X-ray examinations: entrance surface dose (ESD) $\leqslant$ 80 μGy and ESD $\leqslant$ 50 μGy, respectively [2,3].

The European Commission also recommended the use of a higher kV radiographic technique, 60–65 kV with additional filtration for neonatal AP chest examinations. This differs from the 55 kV and 3.2 mAs with no additional filtration used for neonatal

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AP chest examinations at the X-ray department of Universitas Academic Hospital (UAH), Bloemfontein, South Africa [2]. However, changing the beam parameters to the recommended values will influence the image quality.

Image quality is characterized by physical parameters during the primary image formation stage, such as contrast, noise and resolution, as well as image display parameters and observer perception of image quality. Månsson found that the investigation of physical image parameters alone showed poor correlation to clinical image quality [4]. This may be due to the patient anatomical detail (also referred to as structural noise) that has a large influence on the observer's perception and judgement of image quality [5]. It is therefore important to not only evaluate physical image quality, but also subjective image quality.

Subjective evaluation of image quality can be challenging. Unlike contrast and resolution requirements, no specific value is associated with subjective image quality evaluation. The only requirement is that the images should be diagnostically acceptable and, therefore, it is dependent on the preference of the observer, unless the truth is known e.g. a diagnosis has been confirmed and the observer has agreed with this fact in reading the image. When using subjective evaluation, it is important to select appropriate phantoms that will mimic the clinical scenario.

The aim of this study was to evaluate the effect of different beam parameter combinations on image quality of neonatal chest images, using a live rabbit phantom to simulate the neonatal chest, in an attempt to decrease the ESD compared to current practices.

2. Methods and materials

2.1. Image acquisition and display

Five live, sedated rabbits with a weight of approximately 2000 g were used to simulate the neonatal chest. The anatomical regions such as heart, lungs and diaphragm contribute to structural noise, imitating the clinical situation. Six images at predetermined imaging parameter combinations were obtained for each of the five rabbits i.e. an image at each of the six imaging parameter combinations (Table 1). These imaging parameter ranges were determined using a chicken phantom to minimize the radiation dose to the live rabbits and meet with the requirements of the Institution's Animal Ethics Committee. The kVs ranged between 55 kV and 70 kV with 2 mm additional Al filtration. The mAs were altered to keep the exit dose as close as possible to 10 μGy [6]. The image acquired with 55 kV, 3.2 mAs and no additional filtration (BP5532) was used as the reference image as this is the current protocol at UAH.

Radiographic acquisitions were performed using a Siemens Mobilett XP mobile X-ray unit. Correct performance of the unit was ensured by performing periodic quality control tests as specified by the South African Directorate of Radiation Control [7]. The ESD values were determined using an indirect method similar to the method use by Armpilia et al. [8].

Acquisitions were performed at the same focus to detector distance (FDD) of 100 cm used in clinical practice. The rabbit was positioned on top of the computed radiography (CR) cassette in a posteroanterior (PA) orientation, since this was more reproducible with the field centred at the middle of the shoulder blades and the collimation set to include the entire chest area. The imaging plates were read out within 5 min of image acquisition using the Agfa mobile chest X-ray setting with S = 200 applying MUSICA^2 processing.

Table 1
Beam parameters in order of decreasing entrance surface dose (ESD).

Beam reference*	kV	mAs	Additional filtration (2 mm Al)	ESD (μGy)
BP5532 (image reference)	55	3.2	No	90.9 ± 0.6
BP5516	55	1.6	No	40.4 ± 1.7
BP5532F	55	3.2	Yes	42.4 ± 1.5
BP6020F	60	2.0	Yes	32.7 ± 1.2
BP6620F	66	2.0	Yes	44.7 ± 2.9
BP6610F	66	1.0	Yes	20.4 ± 0.6

* For ease of reference in the text, the beam parameters are included in the reference names of the beam settings used throughout the document.

2.2. Image acceptability evaluation

To establish the acceptability of the diagnostic quality of the images, observers were requested to rate the images using the 5-point scale as shown in Table 2. The mode was calculated for each observer's score. Observers were instructed to ignore problems with positioning when considering the quality of an image as this study was intended to determine the effect of varying ESD on image quality and not the effect of radiographic technique. Observers were allowed to adjust the window width and level of the images according to personal preference as they would have done when evaluating a clinical image.

2.3. Subjective image quality evaluation using rank ordering

Based on the image criteria for new-born chest imaging according to the European Commission, three main anatomical categories were identified for subjective evaluation of image quality in this study, namely: vascular lung pattern (referred to as *lung pattern*), mediastinum, including borders of the heart (referred to as *mediastinum*), and diaphragm together with the costophrenic angles (referred to as *diaphragm*) (Fig. 1).

Image quality evaluation was done using a variation of the multiple rank order method described by Ravenel et al. [9]. Eight radiology registrars in their third to final year of training, blinded to the dose parameter information, ranked the images. Two images were simultaneously displayed on Barco 3MP reporting monitors that complied with the AAPM TG18 requirements [10]. Observers were required to choose one of the two displayed images. The image not selected was replaced by another image, and the process was repeated until the best image was identified. This visual evaluation process was then repeated for the remainder of the images until a ranking from best (rank = 1) to worst (rank = 6), according to the observers' professional judgement and individual preference, was obtained for each rabbit image set. The three anatomical regions mentioned above was evaluated individually.

Table 2
Image quality scoring criteria (5-point scale).

Score	Diagnostic quality	Explanation
1.	Non-diagnostic quality with high level of noise	Recommend that the examination should be repeated
2.	Borderline diagnostic quality with high level of noise	Study considered barely passable, might recommend a higher dose next time
3.	Acceptable diagnostic quality with moderate noise level	The image is adequate and the dose could possibly be reduced without compromising image quality
4.	Good diagnostic quality with moderate to low noise level	The dose should be reduced
5.	Excellent diagnostic quality with low level of noise	The dose should definitely be reduced