Rhys Morris

CoRIPS Research Grant 166

£4,770 awarded

Title: Optimisation of image quality and radiation dose for incubator imaging

Principle Aim

The principle aim of this project is to optimise image quality and radiation dose for neonates who require imaging whilst in the incubator.

Objectives:

1. Explore the impact of incubator design (attenuation) on image quality and radiation dose for both direct and tray acquisition.

2. Explore the effect of using a standard FRD in comparison to maximum achievable FRD on image quality and radiation dose when imaging a neonate in the incubator.

3. Explore the effect of reducing mAs for both direct and tray exposure

The above objectives will be explored using both DR and CR mobile equipment

Neonates on neonatal units often require many radiological examinations during their first weeks of life (Del Rio, et al 2016). Due to the increased sensitivity of newborns to long term risk of radiation exposure it is important to reduce their dose where possible without compromising image quality. Jiang et al, (2015) also reinforces this by suggesting that neonatal units is one of the most critical areas for dose optimisation, as it has the youngest patients, who often require multiple imaging exams. Neonates are maintained in the incubator and warmer systems to ensure a well-regulated, stable and protective environment which also reduces chance of cross-infection. Carver and Carver (2012) suggested that opening the incubator may change temperature within the incubator which can adversely affect the neonate. They are also susceptible to noise and vibration which should be kept to a minimum. To perform radiographic imaging of neonates, a mobile radiography system is used with an image receptor (IR). The radiographer can place the neonate directly onto the IR or use the built in tray under the incubator; both these methods have their limitations (Ehrlich and Coakes, 2016). Placing the neonate directly onto the IR results in an image without magnification and allows

for simple visual check of collimation by means of the contrast provided by the black background of the IR. In addition, there are no objects between the neonate and the IR resulting in limited additional attenuation from other structures. Placing the IR in the tray on the other hand eliminates the unnecessary movement of the neonate during imaging and therefore minimising the risk of accidental displacement of catheters, endotracheal tubes or other support devices. It also has potential benefits from a cross contamination perspective. When the IR is placed in the tray, it makes judgement of collimation and alignment more difficult, and also the radiation beam must pass through the extra thickness of the mattress and of the IR holder system, which recues bam attenuation and hence detector dose (Mutch and Wentworth 2007; Jiang et al., 2016; Rizzi et al., 2013;Del Rio et al., 2016). A further variable is the presence or removal of the incubator canopy/lid; typically it is left in place, but this provides a further reduction in beam attenuation.

As seen above, issues with incubator imaging are often described and acknowledged within the literature however the progression from knowing the problem exists to overcoming and solving the problems are limited. The limited studies that have already explored incubator imaging have many limitations which make the evidence very difficult to translate into clinical practice. These limitations include the lack of anthropomorphic phantoms used for visual image quality analysis, the authors being used as observers, the use of exposure index and detector dose as units and the fact that only some variables are individually explored instead of it being a more holistic experiment involving various variables and parameters. In addition, with the limitations in mind, there is often an assumption that acquisition parameters will need modifying to increase radiation dose due to attenuation of the beam by various incubator components, for example Rizzi et al (2013) commented that the radiation beam must pass through the extra thickness of the mattress and of the image receptor holder system, possibly incurring attenuation and alteration of the energy spectrum requiring and increase in exposure parameters. These assumptions need to be proven with a high quality optimisation study exploring the impact that the above two method of imaging a neonate within an incubator has on visual image quality and effective dose.

Method

This project will be registered with the service improvement team within the study's institution as ethical approval is not required following discussion with the R&D department.

In order to better inform the below method, a preliminary study has been conducted by a colleague. They've sent a current working practice survey to all x-ray departments with a neonatal unit across Wales and North West England to explore variation in practice. The response rate was over 60% with a 100% response from Wales. This study is currently being reviewed by Radiography Journal and will therefore be referred to as 'the current working practice survey in review' within this proposal below.

Imaging Equipment

Images will be acquired using two different portable systems. One will be a Shimadzu Mobile DaRt Evolution (Shimadzu Corp., Kyoto, Japan) mobile x-ray unit. For the images captured using this Shimadzu mobile unit, the same 18x24cm Fuji IP HR-V image receptor will be used throughout the study and consequently processed using a Fuji FCR Capsula XII with 50-micron resolution. The second mobile machine used will be a DR Samsung GM85 mobile. For this unit the images will be captured using a 25x30cm wireless, lightweight S-Detector™ (MIS Healthcare, London)

Incubator

The experimental images will be acquired on two different incubators for comparison which are: Drager Caleo and GE Giraffe which were found to be the two most commonly used incubators within neonatal units across Wales and North West England according to 'the current working practice survey in review'. Both the above incubators come with an integrated x-ray tray.

Anthropomorphic phantom

For this study, the commercially available Gammex 16 neonatal anthropomorphic phantom will be used (Rothband LTD). The Gammex phantom simulates a 1 - 2 kg neonate anatomically and has the same radiation attenuation characteristics as a real neonate. According to Smans (2010) this phantom is the only phantom found within the literature that is both anatomically and radiographically similar to a real neonate.

Visual display and monitors

High quality 24.1 inch NEC (EA243WM) monitors with a resolution of 5 megapixels will be used to display the images for visual evaluation and also for calculating CNR.

Imaging technique

The phantom will be positioned in the incubator for a standard supine AP chest ensuring the median sagittal plane is coincident with, and at right angles to the incubator tabletop and tray beneath (Carver and Carver, 2012). The centring point will be fixed in the midline at the level of the sterna angle (between the nipples) with the collimation adjusted to the region of clinical interest for each FRD to include the lung apices, lateral margin of both lungs, cariophrenic and costophrenic sucli in accordance with radiographic textbooks (Carver and Carver 2012; Whiteley et al., 2015). This area of clinical interest will be marked with tape in order to maintain the collimation size for all exposures. This allows for the same area of coverage at the surface of the phantom to ensure the collimation does not affect radiation dose or image quality.

Experimental design

For the first phase of the experimental study, three independent variables will be used, these were informed by 'the current working practice survey in review': direct v tray (attenuation of canopy only v canopy, mattress and incubator tabletop), FRD (standard 100cm v maximum achievable), and portable machine (CR V DR). All other acquisition parameters will be kept consistent and according to those typically employed in clinical practice and within the literature as suggested by Rizzi et al. (2014) plus informed by 'the current working practice survey in review'. These are: 60kV tube voltage, 1.2mAs, small focus (0.6mm), and 3.2mm Al total filtration.

The second phase of the experiment will focus on mAs. From the standard mAs used for phase 1, which was 1.2mAs, the mAs will be incremented three below (1, 0.8, 0.5) and one above (1.6) in accordance with standard practice found in 'the current working practice survey in review' and the variation seen in previous neonatal studies (Mutch and Wentwirth, 2007; Jiang et al., 2016; Rizzi et al., 2013;Del Rio et al., 2016). These exposures will be acquired both directly behind the neonatal phantom and within the incubator tray for comparison. All other parameters will be kept consistent: 60kV, maximum achievable FRD using DR portable machine only.

Image quality evaluation

The images will be analysed visually by 3 consultant radiologists and 3 diagnostic radiographers with more than five years clinical experience. Six observers was deemed sufficient and in accordance to Burgess (2011).The observers will be blinded to the acquisition parameters used to acquire the images thus enabling them to score image quality with minimum bias from prior knowledge (Martin et al., 2013)Images will be evaluated using an absolute visual grading criteria whereby the observer's rate their decision on the visibility of specific features within the various acquired images.VGA methods are sensitive to small changes

in image quality and is characterised by attractive simplicity and powerful discriminating properties (Mansson, 2000).The initial image quality criteria's were taken from Uffmann et al. (2004) Martin et al. (2013), Ladia et al. (2016) and the European Commission recommendations. Numerous criterion where excluded as they did not relate to an anthropomorphic phantom (e.g. amount of inspiration) and those unaffected by adjustment in acquisition parameter (positional criteria). This meant that six criteria remained to be assessed using the rating scale seen in table 1. After completing this for each image, the observer will also be asked to rate the overall image quality using the below ratings seen in Table 1 in accordance with Alsleem and Davisson (2012).

Table 1 - Image quality criteria and rating scale used to assess chest

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Chest exposure criteria	Criteria rating scale
1. Reproduction of the thorax	(1) Criterion definitely not fulfilled
2. Reproduction of the vascular pattern in the central two thirds of the lungs	(2) Criterion probably not fulfilled
3. Reproduction of the trachea and proximal bronchi	(3) Indecisive whether criterion fulfilled or not
4. Visually sharp reproduction of the diaphragm and costo-phrenic angles	(4) Criterion probably fulfilled
5. Reproduction of the spine and paraspinal structures and visualisation of the retrocardiac lung and 6. the mediastinum	(5) Criterion definitely fulfilled
6. Reproduction of the mediastinum	
Overall Image Quality	(5) *excellent image quality* (no limitations for clinical use), (4) *good image quality* (minimal limitations for clinical use), (3) *sufficient image quality* (moderate limitations for clinical use but no considerable loss of information), (2) *restricted image quality* (relevant limitations for clinical use, clear loss of information), (1) poor image quality (image must be repeated because of information loss).

CNR

CNR will also be calculated for comparison (objective measure) by placing a region of interest (ROI) on two contrasted homogeneous structures within the anthropomorphic chest phantom images. The ROI will be placed in the same position for all acquired images in accordance with Bloomfield et al. (2014).Image J software (National Institutes of Health, Bethesda,MD) will be used to calculated CNR; a software tool used regularly in literature for similar calculations (Lanca et al., 2014; Desai et al., 2010; Jang et al., 2011).). ImageJ establishes the mean pixel values (signal) and the standard deviation (noise) for the ROI (Sun et al., 2012).The following equation was then used to determine CNR:

$$C = \frac{|S_A - S_B|}{\sigma_o}$$

Where S_A and S_B are signal intensities for signal producing structures *A(ROI1)* and *B (ROI2)* and σo is the standard deviation (blue ROI) of the pure image noise

Radiation dose calculation

Effective dose

Effective dose will be calculated using Monte Carlo dosimetry simulation software (PCXMC 2.0)(STUK, Helsinki, Finland). This software uses tissue weighting factors of ICRP Publication 103 (2007) to estimate effective dose in milliseverts (mSv). DAP will be used in this estimation along with the acquisition parameters.

Optimisation score

Most optimisation studies consider radiation dose and image quality data separately; however Williams, Hackney, Hogg and Szczepura (2014) proposed a method to combine image quality and radiation dose data where the image quality score is divided by radiation dose to give a figure of merit. This figure of merit would signify an optimisation score (OS) where a high score would indicate better image quality at lower dose.

Statistical analysis

All data were inputted into Excel 2007 and transferred to SPSS software package (PASW Statistics 18: version 18.0.2, SPSS Inc., Chicago, IL) for analysis. For the visual image quality data, intra- and inter-observer variability will be evaluated by Intra-Class Correlation Coefficient (ICC) with >0.75 indicated as excellent, 0.40-0.75 as fair to good and <0.40 poor. Image quality data and radiation dose data are to be interpreted in various groupings (e.g. different incubator, direct v tray, CR v DR) and subsequently analysed using an independent t-test with a probability level of $p<0.05$ (95%) regarded as significant. Averages, standard deviations and percentages were also used for simple comparisons between and within groups. In order to control the presence of multiple variables and secure against an indeterminate outcome, a specialised statistical testing will be undertaken by a statistician using sequential analysis and Kruskal-Wallis testing. The data from the above analysis will highlight areas for improvements and areas where practice needs change.

Potential Impact of the study

The data and results will enable us to maximising insight to inform our research and contribution to evidence based practice. The collation of the data from this

study will increase the body of knowledge surrounding this area of imaging where we can strive to standardise and optimise clinical practice. In addition, from a quality, safety and health economic efficacy, this work would refine what it is we need to do different and where relevant better in order to delivered optimal diagnostic care for clarity for practitioners on what is best practice.

Dissemination strategy

With the support and assistance from my research supervisor, the findings from this research project will be put forward for publication in Radiography Journal (perhaps more than one article) and will be submitted to be presented in UKRC and other conferences such as ECR and BIR (as a novice researcher I am open to any more suggestions from the SOR regarding dissemination)

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