Optimising image quality and radiation dose with a focus on geometry and attenuation

Jenna Tugwell-Allsup BSc (Hons), MPhil

Thesis for the Degree of Doctor of Philosophy
PhD by Published Works
Directorate of Radiography
School of Health Sciences
University of Salford
Greater Manchester
M6 6PU

2021

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Optimisation in medical imaging ensures an appropriate balance is achieved between acquiring images of diagnostic quality and the radiation dose received by the patient. Pragmatic, simple and effective methods are essential to ensure that optimisation techniques are adopted into clinical practice.

The six papers presented within this thesis explore geometry and/or attenuation for various imaging techniques in order to optimise image quality and radiation dose. The first paper explores the impact of SID and magnification on image quality and radiation dose for AP pelvis on the x-ray tabletop. The next two papers explore SID for AP pelvis trolley work. The additional geometry and attenuation considerations from the mattresses and image receptor holder, as well as the lack of AEC, reinforced the importance of optimising this examination. The final three papers focus on neonatal chest imaging within incubators, which presents similar challenges to trolley imaging in terms of geometry (SID, OID and magnification) and attenuation. The overall aim was to establish optimal acquisition parameters for these imaging techniques.

To demonstrate the collective contribution of the six papers, the thesis is spilt into sections that critically evaluate new and novel findings. The first section demonstrates the methods used to evaluate image quality and radiation dose with certain areas highlighted as requiring improvements, such as the standardisation of the methods used to derive SNR/CNR and their correlation to visual image quality. Geometry and attenuation are then considered individually to highlight their impact on image quality and radiation with numerous recommendations made for clinical practice. These include the use of maximum achievable SID for AP pelvis (tabletop and trolley) to reduce patient radiation dose but to also ensure reduction in magnification especially from the increased OID associated with trolley imaging. Maximum achievable SID is also advocated for neonatal chest imaging when using the image receptor holder, with a 100cm SID at lower mAs found to be optimal for direct neonatal chest imaging. The use of maximum achievable SID for trolley and incubator imaging requires a corresponding increase in mAs to compensate for the combined effect of increasing SID and the additional attenuation. Using maximum achievable SID will also result in some magnification variation within images and therefore it is recommended that images are annotated with the SID used, and whether an image receptor holder is used, to help with image interpretation.

The impact of the work is considered through evaluating educational impact, citation analysis, training opportunities, implementation, influence on procurement, and manufacturer collaboration. Overall, the work demonstrates developments and new knowledge when optimising image quality and radiation dose for AP pelvic imaging (tabletop and trolley) and neonatal chest imaging with the main findings related to geometry and attenuation. Increasing SID is advocated for all examinations explored, with the exception of direct neonatal chest imaging. The recommended increase in SID may require a corresponding increase in mAs to compensate for geometry (SID and OID) and attenuation from the mattresses and image receptor holder of trolleys and incubators. The difference in OID for the various techniques, in combination with the maximum achievable SID, will cause variation in image magnification and this should be made transparent to those interpreting the images.

ABBREVIATIONS

Specifically to geometry

Used in the thesis	**Abbreviated**	**Past definition**	**Abbreviated**	**Present/Other definition**	**Abbreviated**
Source to image receptor distance	SID	Focus to film distance	FFD	Focus to receptor or detector distance	FRD/FDD
Object to image receptor distance	OID	Object to film distance	OFD	Object to receptor or detector distance	ORD/ODD
Source to object distance	SOD	Focus to object distance	FOD		

ACKNOWLEDGEMENT

My initial research journey began at OPTIMAX 2013 where Professor Peter Hogg introduced me to the field of image quality and radiation dose optimisation with enthusiasm and substantial guidance. This is where I met Dr Andrew England who has provided me with support and supervision, leading to many collaborations and further studies.

During the past 12 months of completing this thesis, both my Dr Andrew Tootell and Dr John Thompson have been extremely supportive and encouraging whilst providing me with critique, knowledge and direction. Their advice and guidance throughout this period has kept me on track.

Many thanks to the co-authors I have worked with in the production of the papers presented within this thesis. Without their input and advice on the various aspects, this collection of papers would not exist.

I am also grateful to my husband and children for their endless support, encouragement and patience as they accompanied me along this exciting yet challenging journey.

Finally, I would like to acknowledge my employer Betsi Cadwaladr University Health Board (BCUHB) for their continued support through the research process and conduction of my studies.

DECLARATION OF ORIGINALITY BY POSTGRADUATE CANDIDATE

DECLARATION 1 FORM

Declaration of Originality by Postgraduate Candidate (for softbound thesis) **1**

Candidates for postgraduate degrees must present this completed form to askUS, Student Administration, ground floor, University House, when submitting their **two** soft-bound theses. In addition, an electronic version of the thesis (pdf format) should be sent to the candidate's Research Support Officer.

Name of candidate (in BLOCK CAPITAL LETTERS as it appears on the thesis)

JENNA TUGWELL- ALLSUP

Student number: 00362867

School: HEALTH SCIENCES

Degree (PhD, DMA, Professional Doctorate, MSc, MPhil, MRes – Please specify): PHD by Published Works

This is to certify that the copy of my thesis, which I have presented for consideration for my postgraduate degree: -

1. embodies the results of my own course of study and research
2. has been composed by myself
3. has been seen by my supervisor before presentation
4. has been granted the appropriate level of ethics approval

If you have a Student support or reasonable adjustment plan, please indicate if you would like this to be shared with your examiners .....

Signature of candidate: JR Allsup Date: 27/5/2021

Email address (to which information concerning examiners' decision and final binding can be sent):

Jenna.R.Allsup@wales.nhs.uk

The candidate's supervisor is asked to declare here that s/he has approved the submission of the thesis. If the supervisor decides to withhold approval, the candidate shall have the right of appeal to the Associate Dean of Research and Innovation. A candidate may be permitted to submit a thesis despite the Supervisor withholding approval, providing the Associate Dean of Research and Innovation approves submission.

HeCoS codes (please add up to 3 HeCoS codes which best fit with the student's research area). You will find the list of HECOS codes at
https://testlivesalfordac.sharepoint.com/:x:/r/sites/DoctoralSchoolHub/Shared%20Documents/HECOS%20List.xlsx?d=w3884f73079bd4766b3571d4e3401e928&csf=1&web=1&e=OagDNA

100129

Signature of Supervisor: A K Coffelt Date: 27th May 2021

[For your information the dates of the Postgraduate Research Awards Board are published here
https://testlivesalfordac.sharepoint.com/sites/DoctoralSchoolHub/SitePages/Postgraduate-Research-Awards-Board-(PRAB)-Dates.aspx]

SUBSTANTIATED AUTHOR CONTRIBUTIONS

The contribution of all those eligible for authorship has been recognised by Jenna Tugwell-Allsup in all the papers included in this PhD by published works thesis.

- ✓ No eligible author has been denied authorship of the opportunity to contribute
- ✓ No ineligible author has been included on any publication
- ✓ Where appropriate, acknowledgements have been made to participants who do not satisfy enough criteria to be considered a co-author
- ✓ The contribution and ownership displayed in Table 7 is accurate and supporting e-mails presented in Appendix 9

I hereby declare that the above statements have been satisfied. I sign to acknowledge the contribution of all authors in accordance with the University Of Salford Code Of Conduct.

Signed:

Dr Andrew Tootell
University of Salford
PhD Supervisor

Dr John Thompson,
University of Salford
PhD supervisor

LIST OF PUBLISHED WORKS PRESENTED

Paper number	Publication title	Date of Publication	Journal	Page number of full text
1	Increasing source to image distance for AP pelvis imaging – Impact on radiation dose and image quality.	2014	Radiography	on page 7-13below
2	Antero-posterior (AP) pelvis x-ray imaging on a trolley: impact of trolley design, mattress design and radiographer practice on image quality and radiation dose.	2017	Radiography	on page 19-36
3	Challenges Associated With X-ray Imaging of Stretcher-Bound Patients.	2017	Radiologic Technology	on page 37-61
4	A systematic review of incubator-based neonatal radiography – what does the evidence say?	2020	Radiography	on page 62-76
5	Imaging neonates within an incubator – a survey to determine existing working practice.	2020	Radiography	on page 77-89
6	Optimisation of image quality and radiation dose for incubator imaging.	2020	Radiography	on page 90-104

Note – Paper 1 to 6 will be referred to within the thesis and this table may be useful for cross-referencing purpose.

PREFACE

This thesis is a critical review of six studies that were accepted for publication in International Journals between 2014 and 2020. The aim of this review is to demonstrate the work's fulfilment of the requirements of a doctoral degree set out by Salford University guidance and in line with the Quality Assurance Agency for UK Higher Education (QAA) (2020) whom state:

- *"All UK doctorates, regardless of their form, continue to require the main focus of the candidate's work to demonstrate an original contribution to knowledge in their subject, field or profession, through original research or the original application of existing knowledge or understanding"*

In relation to PhD by publication:

- *"A candidate presents a portfolio of interconnected, published research papers contextualised by a coherent narrative, demonstrating overall an original contribution to knowledge. Such publications may include papers, chapters, monographs, books, scholarly editions of a text, technical reports, creative work in relevant areas, or other artefacts."*

(QAA, 2020)

The thesis begins by setting the scene for the body of research, followed by the rationale for conducting the work, whilst providing an overview of key themes for the remainder of the thesis. The six published papers are then presented in full before moving onto the key themes to be critically discussed. These themes include: methods to evaluate image quality and radiation dose, and the impact of geometry and attenuation on image quality and radiation dose in the context of the six papers. Author's contribution and the pathway to impact of the published works is subsequently considered whilst lastly reflecting on the overall contribution to knowledge from the six studies and the future direction/ further research to be conducted.

1. INTRODUCTION

This thesis analyses the original contribution to knowledge from six interconnected, published research papers, all exploring geometry and/or attenuation to optimise image quality and radiation dose. This opening chapter provides a brief background, the rationale for conducting the work, a summary of aims, and an overview of the themes and layout for the remaining chapters.

1.1 - BACKGROUND

Medical imaging plays an important role in the diagnosis and treatment of many diseases, with the number of radiological examinations having significantly soared in the past decade (Royal College of Radiologists (RCR), 2019). This increased utilisation of medical imaging corresponds to an increase in exposure to ionising radiation for patients. Radiation protection from medical imaging is governed by various legislations including The European Council's (2013) directives (2013/59/Euratom) and the Ionising Radiation (Medical Exposure) Regulations (IRMER) of 2017, and are also supported by organisations such as The International Commission on Radiological Protection (ICRP) who provide recommendations and guidance on radiation protection. One of the main requirements of such regulations is to reduce the amount of radiation delivered to patients by optimising all medical exposures. Justification also plays an important role in optimisation. Before optimisation can occur, the exposure must show a net benefit to the patient by ensuring that the correct imaging examination/technique has been selected and that image quality is sufficient to impact on diagnosis (Malone et al., 2012; Sandborg, Båth, Järvinen, & Faulkner, 2015). Justification may hence have a significant impact on the approach to optimisation because at times, the radiation burden may only be a small component to consider. Optimisation can involve decreasing patient radiation dose without compromising image quality or be focused on improving image quality to aid diagnosis whilst ensuring a consistent radiation dose (Aichinger, Dierker, Joite-Barfuß & Säbel, 2004).

Acquiring images of diagnostic quality involves the interplay between many different x-ray acquisition parameters such as geometry, exposure factors and grid selection. Geometric factors affect beam geometry including source to image distance (SID), object to image receptor distance (OID) and focal spot size (Carroll, 2018). These factors can easily be modified within clinical practice whilst having an impact on image quality (such as magnification and unsharpness; see Figure 1) and radiation dose to

the patient (Heath et al., 2011) Nevertheless, these geometric factors have not been rigorously explored within current optimisation literature, especially in situations where there may be additional geometry to consider, such as the increased OID seen for patients who present on trolleys, or for neonates presenting within incubators. The lack of optimisation studies on geometry was also surprising, especially considering that the three safety principles of radiation protection are time, distance and shielding (Kim, 2018). The role of increased distance from the radiation source in reducing radiation dose to staff and the public has been a radiation safety principle for decades and advocated by ICRP (1993, 2007). However, increasing distance for patient examinations has not been thoroughly explored and adopted into clinical practice.

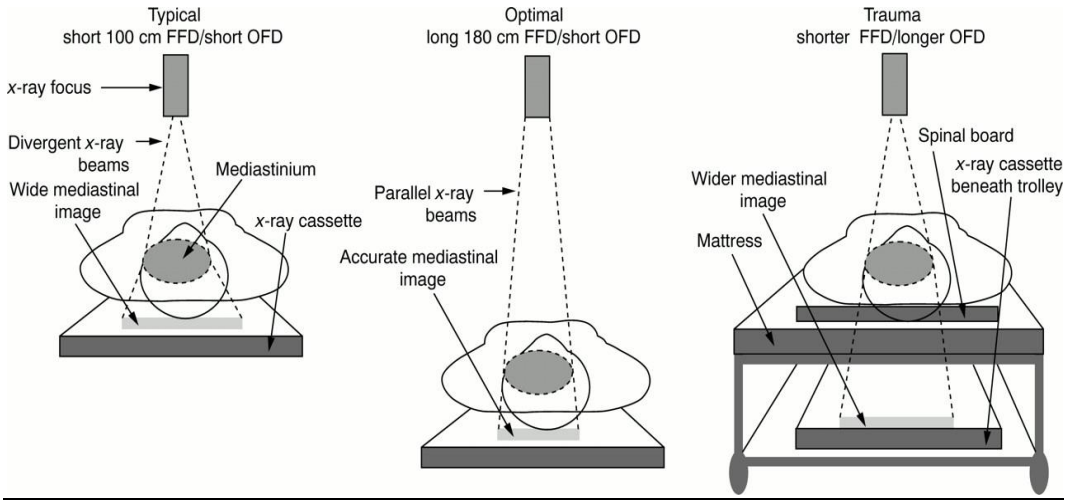


FIGURE 1 - FIGURE DEMONSTRATING HOW CHANGING SID AND OID IN VARIOUS CIRCUMSTANCES INCLUDING ON A TROLLEY INFLUENCE MAGNIFICATION (GLEESON, SPEDDING, HARDING & CAPLAN, 2001)

1.2 - RATIONALE/PURPOSE OF THE WORK

The six publications presented within this thesis were conducted over a period of seven years and have chronologically influenced the ideas and content of the subsequent publication(s). The first study (Paper 1) explored increasing SID for AP pelvis to reduce radiation dose. The next two studies (Paper 2 and 3) continued to focus on SID and AP pelvis, but, with additional geometry and attenuation consideration for trolley imaging. It was apparent that the challenges associated with trolley imaging in terms of geometry (SID, OID and magnification) and attenuation were similar for imaging neonates within incubators, and therefore became the focus for the final three studies (Papers 4, 5 and 6).

In 2012, University of Salford hosted the first ever OPTIMAX research summer school. The aim was to developed students' understanding of the underlying principles of optimisation; focusing on methods used to evaluate image quality and radiation dose. Increasing distance was chosen as the area to explore as it is a simple yet effective method that a radiographer can modify within clinical practice to reduce radiation dose whilst maintaining images of diagnostic quality (England et al., 2015; Heath et al., 2011.). Several publications (Farrell et al., 2008; Heath et al., 2011; Poletti & McLean, 2005) already existed within this area and yet limited evidence was available to demonstrate that increasing SID from traditional distances were adopted within clinical practice. These prior studies (Brennan, McDonnell & O'Leary, 2004; Farrell et al., 2008; Grondin et al., 2004; Heath et al., 2011; Poletti & McLean, 2005), found increasing SID to be an effective dose reduction method, however, there were still areas of uncertainty with a need to consolidate previous findings to facilitate a transition into clinical practice. Some of these studies were based on film-screen radiography (Brennan et al., 2004; Grondin et al., 2004), or had flaws in terms of clinical practicality (Farrell et al., 2008; Heath et al., 2011; Woods & Messer, 2009).

AP Pelvis was the examination of interest for Paper 1 and continued to be the examination of interest for Paper 2, due to the frequency of this examination in clinical practice, the dose implications associated with AP pelvic imaging (radiosensitive organs are exposed to ionising radiation) and also the limited studies identified for this examination relating to SID. From a prior literature search on AP pelvis and SID, only four were found that used digital imaging systems. Of the four, the first focused on radiation dose alone and therefore did not consider image quality (Poletti & McLean, 2005), the second was a conference proceeding with limited data available (Farrell et al., 2008) with the third being an article in Imaging and Therapy Practice (Woods & Messer, 2009); both latter studies not rigorously peer reviewed. The fourth study by Heath and colleagues (2011) was similar to Paper 1, but with certain limitations addressed and a CR radiography system used as oppose to DR. At the time of publication (Paper 1 = 2014), CR was widely used within public hospitals and was frequently cited in similar optimisation studies (Davey & England, 2015; Lanca et al., 2014; Ma et al., 2013; Seeram, Davidson, Bushong & Swan, 2013). Even today, CR is still widely available and used within various UK and international hospitals (Al-Murshedi, Hogg & England, 2020; Gunn et al., 2020; Tugwell-Allsup, Kenworthy & England, 2020) and continues to feature in optimisation studies (Freitas et al., 2020; Hinojos-Armendáriz, Mejía-Rosales & Franco-Cabrera, 2018). Direct digital radiography (DDR) technology, as used by Heath and colleagues (2011), was fairly new and not in widespread use at the time of conducting the study, and therefore the use of CR for Paper 1 was very relevant and transferable to clinical practice. It was, and still remains the only study to be published within a peer-reviewed Journal exploring SID for AP pelvic imaging using CR, an anthropomorphic phantom, whilst

evaluating both image quality and radiation dose. The independent variables and outcome measures used for Paper 1 also allowed further contribution to knowledge by using both the automatic exposure control (AEC) and a fixed mAs, small SID increments of 5cm, and measured femoral head diameter (FHD) to calculated magnification at each SID increment to support assumptions made by previous authors (Heath et al., 2011).

Following the completion of Paper 1, it was recognised that AP pelvic imaging is often performed on trolleys and that findings from Paper 1 may not be transferable to AP pelvis performed on a trolley. This is because of the additional geometry (increased OID) and attenuation considerations associated with the specialised mattresses and image receptor holder, in addition to the unavailability of the AEC. In comparison to an x-ray room, with specialised equipment to facilitate imaging such as the tabletop and Bucky, trolleys are not designed with imaging as the primary focus and therefore some design feature may adversely affect image quality and radiation dose (Aichinger et al., 2004). In order to explore the feasibility of conducting research on trolley imaging, a survey was distributed to local radiographers to identify current working practices (Tugwell, 2014). The findings of this survey in terms of variability in practice amongst radiographers working within the same Health Board reinforced the necessity to explore and optimise this area. AP pelvis remained the imaging examination of interest for the same reasons as Paper 1 but also optimisation is not always about reducing patient radiation dose, it may involve exploring methods to maintain or increase image quality whilst keeping a consistent dose. Cannon, Silvestri and Munro (2009) demonstrated that hip fractures can be missed if image quality is not optimal. The pelvis is a common area for injury following trauma with patients presenting on trolleys for both initial and post-operative imaging, and yet, no guidelines, textbooks or prior studies were found that aided in approaching such examination on the trolley in terms of appropriate acquisition parameters to be used. The third publication presented within this thesis (Paper 3) was therefore an educational review publication attempting to summarise and educate individuals on the challenges associated with imaging patients on trolleys. This paper involved a rigorous literature review (not enough studies to enable a systematic review).

Whilst conducting the literature search for Papers 2 and 3, a study by Mutch and Wentworth (2007) on neonatal incubator imaging was identified. Similar challenges associated with trolley imaging were recognised for this imaging technique in terms of the additional geometry and attenuation consideration from the image receptor holder, the Perspex surround and the mattresses used. The necessity to optimising this imaging technique was further emphasised due to neonates being more sensitive to the effects of radiation owing to their rapid development (Khong et al., 2013). A neonate's

life expectancy is also theoretically longer meaning that there is more time for the harmful effects of radiation to manifest (Jiang, Baad, Reiser, Feinstein, & Lu, 2015).

The final three studies (Papers 4, 5 & 6) presented within this thesis were therefore based on neonatal imaging within incubators. Paper 4 was a systematic review to determine what empirical evidence existed for this imaging technique and to also inform the subsequent two studies (Paper 5 and 6). Capturing all previous studies on optimising neonatal incubator imaging allowed for scrutiny of methods utilised especially in terms of whether they considered all geometric factors and attenuation, and also whether the outcome measures used were clinically relevant. Following completion of Paper 4, it was evident that a significant gap in the knowledge existed when imaging neonates. These included, limited visual evaluation of image quality using anthropomorphic phantoms with clinically experienced observers, lack of consideration to geometry, and also limited evidence on effective dose hence the risk associated with the radiation exposure to the neonate (Mutch & Wentworth, 2007; Rizzi et al., 2014). In addition, studies found within the systematic review predominantly focused on one or two independent variables such as the impact of mattresses only on radiation dose and image quality (Jiang et al., 2015; Rattan et al., 2013) as oppose to focusing on numerous variables/factors associated with neonatal imaging.

Paper 5 followed on from the systematic review and was a survey to determine existing working practice for neonatal imaging across Wales and North West England. This was deemed necessary before commencing the optimisation study as no guidelines existed to identify an optimal protocol for digital neonatal chest radiography and therefore selecting independent variables would have been difficult to justify. There continues to be reliance on the Commission of the European Communities (CEC) (1996a) when selecting acquisition parameters and technique for neonatal imaging (Al-Murshedi et al., 2020) and yet they were developed for film/screen. The American College of Radiology (ACR) (2014) adapted guidelines for digital systems however they fail to provide any recommendations with regards to optimal acquisition parameters. Paper 5 not only helped justify the independent variables used for Paper 6 but it also informed on the appropriate increments necessary for such variables.

Paper 6 is the final study presented within this thesis, conducted as an optimisation experiment under controlled conditions. As AP pelvis is a rare examination performed on neonates within incubators, a decision was made to explore for this study the commonest radiographic examination for this group of patient, which are chest x-rays (Jiang et al., 2015). As chest x-rays are already a very low dose examination, optimisation was focused around improving image quality to aid diagnosis or maintain image quality at reduced dose when considering the use of the incubator tray in comparison to a direct exposure. SID, OID and attenuation was again the main focus within this study.

1.3 - SUMMARY AND AIMS

The aim of the six studies presented within this thesis was to investigate geometry and attenuation for different imaging examinations. This was even more pertinent for examinations performed on equipment not designed with imaging as primary focus and have additional geometry and attenuation considerations such as that seen for trolley and incubator imaging. This consequently allowed for greater understanding of the effects of geometry and attenuation on image quality and radiation dose in order to establish new knowledge that could be applied to clinical practice. The overall aim of this thesis is to demonstrate the novel and unique contribution to knowledge from the six papers within this niche area of optimisation.

1.4 - OVERVIEW OF MAIN THEMES AND THE STRUCTURE OF THE THESIS

In order to fulfil the requirement of a PhD by Published Works, the remaining thesis will critically analyse and demonstrate the novel contribution to knowledge by presenting emerging themes and findings found across the six published studies. This is achieved by firstly presenting the six published studies in full, followed by an introduction to the principles of optimisation in medical imaging. This leads into two overarching themes of evaluating image quality and measuring radiation dose. The methods used to determine image quality and radiation dose within the studies will be critically discussed and justified, with any limitations and contribution to knowledge highlighted. This will ultimately lead onto the next two sections whereby geometry and attenuation are critically evaluated in terms of their impact upon image quality and radiation dose. The thesis will subsequently consider intellectual ownership and contribution followed by summarising the pathway to impact of the work under various sub-headings including citation analysis and clinical impact, to ensure their influence is captured accordingly. The thesis concludes with an overall summary of the contribution to knowledge and a section on future direction and further studies in light of the findings from the six papers presented.

2. PUBLISHED STUDIES

This chapter contains the full text author accepted version of the six published studies presented within this thesis. The references for each paper follow the referencing style of the publishing Journal. In addition, the tables and figures presented within these published papers are not listed as tables and figures within this thesis, and are numbered according to their order in each individual paper.

2.1 - PAPER 1

Increasing source to image distance for AP pelvis imaging - Impact on radiation dose and image quality

Tugwell JR, Everton C, Kingma A, Oomkens DM, Pereira GA, Pimentinha DB, Rouiller CAI, Stensrud SM, Kjelle E, Jorge J, Hogg P.

Abstract

Aim: A quantitative primary study to determine whether increasing source to image distance (SID), with and without the use of automatic exposure control (AEC) for antero-posterior (AP) pelvis imaging, reduces dose whilst still producing an image of diagnostic quality.

Methods: Using a computed radiography (CR) system, an anthropomorphic pelvic phantom was positioned for an AP examination using the table bucky. SID was initially set at 110 cm, with tube potential set at a constant 75 kVp, with two outer chambers selected and a fine focal spot of 0.6 mm. SID was then varied from 90 cm to 140 cm with two exposures made at each 5 cm interval, one using the AEC and another with a constant 16 mAs derived from the initial exposure. Effective dose (E) and entrance surface dose (ESD) were calculated for each acquisition. Seven experienced observers blindly graded image quality using a 5-point Likert scale and 2 Alternative Forced Choice software. Signal-to-Noise Ratio (SNR) was calculated for comparison. For each acquisition, femoral head diameter was also measured for magnification indication.

Results: Results demonstrated that when increasing SID from 110 cm to 140 cm, both E and ESD reduced by 3.7% and 17.3% respectively when using AEC and 50.13% and 41.79% respectively, when

the constant mAs was used. No significant statistical (T-test) difference (p 0.967) between image quality was detected when increasing SID, with an intra-observer correlation of 0.77 (95% confidence level). SNR reduced slightly for both AEC (38%) and no AEC (36%) with increasing SID.

Conclusion: For CR, increasing SID significantly reduces both E and ESD for AP pelvis imaging without adversely affecting image quality.

Introduction

Optimisation, a strategy of reducing dose to the patient whilst still producing an image of diagnostic quality, is imperative in radiography and is recommended by both the International Commission on Radiological Protection[1] and the European Medical Exposure Directive.[2] This principle is important for all examinations that involve ionizing radiation, however it is especially important for high dose examinations. European figures identified pelvic and hip radiography to be third biggest contributor to dose from medical imaging in the UK, with an annual frequency of 39 per 1000 of population.[3] Pelvic radiography is a high dose examination that irradiates radiosensitive organs such as the gonads; consequently there have been numerous attempts to reduce the amount of radiation to patients from this examination.[4,5] Increasing the Source to Image Distance (SID) is a simple and economical method which has been investigated for reducing the dose of an antero- posterior (AP) pelvis. Previous studies exploring this technique have been primarily focused on film-screen based radiography [6,7] with limited data on computed radiography (CR)[8-10] and direct digital radiography4 (DDR). With the advent of new digital imaging systems in radiography departments and subsequent reports regarding 'dose creep',[11–13] it is important to focus on keeping the dose as low as reasonably practicable whilst producing an image of diagnostic quality for digital radiography. The purpose of this study was to determine whether increasing SID for AP pelvis, with and without the use of the automatic exposure control (AEC) for a CR system, reduces dose whilst still producing an image of diagnostic quality.

Methods

Imaging equipment

All exposures were performed using a Wolverson Acroma X-ray unit (high frequency generator with VARIAN 130HS standard X-ray tube) with a total filtration of 3 mm Al. The unit incorporated a moving grid (ratio of 12:1, focused at 110 cm ± 15 cm) mounted in the table Bucky. The same image

receptor (35 cm 43 cm Agfa CR imaging plate) was used throughout the study and processed using a 35-X reader with a spatial resolution of 10 pixels per mm and grey scale resolution of 12 bits per pixel.[14] Routine quality assurance was performed prior to image acquisition to verify CR reader performance, tube mA, kV, exposure time and collimation, to ensure reliability and consistency of the equipment utilised.[15]

Phantom and imaging technique

All radiographic exposures were undertaken using an anthropomorphic pelvis phantom positioned on the X-ray table for a standard AP examination.[16] The initial acquisition parameters of 110 cm SID using the outer AEC chambers, 75 kVp, and fine focal spot [16-18] were selected to acquire the reference image for visual grading analysis. A series of images were then produced at increasing SID (90 cm to a 140 cm), with two images acquired at each 5 cm interval, one using the AEC and the other using a constant mAs of 16 mAs. 16 mAs was derived from the initial standard acquisition parameters utilising the AEC. Collimation was adjusted to the region of clinical interest (iliac crest, greater trochanters and proximal third of femurs) for each SID increment, such that the area of phantom irradiated remained constant.[19] To mimic clinical conditions the appropriate look up table (LUT) for pelvis radiography was used. No alteration of the window width and level was made.

Visual analysis of image quality

Images were analysed visually using two alternative forced choice comparisons (2AFC). 2AFC assesses the psychophysical responses of the observers who are presented with two separate stimuli displayed side by side.[21] Bespoke software was used to display two images simultaneously on dual monitors and capture observer comments about quality.[20] The software allowed the reference image to be permanently displayed on one screen with all other images to be scored against the reference image displayed were displayed in random order on the other screen.

Using a 5-point Likert scale, seven radiographers with a mini- mum of five years clinical practice experience assessed and scored images. The image quality criteria (Fig. 1) was adapted from Euro- pean Guidelines on Quality Criteria for Diagnostic Radiographic Images[22] in conjunction with scales used in other literature[4,23] and an unpublished psychometric image quality scale (Chronback's Alpha >0.8). Images were displayed on two 24.1 inch NEC (EA243WM) monitors with a resolution of 2.3 megapixels. Moni- tors were calibrated for Digital Imaging and Communications in Medicine (DICOM) grayscale standard display function and to the recommended specification of the Royal College of Radiologists.[24] To determine that display quality consistency of the dual screen monitors

was maintained a visual pattern check was undertaken prior to every radiographer doing the visual analysis. Lighting conditions were maintained at a dimmed and consistent ambient level throughout the visual image quality experiment. The radiographers were blinded to the acquisition parameters of the images they were provided with a set of instructions on what to do in the experiment and they were prohibited from manipulating the images.

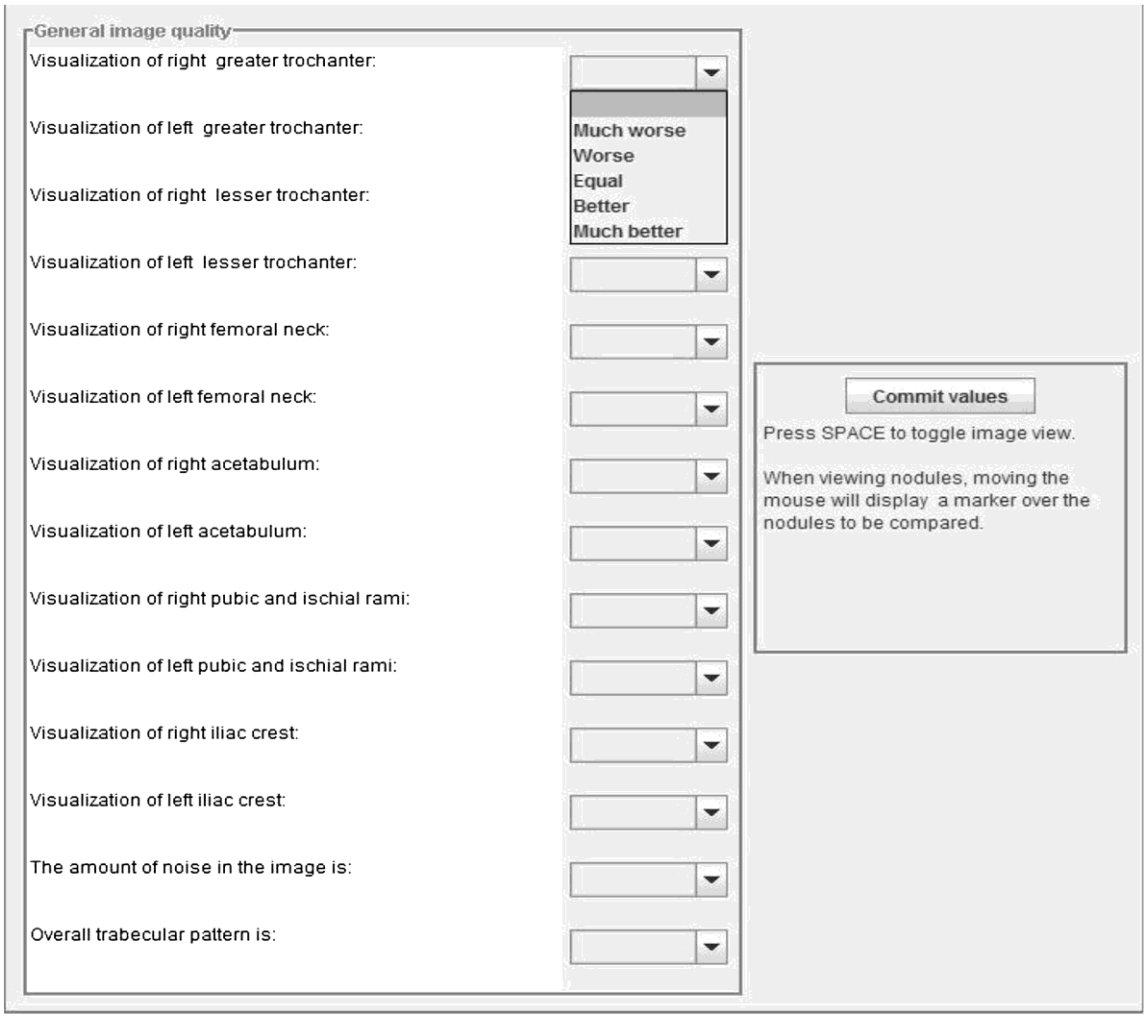


Figure 1 - Image quality criteria items and the 5-point Likert scale for the observer's response

Signal to noise ratio (SNR)

SNR, the mean and standard deviation pixel value for all acquired images, was calculated for each image with Image J software (National Institutes of Health, Bethesda, MD) http://rsb.info.nih.gov/ij/using a constant region of interest.[25]

Radiation dose calculations

Dose Area Product (DAP) readings were recorded. An average of three readings was taken for each image acquisition. Entrance surface dose (ESD), including backscatter, was measured at the surface of the phantom using an Unfors Calibration device (Unfors Equipments, SE) and averaged in the same manner. Effective dose (E), organ doses and effective risk were calculated from the DAP using Monte Carlo simulation software (PCXMC).[26] The reliability of this software is supported by literature demonstrating results in close agreement with dose measurements and calculations of other phantom models.[27-29] Effective risk was estimated for the ages of 15 and 60 to compare the lifetime cancer risks.

Magnification

Magnification was assessed at each 5 cm SID increment. For this, a senior radiographer with experience in pre-operative hip arthroplasty templating measured the femoral head diameter twice and calculated the average.

Statistical analysis

For visual image quality data, intraobserver variability was evaluated by Intraclass Correlation Coefficient (ICC) using a 2-way random effect model for absolute agreement.[30] Image quality data was assessed using t-tests with a probability level of $p < 0.05$ (95%) regarded as significant.

Results

Radiation dose

The results show that with increased SID, both ESD and E reduce in all situations. When utilising the AEC, the ESD and E were 0.902 mGy and 0.073 mSv respectively at 110 cm SID. The ESD was reduced by 17.3%, to 0.746 mGy when SID was increased to 140 cm. However only a 3.7% reduction to 0.071 mSv was found when considering E. Without AEC, further reduction was present at 140 cm SID, with ESD and E reduced by 50.13%, to 0.457 mGy and the E reduced by 41.79% to 0.044 mSv. Dose increased (with and without AEC) when SID was decreased from 110 cm (see Figs. 2a and 2b).

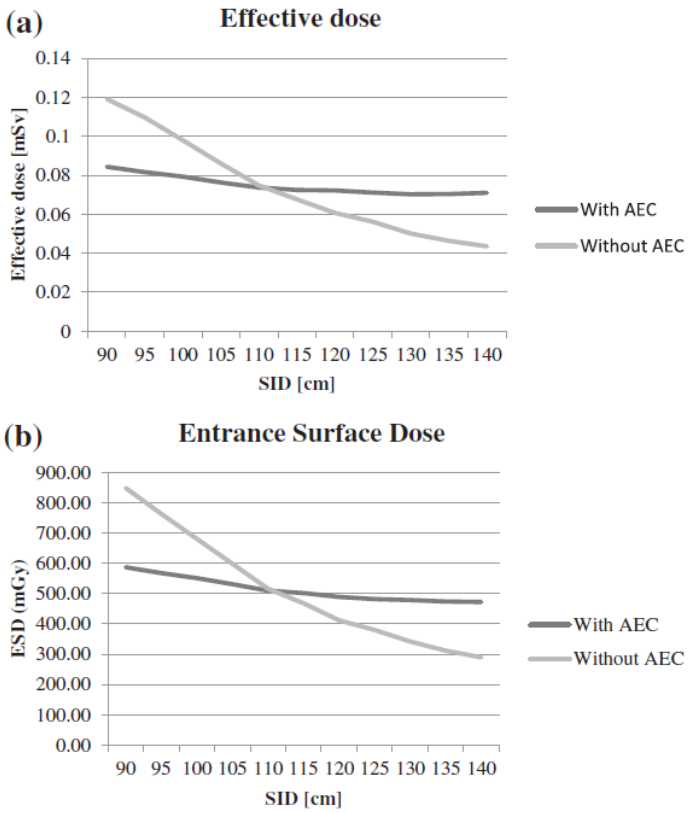


Figure 2. a) Comparison of effective dose (mSv) with and without AEC, when the SID is increased. b) Comparison of entrance surface dose (mGy) with and without AEC, when the SID is increased.

Effective risk

The risk of exposure-induced death from cancer for a 15 and 60 year old when utilising the AEC at both 110 cm and 140 cm is five per million and three per million, respectively. The risk reduces when the AEC is not used, at 140 cm SID, to three per million and two per million respectively.

Image quality

For the 2AFC visual grading data, all fourteen items were included within the image quality criteria, with a score of 42 equal to the reference image, a score of >42 is considered an improvement in image quality and <42 considered a decrease in image quality. The 2AFC results demonstrate that when SID was increased (with and without AEC), there was no reduction in image quality ($p = 0.967$). The SNR results did however reveal a slight decrease in image quality at increased SID for both AEC and no AEC of 38% and 36% respectively (see Figs. 3a and 3b). The ICC value for the seven observers was 0.77 (95% confidence interval) proposing a high level of agreement between the observers.

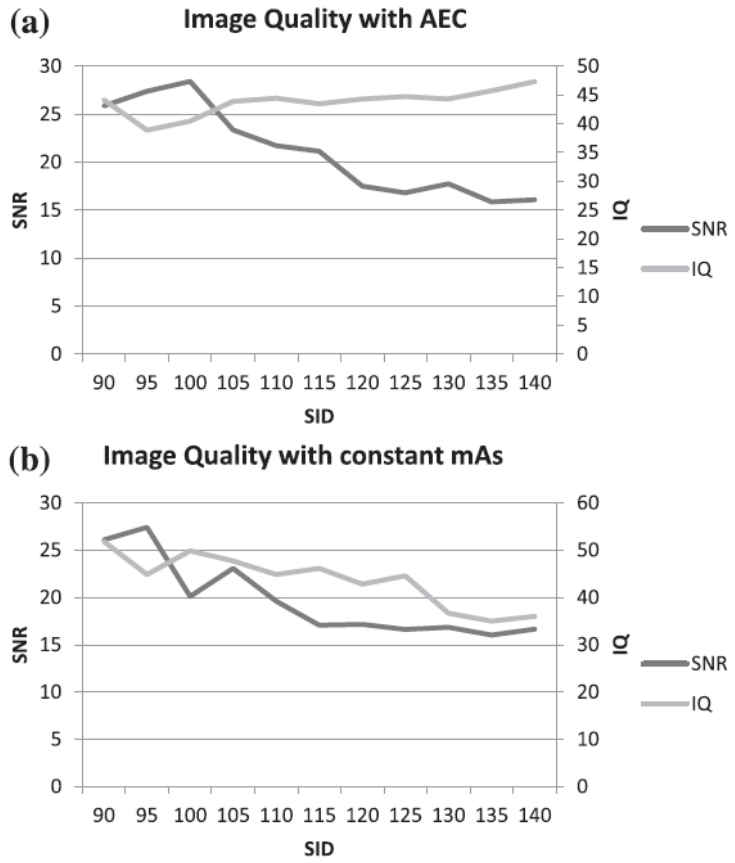


Figure 3. a) Relation between subjective (IQ) and objective (SNR) measurement of image quality, whilst increasing the SID (cm), considering the use of AEC. b) Relation between subjective (IQ) and objective (SNR) measurement of image quality, whilst increasing the SID, when not considering the use of AEC.

Magnification

When SID was increased from 110 cm to 140 cm, femoral head diameter reduced by 5.4 mm with a 2 mm average reduction in magnification for every 10 cm SID increment (see Table 1).

Table 1 - Demonstrating femoral head diameter difference at varying SID.

SID	Mean diameter of head of femur (mm)	Variance from reference image (mm)	Variance from reference image %
90	67.2	−4.9	−7.87%
95	65.1	−2.8	−4.49%
100	64.5	−2.2	−3.53%
105	63.8	−1.5	−2.41%
110	62.3	0	0.00%
115	61.6	0.7	1.12%
120	60.6	1.7	2.73%
125	58.9	3.4	5.46%
130	58.1	4.2	6.74%
135	57.6	4.7	7.54%
140	56.9	5.4	8.67%

Discussion

The results suggest that increasing SID from 110 cm to 140 cm reduces ESD and E by 17.3% and 3.7% respectively when utilising the AEC. Further reduction of ESD (50.13%) and E (41.79%) was identified when the AEC was not utilised. Data from our study is similar to Heath et al.,[4] who found a dose reduction of 7.9% when SID was increased from 110 cm to 140 cm using the AEC. Woods and Messer[10] found a larger reduction in dose when they utilised the AEC (33.7%), but smaller reduction when a constant baseline mAs was used for each increment (45.2%). Other studies[6-9] also identified dose reduction when increasing SID.

Our data demonstrates that dose reduction can be identified with as little as 5 cm SID increments, which is of interest because earlier studies suggest that increments of 10 cm are needed to see a dose reduction effect. In addition, the majority of previous studies[4,7,8] either utilised the AEC or increased mAs when increasing SID to compensate for dose reduction with regard to the inverse square law, therefore maintaining a constant dose at the receptor. Brennan et al.[6] found an increase of 60% in mAs at increased SID when utilising the AEC. This study used constant mAs (derived from the standard acquisition parameters used for the reference image). Brennan found that image quality could still be maintained without the need for a consequent increase in dose (mAs value) at increased SID increments.[6] The use of AEC is not always an option in cases such as trauma, paediatric radiography or for patient with metallic implants, so it is imperative that we understand the consequences of increasing SID for these types of imaging if this dose reducing technique is to be implemented into clinical practice.

Even though our study demonstrated increasing SID, with and without AEC, to be a successful dose reducing technique without a significant detrimental impact on image quality, radiographers should be cautious when implementing the technique in clinical practice. For instance, our data demonstrates that femoral head diameter reduces as SID is increased; this may lead to issues with interpretation if images are acquired at different SID for the same patient.[4] Radiographers could annotate and document the SID utilised for the images for reference of the reporting clinician raising awareness of the potential magnification differences from previous images. Our study did not explore the potential image quality benefits of increasing SID on geometric unsharpness. Further work needs to be done on the significance of magnification reduction in clinical practice and the impact it may have on calculations for pre-operative measurements and whether there are geometric unsharpness implications. There were minor differences between image quality using Image J and the 2AFC software in our study with the SNR results revealing a consistent decrease in image quality when SID was increased. A reasonable explanation for this would be that objective physical measures of image quality are more sensitive to changes in pixel values with regards to noise and signal. The human eye may not be able to distinguish between this amount of change in an image.[31]

Further work

This study was performed using a single CR system and there- fore the outcomes would need to be confirmed on different digital systems. Furthermore, the images were acquired using an anthropomorphic pelvis phantom, this decreases the clinical relevance of the study as there is no disease present when comparing image quality; the results need to be confirmed using patients of various body habitus in practice.

Conclusion

Within the parameters of this study it was demonstrated that increasing SID for AP pelvis imaging using CR reduces both ESD and E with no significant impact on image quality. The reduction in radiation dose at incrementing SID is greater when exposures are manually set. Increasing SID is a simple and cost-effective means of reducing dose to patients and should be considered and explored further in clinical practice.

References

1.European Commission. Council directive 97/43/Euratom on health protection of individuals against the dangers of ionizing radiation in relation to medical exposure, and repealing directive 84/466/Euratom. Off J Eur Communities 1997;L180(40):22.

2.International Commission on Radiological Protection. Radiological protection and safety in medicine, ICRP publication 73. Annals ICRP 26. Oxford: Pergamon Press; 1996.

3.Hart D, Wall BF, Hillier MC, Shrimpton PC. Frequency and collective dose for medical and dental X-ray examinations in the UK. Health Protection Agency; 2008. Report HPA-CRCE-012.

4.Heath R, England A, Ward A, Charnock P, Ward M, Evans P, et al. Digital pelvic radiography: increasing distance to reduce dose. Radiol Technol 2011;83(1): 20e8.

5.Doolan A, Brennan PC, Rainford LA, Healy J. Gonad protection for the antero- posterior projection of the pelvis in diagnostic radiography in Dublin hospi- tals. Radiography 2004;10:15e21.

6.Brennan PC, McDonnell S, O'Leary D. Increasing film-focus distance (FFD) re-

duces radiation dose for X-ray examinations. Radiat Prot Dosim 2004;108(3): 263-8.

7.Grondin Y, Matthews K, McEntee M, Rainford L, Casey M, Tonra M, et al. Dose- reducing strategies in combination offers substantial potential benefit to fe- males requiring X-ray examinations. Radiat Prot Dosim 2004;108(2):123-32.

8.Poletti J, Mclean D. The effect of source to image-receptor distance on effective

dose for some common X-ray projections. Br J Radiol 2005;78:810-5.

9.Farrell KRC, Abbott C, Round K, Willis SJ, Yalden R, Knapp KM. Pelvic projection radiography: increasing the source to image distance provides diagnostic im- ages at reduced dose. In: Proceedings of the UK radiological congress; 2008. p. 16.

10.Woods J, Messer S. Focusing on dose. Synergy Imaging Ther Pract 2009 September:16-20.

11. Maa WK, Hogg P, Tootell A, Manning D, Thomas N, Kane T, et al. Anthropo- morphic chest phantom imaging e the potential for dose creep in computed radiography. Radiography 2013;19:207e11.

12. Gisbon D, Davidson R. Exposure creep in computed radiography, a longitudinal study. Acad Radiol 2012;19(4):458e62.

13. Uffmann M, Schaefer-Prokop C. Digital radiography: the balance between image quality and required radiation dose. Eur J Radiol 2009;72:202e8.

14. CR 35-X Digitizer. Small footprint digitizer for the complete range of clinical application. Agfa Health Care; 2007. http://radonmedicalimaging.com/pdf/ agfa_CR_35-X.pdf [online accessed 16.08.13], pp. 3e4.

15. Institute of Physics and Engineering in Medicine (IPEM). IPEM report 91 rec- ommended standards for the routine performance testing of diagnostic X-ray imaging systems. 2nd ed. York: IPEM; 2005.

16. Whitley AS, Sloane C, Hoadley G, Moore AD, Alsop CW. The hip, pelvis and sacroiliac joints. In: Clark's positioning in radiography. 12th ed. London: Hodder Arnold; 2005. pp. 141e62.

17. Bontrager KL, Lampignano JP. Handbook of radiographic positioning and tech- niques. 7th ed. St. Louis: Mosby; 2005.

18. Aldrich J, Duran E, Dunlop P, Mayo J. Optimization of dose and image quality for computed radiography and digital radiography. J Digital Imaging 2006;19(2): 126e31.

19. Williams L. Pelvis and hips. In: Carver B, Carver E, editors. Medical imaging: technique, reflection and evaluation. Philadelphia: Churchill Livingstone/Elsev- ier; 2006. pp. 121e33.

20. Hogg P. Software for image quality evaluation using a forced choice method. In: United Kingdom radiological conference. Manchester/London, UK: British Insti- tute of Radiology; 2012. p. 139.

21. Pelli DG, Farell B. Handbook of optics. Fundamentals, techniques, and design, vol.

1. New York: McGraw-Hill; 1995.

22. European Commission. European guidelines on quality criteria for diagnostic radiographic images; 1996. EUR 16260 EN.

23. Manning-Stanley A, Ward A, England A. Options for radiation dose optimisa- tion in pelvic digital radiography: a phantom study. Radiography 2012;18: 256e63.

24. The Royal College of Radiologist. Picture archiving and communication systems (PACS) and quality assurcance. 2nd.ed. London: The Royal College of Radiolo- gists; 2012.

25. Hein LR, Campos KA, Caltabiano PC. Low voltage and variable-pressure scan- ning electron microscopy of fractured composites. Micron 2012;43:1039e49.

26. Tapivaara M, Lakkisto M, Servomaa A. PCXMC: a PC-based Monte Carlo program for calculating patient doses in medical X-ray examinations. Helsinki: Finnish Centre for Radiation and Nuclear Safety; 1997. Report STUK-A139.

27. Schmidt PWE, Dance DR, Skinner CL, Smith IA, McNeill JG. Conversion factors for the estimation of effective dose paediatric cardiac angiography. Phys Med Biol 2000;45:3095e107.

28. Schultz FW, Geleijns J, Spoelstra FM, Zoetelief J. Monte Carlo calculations for assessment of radiation dose to patients with congenital heart defects and to staff during cardiac catheterization. Br J Radiol 2003;76:638e47.

29. Helmrot E, Pettersson H, Sandborg M, Alte´n JN. Estimation of dose to the un-born child at diagnostic X-ray examinations based on data registered in RIS/ PACS. Eur Radiol 2007;17:205.

30. Rosner B. Fundamentals of biostatistics. Belmont: CA: Duxbury Press; 2005.

31. Smith SW. The scientist and engineer's guide to digital signal processing. San Diego: California Technical Publishing; 1997. p. 650.

2.2 - PAPER 2

Antero-posterior (AP) pelvis x-ray imaging on a trolley: Impact of trolley design, mattress design and radiographer practice on image quality and radiation dose

Tugwell JR, England A, Hogg P.

Abstract

Introduction: Physical and technical differences exist between imaging on an x-ray tabletop and imaging on a trolley. This study evaluates how trolley imaging impacts image quality and radiation dose for an antero-posterior (AP) pelvis projection whilst subsequently exploring means of optimising this imaging
examination.

Methods: An anthropomorphic pelvis phantom was imaged on a commercially available trolley under various conditions. Variables explored included two mattresses, two image receptor holder positions, three source to image distances (SIDs) and four mAs values. Image quality was evaluated using relative visual grading analysis with the reference image acquired on the x-ray tabletop. Contrast to noise ratio (CNR) was calculated. Effective dose was established using Monte Carlo simulation. Optimisation scores were derived as a figure of merit by dividing effective dose with visual image quality scores.

Results: Visual image quality reduced significantly ($p < 0.05$) whilst effective dose increased significantly ($p < 0.05$) for images acquired on the trolley using identical acquisition parameters to the reference image. The trolley image with the highest optimisation score was acquired using 130 cm SID, 20 mAs, the
standard mattress and platform not elevated. A difference of 12.8 mm was found between the image with the lowest and highest magnification factor (18%).

Conclusion: The acquisition parameters used for AP pelvis on the x-ray tabletop are not transferable to trolley imaging and should be modified accordingly to compensate for the differences that exist. Exposure charts should be developed for trolley imaging to ensure optimal image quality at lowest possible dose.

Introduction

There are many technical and physical challenges associated with imaging on a trolley which have subsequent impact on image quality and radiation dose. These challenges include: the absence of AEC on a trolley; grid selection; geometric factors; mattress and trolley design.

An antero-posterior (AP) pelvis projection is often performed on trolley bound patients especially in trauma situations because transferring them onto the x-ray tabletop could exacerbate injuries causing further harm.[1] The AP pelvis projection irradiates radiosensitive organs including the gonads and is ranked the third highest radiation dose examination by the Health Protection Agency (HPA).[2] Lead shielding of the gonads is considered essential when imaging the pelvis except for the initial imaging such as for trauma since it might obscure important diagnostic information. Organ dose from a single AP pelvis projection can typically reach 2.1 mGy for the testes and 0.52 mGy for the ovaries, which are within the primary beam.[3] With the challenges associated with trolley imaging, combined with the radiation implications of AP pelvis projection, it seems to be an important area to explore and subsequently optimise. The aims of this study were to: 1. explore whether acquisition parameters used for AP pelvis radiography on the x-ray tabletop are transferable to trolley imaging; 2. evaluate different acquisition parameters for trolley imaging in order to optimise image quality and radiation dose for an AP pelvis projection.

Method

This study used an experimental approach by imaging a pelvic anthropomorphic phantom under controlled conditions.

Imaging equipment and technique

A Philips Bucky Diagnost x-ray unit with an Optimus 50 Kw high frequency generator was used (Philips Healthcare, Netherlands).

The same 35 x 43 cm Fuji IP HR-V computed radiography image receptor (Barium Flurohalide (BaFX) phosphor) was used for all exposures. This was processed using a Fuji FCR Capsula XII with 50-micron resolution (Fujifilm Medical Systems, Japan). Quality assurance was conducted on all equipment prior to image acquisition in accordance with IPEM 91,[4] which included radiation output reproducibility and sensitometry testing. All test results fell within expected tolerances. Images were acquired using a Rando SK250 sectional lower torso anthropomorphic pelvis phantom.[5] The phantom was positioned supine on the x-ray tabletop for the acquisition of a reference image which was subsequently used as the optimal comparison image. The acquisition parameters used to acquire the x-ray tabletop reference image were those typically employed in clinical practice and recommended in various published work.[6-11]

They included a 110 cm source to image distance (SID), the outer chambers of the automatic exposure control, 75 kV, an oscillating grid mounted into the x-ray table Bucky, 3.2mmAl equivalent total filtration and a broad focal spot size (1 mm). For all exposures, the collimation was adjusted to

the region of clinical interest to include the iliac crests, greater trochanters and proximal one third of the femora.

Experiment technique

The experimental images were acquired on one commercially available trolley (Lifeguard 50 trolley) using two different mattresses (standard 65 mm and Bi-Flex 130 mm). Images were also acquired with the image receptor holder (platform) elevated and lowered, for comparison. The Lifeguard 50 trolley platform that accommodates the image receptor should be elevated prior to an exposure to reduce object to image distance (OID). However, in clinical practice this elevation may not always be achieved.[12] All images were acquired with a commercially available stationary focused grid (focused to 105 cm ± 15 cm) with a grid ratio of 10:1 and strip density of 40 lines/cm.[13] Initially, images were to be acquired with and without a grid to explore the air gap technique however this idea was eliminated following a preliminary experiment demonstrating significant image quality deterioration without a grid. For each projection on the trolley, the mAs increment was varied from 16 mAs (which was the AEC reading derived from the acquisition parameters used to acquire the reference image) to 20 mAs, 25 mAs and 32 mAs. Three different SIDs were also used, with an initial setting of 110 cm and then two further distances of 120 cm and 130 cm. These were to compensate for the increased OID as a result of trolley design but also to reduce radiation dose as found in previous studies.[14-16] A 130 cm SID was considered the maximum practical and achievable SID to be used considering the effective range of the stationary grid and grid cut off. Both Heath et al. and Tugwell et al. also found that image quality deteriorated at higher SID values.[14,16] SID was measured manually with a tape measure by two radiographers to ensure consistency. All other acquisition parameters remained constant including the use of 75 kVp. This resulted in 48 experimental images being produced on the trolley under different conditions.

Radiation dose calculations

Entrance surface dose (ESD) was measured at the surface of the phantom at the centre of the collimation field using the Unfors Mult-O-Meter 407L ionising chamber (Unfors Equipments, Billdal, Sweden). Three repeated exposures were performed and then averaged in order to reduce random error. Effective dose was calculated using Monte Carlo dosimetry simulation software (PCXMC 2.0) (STUK, Helsinki, Finland). This software uses tissue weighting factors from ICRP Publication 103[17] to estimate effective dose in milliseverts (mSv). Dose area product (DAP) was used in this estimation along with the acquisition parameters.

Assessment of image quality

Following ethical approval from the School of Healthcare Sciences, University of Salford (HSCR14/104), relative visual grading analysis (VGA) with bespoke software to present the images and capture responses from observers.[18] Previous research has reported on the benefits of relative VGA in comparison to an absolute VGA as it allows easier detection of differences in quality as oppose to observers evaluating images utilising criteria without a comparison reference image.[19] The observers consisted of five diagnostic radiographers with more than five years clinical experience who were blinded to the parameters used to acquire all images. The bespoke software allowed for two images to be presented simultaneously on dual side-by-side 5 megapixel monitors4,[20]; one the reference image (standard practice x-ray tabletop image) which was permanently displayed on the left monitor whilst the experimental images (acquired on the trolley) were displayed in random order in the right monitor. The display software prohibits post processing capabilities such as zooming and window adjustments and therefore differences detected between images would more likely be the result of acquisition parameters/technique change. The monitors were calibrated for Digital Imaging and Communications in Medicine (DICOM) grayscale standard display function which is to the recommended specification of the Royal College of Radiologists.[21] A visual pattern check (AAPM in report 93) was undertaken prior to each observer undertaking visual evaluation.[22] Room lighting conditions were maintained at a dimmed and consistent level (luminance of >170 cd/m2) in accordance with the European Guidelines on Quality Criteria for Diagnostic Radiographic Images.[23] Observers were required to score the experimental images against the reference image using a visual grading scale which consisted of 15 items[24] (Table 1). The items were scored using a 5-point Likert scale where '1' indicated much worse than the reference image, '2' slightly worse, '3' equal to, '4' better than, and '5' much better than the reference image. Image quality scores for each of the 15 items were totalled; for each image, scores ranged from 15 to 75. An image which scored 45 indicated equal quality to that of the reference image, a score of >45 was considered an improvement in image quality and anything lower than 45 considered a decrease in image quality. An additional item was also included at the end of the 15 item image criteria scale (Table 1), which involved a binary decision (yes or no answer). For this item, the observers considered the overall diagnostic quality of each experimental image, deciding whether they were acceptable or unacceptable for diagnostic purpose. The magnification factor was derived for all images. The right femoral head diameter (FHD) was measured in millimetres by one radiographer with experience in pre-operative hip arthroplasty templating. The measurements were carried out using the ruler (callipers) tool in Synapse PACS system (Fujifilm, Japan) using the same workstations as for the visual image quality assessment task. The femoral head of each image was measured eight times and the

average, standard deviation (SD), minimum and maximum values were then calculated. No cropping was permitted post processing and therefore the displayed magnification could only be influenced by acquisition parameters used to acquire the images. Contrast to Noise Ratio (CNR) was calculated as a physical measure of image quality. CNR has been used successfully as a measure of image quality in various optimisation studies[25-27] and in comparison to Signal to Noise Ratio (SNR), CNR takes into consideration the effect of noise on our ability to distinguish objects within the image because visibility depends on contrast (the difference between signals). A highly exposed image may have a high SNR but show no useful information on that same image.[28] CNR was calculated by placing a region of interest (ROI) on two homogeneous structures within the anthropomorphic pelvic phantom images in order to sample the mean and standard deviation of the pixel value. The ROI was placed in the same position for the experimental images in accordance with Bloomfield et al.[29] to allow a consistent value for comparison (Fig. 1). In order to maintain a consistent ROI, magnification was considered and ROI adjusted to ensure the same anatomy was sampled for all images. This meant that femoral head diameter and thus magnification had to be performed prior to calculating CNR in order to inform the ROI adjustments. This was necessary because using the same size ROI for all images would induce a level of inaccuracy to the CNR measurements since the anatomy sampled within that ROI would vary depending on the magnification level of the image. Image J software (National Institutes of Health, Bethesda, MD) was used to calculate CNR; this software tool is used regularly in literature fo similar calculations.[11,30,31] Using this approach, the mean pixel value and the standard deviation for the ROI was acquired[32]: subsequently the following equation was used to determine CNR:

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

where SA and SB are signal intensities for signal producing structures A (ROI1) and B (ROI2)and so is the standard deviation (blue ROI) of the pure image noise.

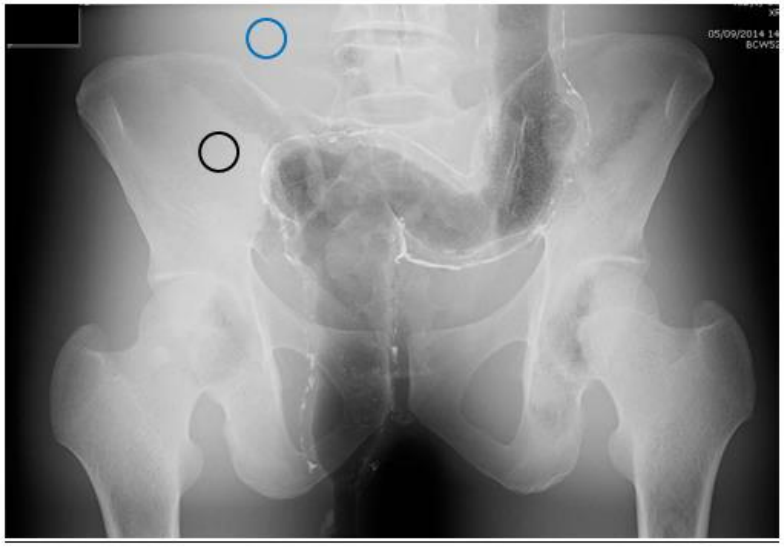


Figure 1 - image demonstrating the two different ROI (circle) locations used to calculate CNR with the blue circle situated in the background and black circle situated within the signal (right iliac crest).

Table 1 - Image quality criteria for AP pelvis developed by Mraity et al. (2016)

	Item
Anatomic region	1. The right lesser trochanter is visualised
	2. The right hip joint is visualised
	3. The right iliac crest is visualised
	4. The right greater trochanter is visualised
	5. The left hip joint is visualised
	6. The left lesser trochanter is visualised
	7. The left iliac crest is visualised
	8. The left greater trochanter is visualised
	9. The pubic and ischial rami are visualised
	10. The proximal femora are demonstrated
	11. The left femoral neck is visualised
	12. The right femoral neck is visualised
	13. Both acetabula are visualised clearly
	14. The body of L5 is sufficiently visualised
	15. The exposure factors are sufficient
Diagnostic accuracy	**16. This image is sufficient for diagnostic purposes**

Optimisation score

Many optimisation studies[11,16,33] consider radiation dose and image quality data separately; however Williams et al.[34] proposed a method to combine image quality and radiation dose data where the image quality scores are divided by radiation dose to give a figure of merit. This figure of merit would signify an optimisation score (OS) where a high score indicates better image quality at lower dose whereas a low score indicates poorer image quality at higher radiation dose. This method (Image Quality/Effective dose) has been developed from studies that have used similar calculations but using SNR rather than visual image quality scores.[22]

Statistical analysis

All data were inputted into Excel 2007 (Microsoft Corp, Washington, USA) in order to facilitate descriptive analysis and then transferred to SPSS software package (PASW Statistics 18: version 18.0.2, SPSS Inc., Chicago, IL) for the inferential analyses. For the visual image quality data, intra- and inter-observer variability was evaluated using Intra-Class Correlation Coefficient (ICC) where >0.75 was considered excellent, 0.40-0.75 as fair to good and <0.40 as poor.[35] Image quality and radiation dose data were interpreted using various groupings (e.g. two different mattresses, two different platform positions) and subsequently analysed using an independent t-test with a probability level of $p < 0.05$ (95%) regarded as significant. ESD and DAP values were consistently the same when undertaking repeat exposures (x3). Pearson's r and scatter plots were used to measure the linear relationship/correlation between visual image quality, CNR and radiation dose. These parametric tests were chosen as all statistical assumptions were met. The Shapiro-Wilk test in SPSS proved that all collected data were normally distributed.[36]

Results

Image quality

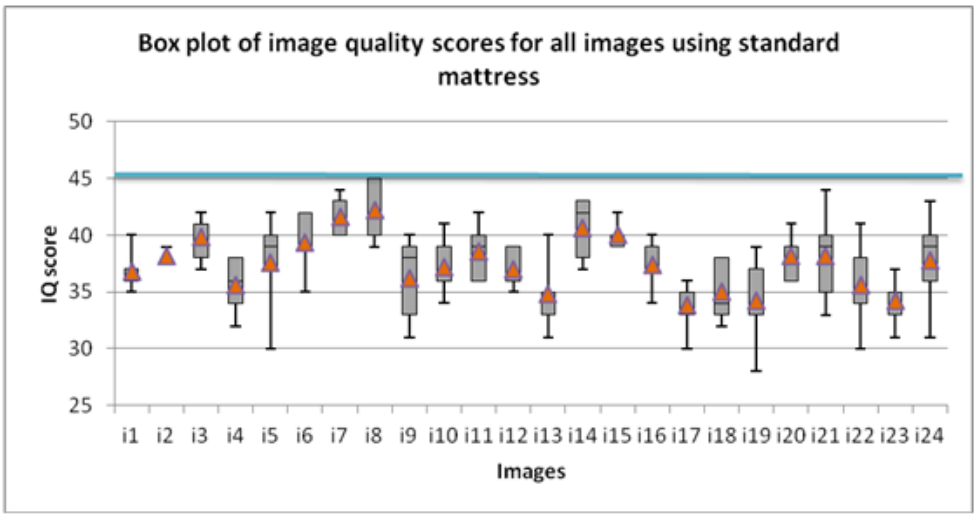
The ICC value for all five observers was 0.8419 (95% confidence interval 0.8137-0.884) implying a high level of agreement.35 ICC was also calculated for the last image quality criterion (item 16) in which the five observers had to decide whether the images were diagnostic or not (yes/no). The ICC for this criterion was 0.49 (95% confidence interval 0.22-0.69) which indicated fair to good agreement amongst observers. From the experimental images, only three (6%) had a mean image quality score equal to or greater than the standard x-ray tabletop acquisition (reference image) (Fig. 2 and Table 2 for image coding). Interestingly, for all the experimental images, these three images had the highest level of magnification with an increase of 10.78 mm (18%) in femoral head diameter compared to the reference image (see Table 3 for magnification results). Visual image quality was

found to be significantly better when the image receptor platform was lowered ($p < 0.02$); no statistically significant difference was found between image quality and the two different mattresses ($p = 0.06$). Of the 48 experimental images, only two were deemed unacceptable by more than half of the observers; these two images were acquired using 16 mAs in conjunction with a 130 cm SID and an elevated platform. Image receptor platform position and mattress thickness had a statistically significant impact on femoral head diameter and hence magnification factor of the images ($p < 0.01$). As expected, when the platform was lowered, magnification increased by 7% and when the Bi-Flex mattress was used in comparison to the standard mattress, magnification increased by 8%. No statistically significant difference in CNR ($p > 0.05$) was identified between platform position with elevated platform CNR being 7.88(SD = 0.42) and lowered CNR being 7.80(SD = 0.29). In addition, no statistically significant difference in CNR ($p > 0.05$) was identified between the two different mattresses with standard mattress having a CNR of 7.82 (SD = 0.39) and Bi-Flex mattress CNR being 7.87 (SD = 0.33).

Table 2 – table demonstrating the coding system for the image acquired (i =image)

Imaging conditions coding [platform position/mAs/SID(cm)]							
Standard mattress					Bi-Flex mattress		
i1	elevated/16/110	i13	elevated/25/120	i25	elevated/16/110	i37	elevated/25/120
i2	down/16/110	i14	down/25/120	i26	down/16/110	i38	down/25/120
i3	elevated/20/110	i15	elevated/32/120	i27	elevated/20/110	i39	elevated/32/120
i4	down/20/110	i16	down/32/120	i28	down/20/110	i40	down/32/120
i5	elevated/25/110	i17	elevated/16/130	i29	elevated/25/110	i41	elevated/16/130
i6	down/25/110	i18	down/16/130	i30	down/25/110	i42	down/16/130
i7	elevated/32/110	i19	elevated/20/130	i31	elevated/32/110	i43	elevated/20/130
i8	down/32/110	i20	down/20/130	i32	down/32/110	i44	down/20/130
i9	elevated/16/120	i21	elevated/25/130	i33	elevated/16/120	i45	elevated/25/130
i10	down/16/120	i22	down/25/130	i34	down/16/120	i46	down/25/130
i11	elevated/20/120	i23	elevated/32/130	i35	elevated/20/120	i47	elevated/32/130
i12	down/20/120	i24	down/32/130	i36	down/20/120	i48	down/32/130

STANDARD



BI-FLEX

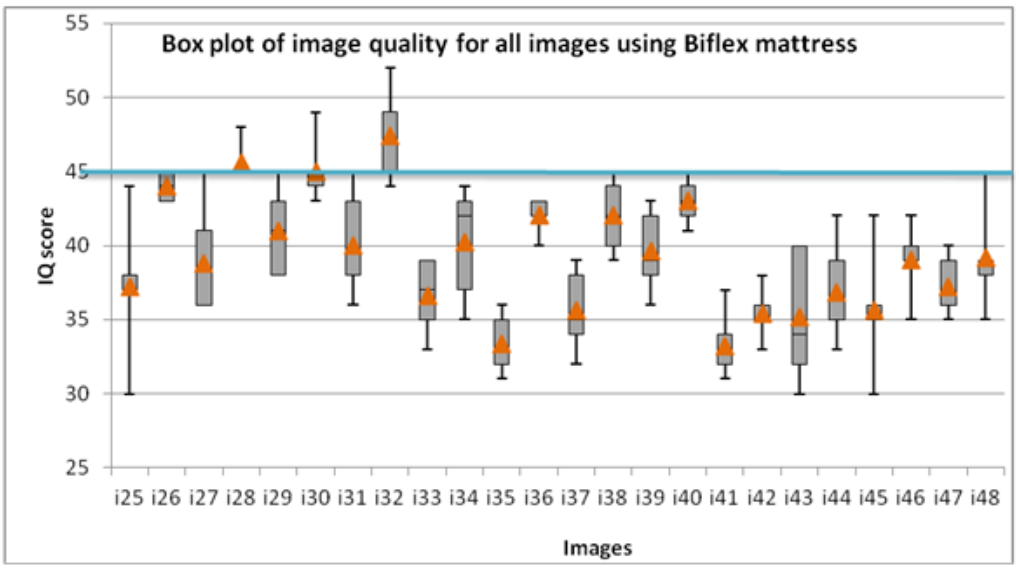


Figure 2 – Box plot demonstrating the relative visual grading image quality scores for all experimental images in comparison to the reference image (blue line)

Table 3 - table describing differences in magnification including standard deviation in brackets and percentage change from reference image of femoral heads diameter for the experimental images.

Trolley images		110		120		130	
Mattress	Tray	Mean diameter and SD (mm)	% change from reference	Mean diameter and SD (mm)	% change from reference	Mean diameter and SD (mm)	% change from reference
Standard	Elevated	60.7(0.3)	0	59.8 (0.1)	-1	58.5 (0.3)	-3
Standard	Not elevated	65.8(0.1)	9	63.6 (0.1)	5	61.8(0.2)	2
Bi-Flex	Elevated	66 (0.2)	9	64.5 (0.2)	7	62.9 (0.3)	4
Bi-Flex	Not elevated	71.3(0.2)	18	68.9 (0.3)	14	67(0.2)	11

Radiation dose

Forty-four of the experimental images (92%) had higher effective dose to that of the reference image with ESD higher for thirty nine of the images (77%). The average ESD and effective dose for the standard mattress at 110 cm SID was 1.91 mGy and 0.19 mSv respectively whereas the average ESD and effective dose for the Bi-Flex mattress at 110 cm SID was 2.28 mGy and 0.23 mSv respectively. This demonstrated a decrease in ESD and effective dose by 37% and 4% when utilising the standard mattress. However, no statistically significant difference was found between effective dose and ESD for the two different mattresses ($p > 0.05$). When the platform was elevated, the average ESD and effective dose were 1.91 mGy and 0.20 mSv respectively at a 110 cm SID. With the platform lowered, the average ESD and effective dose were 2.3 mGy and 0.22 mSv respectively. This demonstrates an increase in both ESD and effective dose when the platform was lowered. Yet again, no statistically significant difference was found between effective dose and ESD for platform position ($p > 0.05$). A Pearson's r correlation identified a low positive relationship between the average visual image quality scores and CNR values (0.35). CNR and effective dose had a moderate positive relationship (0.53), whereas visual image quality and effective dose had a high positive relationship (0.72).[37] Fig. 3 highlights the optimisation scores for the experimental images in comparison to the reference image. The optimisation score for the reference image was 500; none of the experimental images achieved this score with a significant difference observed between the experimental images and the reference image ($p < 0.002$) (Figure 3). The experimental image with the highest

optimisation score was one of the two images deemed non diagnostic by the observers. The subsequent images which had high optimisation scores were those achieved at a 130 cm SID and 20 mAs. No statistically significant difference was found for optimisation scores between platform position ($p = 0.60$) and both mattresses ($p = 0.18$). As demonstrated in Table 4, when comparing the reference image to the experimental images acquired using the same acquisition parameters (16 mAs and 110 cm SID), image quality for both visual image quality scores and CNR decreased by 13% and 3% respectively; however only the visual image quality score results (13%) had a statistically significant decrease ($p < 0.01$), (CNR; $p = 0.012$). In addition, effective dose, on average, more than doubled (56% average increase) for trolley imaging in comparison to x-ray tabletop using the same acquisition parameters, again demonstrating a significant difference in patient dose ($p < 0.01$).

Table 4 - table demonstrating the difference between the results of the reference image and the experimental images acquired with identical acquisition parameters for all outcome measures.

Image condition	mAs	SOD (cm)	SID (cm)	CNR	Effective dose (mSv)	RVGA	Magnification Factor
Reference	16	98.5	110	8.2	0.09	45	60.50
Standard/Elevated	16	97.5	110	7.64	0.12	36.8	60.90
Standard/Down	16	91.5	110	7.99	0.14	38.2	65.67
Bi-Flex/Elevated	16	91	110	8.23	0.15	37.2	65.88
Bi-Flex/Down	16	85	110	7.91	0.16	44	71.27
Average(trolley)				7.94	0.14	39.05	65.97
Standard deviation				0.24	0.02	3.35	4.24
p-value				p= 0.12	p<0.05	p<0.05	P=0.93
% difference				-3%	56%	-13%	9%

*Source to object distance (SOD), Source to image distance (SID), Contrast to Noise Ratio (CNR), Relative Visual Grading Analysis (RVGA)

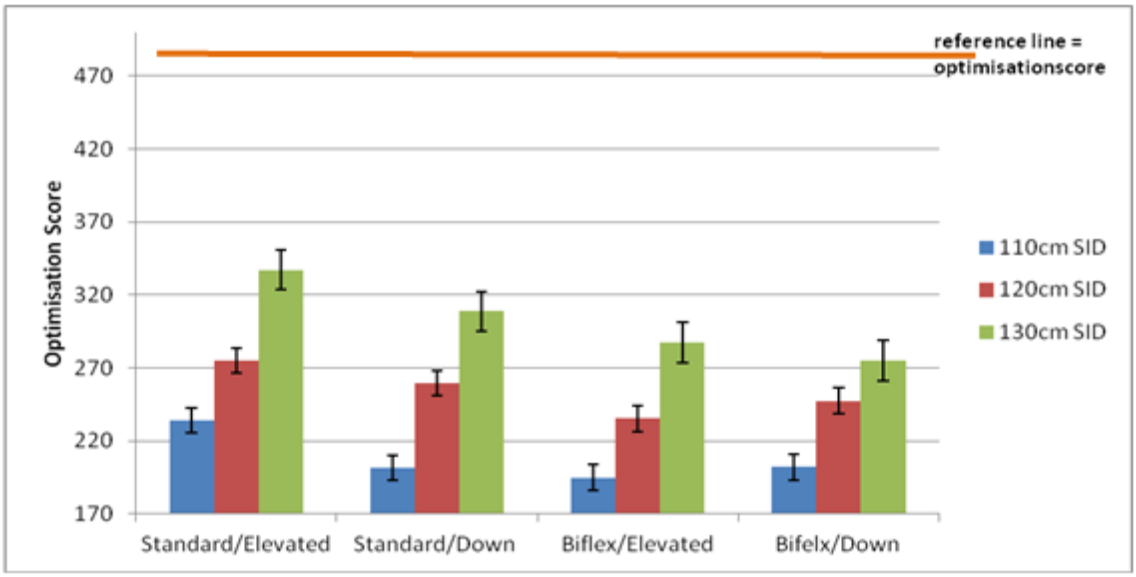


Figure 3– Bar chart demonstrating optimisation scores and standard deviation for various imaging conditions for all mAs values on the trolley in compassion to the reference optimisation score (orange horizontal line)

Discussion

The results demonstrate that the acquisition parameters used for the x-ray tabletop need to be adapted when applying to trolley imaging. Radiation dose can significantly increase whereas visual image quality can significantly decrease for trolley imaging when using standard x-ray tabletop acquisition parameters. As collimation was adjusted to the area of interest for each image acquisition, radiation dose would be influenced by the increased OID at a maintained SID due to beam divergence. This means a larger OID would require collimation to be opened to ensure coverage of the anatomy of interest. The images acquired with a 110 cm SID and 16 mAs were considered to be non diagnostic by the observers. Nevertheless, the reliability and validity of the sixteenth item (yes/ no) is brought into question. For this specific item, the observers had to decide on whether the diagnostic quality of the image was adequate without knowing the clinical indication. This is important because the clinical indication may have influenced observer decision as to the quality of the image because some clinical indications require greater anatomical detail.6 This may be the reason behind the lower ICC value for the last item when compared to the remaining validated items. No significant difference was found for visual image quality or effective dose when comparing the standard and Bi-Flex mattresses. On this basis, the Bi-Flex mattress should therefore be considered gold standard when purchasing this specific Lifeguard 50 trolley as it offers more benefits to patients since it is designed to enhance comfort and reduce pressure ulcer incidence.

Pressure ulcers remain a major problem in healthcare and one of the most costly and physically debilitating medical complications in twentieth century care.[38,39] The only impact that the mattress had on image quality was with regards to magnification. On average, magnification increased by 8% when utilising the Bi-Flex mattress compared with the standard mattress. Magnification may however be an issue that needs attention when imaging AP pelvis because the images might potentially be used for planning orthopaedic surgery without the use of a calibration device. To overcome this problem, specific guidelines need to be established when imaging trolley patients (e.g. maintain constant SID and platform position) in order to minimise variations between different patients and obtain consistent measurements in an individual over time.

Otherwise the use of a calibration ball for all AP pelvis projection could be a tool to consider in overcoming this magnification variation. It is accepted that, in some centres, a request for a traditional tabletop examination may follow if the pelvic image is required for detailed surgical planning. This may generate justification issues and therefore if trolley technique can be further standardised this situation may be avoidable. Three images which had equal or higher visual image quality scores than the reference image were all acquired using the Bi-Flex mattress, platform lowered and an SID of a 110 cm. These conditions resulted in the largest image magnification factor with a femoral head diameter of 25 cm. This raises the question of whether magnification influenced the visual image quality scores, as the criteria were based upon how well structures are visualised. Manning et al.[40] suggests that visual image quality is influenced by more than just the sharpness of anatomical outlines and the image noise, the size and complexity of structures can impact upon observer interpretation too. The principles behind visual acuity and the use of the Snellen chart strengthens this argument that visual perception in radiology may be influenced by the size of the objects observed hence displayed magnification.[41-43] The visibility of an object is proportional to its area with contrast, noise, object size and shape all affecting our ability to extract visual information from an image.28 The fact that there was no statistical difference identified between CNR and the two variables discussed (mattresses and platform position) also suggests that observer assessment may be influenced by something other than contrast and noise. This was why the resultant air gap from these three images was also disregarded as the potential reason for the increase in visual image quality as noise results from scatter however CNR did not detect this improvement. In addition, a grid was used for all images and the use of the air gap in conjunction with a grid has never been previously explored. The purpose of an air gap is to replace a grid as a method of scatter rejection and therefore it could be assumed that both air gap and grid combined would absorb useful image producing photons. Lastly, if the optimisation scores are considered for this current study, the optimum acquisition parameters for imaging the AP pelvis on a trolley were 20 mAs, 130

cm SID, standard mattress and platform lowered. These parameters resulted in an image with the highest optimisation score and also no observers deemed this image to be non diagnostic. See Table 5 for recommended acquisition parameters for trolley imaging based on this study.

Table 5 - Recommendations for the transition of acquisition parameters from x-ray tabletop to trolley for an average 73kg patient

	Mattress	**Platform position**	**OID present[c] (cm)**	**mAs**	**SID(cm)**	**Grid**
Reference (x-ray table top)[a]	Thin mattress used on general x-ray tables[b](2cm)	Fixed (no platform, only Bucky tray)	11.5	AEC (16)	110	Oscillating
Trolley imaging	Bi-Flex (13cm)	Elevated	25	20/25	130	Stationary (Lysholm 10:1, of 40 lines/cm)

[a] The x-ray table-top parameters are based on standard clinical practice using 75kVp, 3.2 mm Al total filtration, broad focus.

[b] The mattress may vary for some institutions whilst others do not use a mattress on the table

[c] Distance from surface of mattress (posterior aspect of phantom) to surface of image receptor.

Limitations

There are further factors that must be explored before implementing these changes into clinical practice which includes the consideration of the following study limitations. More variables need to be explored such as different grids since only one oscillating and one stationary grid was used. This work was also limited to one type of axial examination, the AP pelvis projection. It would be beneficial for further research to be conducted on other body parts that are imaged on the trolley using the image receptor holder in order to reveal its effects on image quality and radiation dose. In addition, this study used one commercially available trolley to perform the experiment. However there are multiple trolley manufacturers with different trolley designs available suitable for imaging which need to be explored. A single anthropomorphic phantom was used which had no size or pathological variation therefore these findings need to be confirmed using patients in clinical practice. Lastly, this study was conducted using one CR system and therefore it would be advisable

to validate the results on different CR and DDR systems especially when considering the different systems available and the technological advancements over the past 20 years.

Conclusion

The results of this study demonstrate that the acquisition parameters used for AP pelvis x-ray tabletop imaging are not directly transferable to trolley imaging. Consideration should be given to the difference between these two situations, especially the increased OID which would benefit from an increase in SID to a 130 cm in order to reduce both magnification and radiation dose. Radiation dose significantly increased for trolley imaging whilst visual image quality decreased. It is therefore important that separate exposure charts or diagnostic reference levels (DRL) are set for trolley imaging to ensure optimal image quality at the lowest possible dose. Lastly, the clinical indication for the AP pelvis on a trolley should be considered when selecting appropriate acquisition parameters because certain exposure factors may be sufficient depending on the objective of the examination.

References

1. Lee C, Porter K. The prehospital management of pelvic fractures. Emerg Med J 2007;24(2):130e3.
2. Hart D, Wall BF, Hillier MC, Shrimpton PC. In: Agency HP, editor. Frequency and collective dose for medical and dental X-ray examinations in the UK, 2008. Oxford, United Kingdom: Health Protection Agency; 2010.
3. Wall BF, Haylock R, Jansen JTM, Hiller MC, Hart D, Shrimpton PC. Radiation risks from medical X-ray examinations as a function of the age and sex of the patient.
Oxford, United Kingdom: Health Protection Agency; 2011.
4. Hiles P, Mackenzie A, Scally A, Wall B. Recommended standards for the routine performance testing of diagnostic X-ray imaging systems. York: Institute of Physics and Engineering in Medicine (IPEM); Report No. 91; 2005.
5. The Phantom Laboratory. Sectional lower Torso SK250 [Internet] [cited 1BC Aug 27]. 2013. Available from: http://www.phantomlab.com/library/pdf/sectional_
SK250DS.pdf.
6. Chan CTP, Fung KKL. Dose optimisation in pelvic radiography by air gap method on CR and DR systems; a phantom study. Radiography 2015;21(3):214e23.
7. Carver E, Carver B. Medical imaging: techniques, reflection and evaluation. 2nd ed. Philadelphia: Churchill Livingstone.

8. England A, Evans P, Harding L, Taylor E, Charnock P, Williams G. Increasing source-to-image distance to reduce radiation dose from digital radiography pelvic examinations. Radiol Technol 2015;86(3):246e56.
9. Harding L, Manning-Stanley A, Evans P, Taylor M, Charnock P, England A. Optimum patient orientation for pelvic and hip radiography: a randomised trial. Radiography 2014;20:22e32.
10. Manning-Stanley A, Ward A, England A. Options for radiation dose optimisation in pelvic digital radiography: a phantom study. Radiography 2012;18:256e63.
11. Lança L, Franco L, Ahmed A, Harderwijk M, Marti C, Nasir S, et al. 10kVp rule - an anthropomorphic pelvis phantom imaging study using CR system: impact
on image quality and effective dose using AEC and manual mode. Radiography 2014;20(4):333e8.
12. Tugwell J. Here comes a trolley: imaging the trolley bound patient - current working practices and experience. Imaging Ther Pract 2014, September. https://
www.sor.org/learning/library-publications/imaging-therapy-practice/ september-2014/here-comes-trolley.
13. Sandborg M, Dance D, Carlsson G, Persliden J. Selection of anti-scatter grids for different imaging tasks: the advantage of low atomic number cover and interspace materials. Br J Radiol 1993;66(792):1151e63.
14. Heath R, England A, Ward A, Charnock P, Ward M, Evans P, et al. Digital pelvic radiography: increasing distance to reduce dose. Radiol Technol 2011;83(1):20e8.
15. Woods J, Messer S. Focusing on dose. Imaging Ther Pract 2009, September:16e20.
16. Tugwell J, Everton C, Kingma A, Oomkens D, Pereira G, Pimentinha D, et al. Increasing source to image distance for AP pelvis imaging e impact on radiation dose and image quality. Radiography 2014;20(4):351e5.
17. The 2007 recommendations of the ICRP on radiological protection, publication
103. Ann ICRP; 2007: 37(2e4).
18. Hogg P, Blindell P. Software for image quality evaluation using a forced choice method. Manchester: United Kingdom Radiological Conference; 2012. p. 139.
19. Almen A, Tingberg A, Mattsson S, Besjakov J, Kheddache S, Lanhede B, et al. The influence of different technique factors on image quality of lumbar spine radiographs as evaluated by established CEC image criteria. Br J Radiol 2000;73(875):1192e9.
20. The Royal College of Radiologists. Picture archiving and communications system (PACS) and guidelines on diagnostic display devices. London: RCR; 2014.
21. The Royal College of Radiologists. Quality assurance in radiology reporting: peer feedback. London: RCR; 2014.

22. Samei E, Dobbins J, Lo J, Tornai M. A framework for optimising the radiographic technique in digital x-ray imaging. Radiat Prot Dosim 2005;114(1e3):220e9.
23. Allen E, Hogg P, Ma WK, Szczepura K. Fact or fiction: an analysis of the 10 kVp 'rule' in computed radiography. Radiography 2013;19:223e7.
24. Mraity H, England A, Cassidy S, Eachus P, Dominguez A, Hogg P. Development and validation of a visual grading scale for assessing image quality of AP pelvis radiographic images. Br J Radiol 2016;89(1061). http://dx.doi.org/10.1259/bjr.20150430.
25. Hess R, Neitzel U. Optimizing image quality and dose for digital radiography of distal pediatric extremities using the contrast-to-noise ratio. Rofo 2012;184(7):643e9.
26. Mori M, Imai K, Ikeda M, Iida Y, Ito F, Yoneda K, et al. Method of measuring contrast-to-noise ratio (CNR) in nonuniform image area in digital radiography. Electron Commun Jpn 2013;96(7):32e41. http://dx.doi.org/10.1002/ecj.11416.
27. Martin C. Optimisation in general radiography. Biomed Imaging Interv J 2007;3(2). http://dx.doi.org/10.2349/biij.3.2.e18.
28. Vladimirov A. Comparison of image quality test methods in computed radiography.[MSc thesis]. University of Tratu, Estonia. Available from: http:// dspace.ut.ee/bitstream/handle/10062/15191/Vladimirov_Anatoli.pdf?sequence¼1 [last accessed 18.05.16.].
29. Bloomfield C, Boavida F, Chabloz D, Crausaz E, Huizinga E, Hustveit H, et al. Experimental article e reducing effective dose to a paediatric phantom by using different combinations of kVp, mAs and additional filtration whilst maintaining image quality. In: Hogg P, Lanca L, editors. Erasmus intensive programme OPTIMAX; 2014. Lisbon, Portugal.
30. Desai N, Singh A, Valentino D. Practical evaluation of image quality in computed radiographic (CR) imaging systems. In: Proceedings of SPIE, medical imaging: physics of medical imaging. San Diego: The International Society of Optical Engineering; 2010. http://dx.doi.org/10.1117/12.844640.
31. Jang K, Kweon D, Lee J, Choi J, Goo E, Dong K, et al. Measurement of image quality in CT images reconstructed with different Kernels. J Korean Phys Soc 2011;58(2):334e42.
32. Sun Z, Lin C, Tyan Y, Ng K. Optimization of chest radiographic imaging parameters: a comparison of image quality and entrance skin dose for digital chest radiography systems. Clin Imaging 2012;36(4):279e86.
33. Ma W, Hogg P, Norton S. Effects of kilovoltage, milliampere seconds, and focal spot size on image quality. Radiol Technol 2014;85(5):479e85.
34. Williams S, Hackney L, Hogg P, Szczepura K. Breast tissue bulge and lesion visability during stereotactic biopsy e a phantom study. Radiography 2014;20:271e6.

35. Rosner B. Fundamentals of biostatistics. 7th ed. Boston: Cengage Learning; 2010.
36. Ghasemi A, Zahediasl S. Normality tests for statistical analysis: a guide for nonstatisticians. Int J Endocrinol Metab 2012;10(2):486e9.
37. Hinkle D, Wiersma W, Jurs S. Applied statistics for the behavioural science. 5th ed. Boston: Houghton Mifflin; 2003.
38. Agrawal K, Chauhan N. Pressure ulcers: back to the basics. Indian J Plast Surg 2012;45:244e54.
39. Angmorterh SK. An investigation into interface pressure (IP) risk of healthy volunteers on modern medical imaging and radiotherapy tables [Degree of Doctor of Philosophy (PhD)]. Manchester, United Kingdom: Univeristy of Salford; 2016.
40. Manning D, Ethell S, Donovan T. Detection or decision error? Missed lung cancer from posteroanterior chest radiographs. Br J Radiol 2004;77(915):231e5.
41. Alexander K. Reducing error in radiographic interpretation. Can Vet J 2010;51(5):533e6.
42. Colenbrander A. Measuring vision and vision loss. In: Tasman W, Jaeger E, editors. Duane's ophthalmology. Philadelphia: Lippincott Williams&Wilkins; 2013.
43. Marchiori D. Clinical imaging: with skeletal, chest, & abdominal pattern differential. 2nd ed. St Louis: Elsevier Health Sciences; 2004.

2.3 - PAPER 3

A review of the clinical and technical challenges associated with x-ray imaging patients on hospital stretchers

Tugwell JR, England A, Hogg P.

After completing this Directed Reading, readers should be able to:

- *Understand the main differences that exist between imaging on an x-ray tabletop and stretcher with particular reference to acquisition parameters.*
- *Explain possible complications associated with imaging on a stretcher and how to overcome them.*
- *Understand the advantages and disadvantages of imaging on a stretcher which will allow for a more informed decision as to whether to transfer the patient onto the x-ray tabletop in certain situations.*
- *Evaluate stretcher design in order to make an informed decision as to its suitability for imaging.*

Abstract

Imaging trolley bound patients can be challenging with many physical and technical variables to consider. These challenges arise due to the differences that exist between imaging a patient on an x-ray tabletop and imaging a patient on the trolley. Patients often present to the imaging departments on trolleys and it is important in certain circumstances that they remain on the trolley for imaging purposes to reduce the likelihood of exacerbating injuries. The purpose of this article is to evaluate and review the physical and technical challenges associated with imaging trolley-bound patients by exploring the need for modification of technique owing to the lack of availability of the AEC, different grids utilised, geometric factors and the different trolley and mattresses designs.

Introduction

Hospital stretchers are essential for imaging unstable or severely ill patients. Stretchers help to significantly reduce moving and handling risks for patients and staff. Patients are imaged on stretchers because transferring them onto an x-ray tabletop could cause further harm, exacerbate pain and result in further discomfort. This is especially the case for patients who may have multiple injuries.[1] In these circumstances radiographers are routinely faced with the challenge of producing images of diagnostic quality while the patient remains on the stretcher. In these situations a variety of physical and technical parameters should be considered, including image receptor (IR) holder, mattress construction and thickness, object to image receptor distance (OID), source to image

distance (SID), the use of a stationary radiation grid and the lack of availability of automatic exposure control (AEC). These variables may influence the selection of the acquisition parameters for stretcher imaging since they distinctly differ from those used when imaging on the x-ray tabletop. To date, we have not found any published optimisation studies exploring the selection of acquisition parameters when imaging patients on a stretcher or that evaluates their relationship with image quality and radiation dose for such a situation.

This article aims to review the challenges of x-ray imaging patients on a stretcher. Stretcher design will firstly be evaluated followed by the technical variations between stretcher imaging and x-ray tabletop and lastly previous published studies specifically conducted on stretcher imaging will be evaluated.

Stretcher design

Considerable differences exist between dedicated x-ray table tops and stretchers. Some stretchers have design features with x-ray imaging in mind; others do not. Ideally a stretcher should combine the needs of multiple patients across a range of clinical scenarios which may or may not include x-ray imaging. Stretchers are sometimes referred to as trolley or gurney.

Stryker Medical is one manufacturer who offers flexible stretchers with x-ray imaging in mind. Stryker(R) recently introduced their multipurpose Prime X stretcher into practice.[2] This stretcher allows patients to remain on *one* stretcher for transportation, treatment and x-ray imaging; in turn this reduces time, cost and the risk to both patient and staff from injury occurring when transferring patients to and from a stretcher. Literature indicates the importance of minimizing patient movement when there is concern about injures.[1,3,4] According to the United Kingdom's Royal College of Radiologists, moving a severely injured patient can cause delays and exacerbate blood loss. [5] The less a patient is moved and the shorter the distance of movement, the greater the chance of survival. It is also important to consider staff safety during manual transferring of patients from stretcher to x-ray tabletop and vice versa. Work-related injuries are an important consideration for healthcare practitioners with injuries occurring often during transferring, repositioning, lifting or moving patients.[2] In certain situations it can, therefore, be appreciated that if it is possible to acquire images of diagnostic quality on the stretcher, it would benefit both the patient and staff by minimizing unnecessary transfers.

There are essential design features that a stretcher must possess to ensure its suitability for x-ray imaging purposes. Many of these features, indicated in Table 1, are highlighted in manufacturer

brochures and textbooks.[2,6-8] As seen in Table 1, imaging stretchers require a number of *essential* features; however, different manufacturers offer *additional* features in order to improve their design and ultimately utility. The additional features are not compulsory for successful stretcher imaging and often incur an extra cost. Table 2 demonstrates a range of different design features for five commercially available stretchers suitable for x-ray imaging. Essential design features comprise the minimum specifications required to enable the radiographer to image the patient safely and successfully on the stretcher. The imaging departments should therefore be involved in decision making and evaluating new stretchers during procurement to ensure they are fit for purpose; this becomes paramount when the lead department who intends to purchase the stretcher is not the imaging department (e.g. emergency department).[8] A number of essential stretcher design features are now considered:

Table 1 - Compulsory and desirable characteristics of an imaging trolley (Carter et al., 1994; Whitley et al., 2015; Stryker, 2012; ArjoHuntleighs Healthcare)

Compulsory	**Desirable**
A tray or platform beneath the trolley to accommodate a large image receptor and stationary grid	A movable tray or platform underneath the trolley that allows the image receptor to be positioned with no restrictions. (landscape, portrait or angled)
Full length radiolucent trolley top (usually carbon fibre)	Image receptor tracking device
Low attenuating (radiolucent) mattresses	Lightweight with excellent manoeuvrability and designed to reduce pressure ulcers
An adjustable backrest which can be positioned at various angles.	Light and easy assisted tilting back rest enabling various angles for patient position.
A good adjustable height range allowing acceptable SID to be achieved	Lateral cassette holder for horizontal beam lateral examinations

Table 2 - Specifications of different commercially available trolleys suitable for imaging					
Trolley manufacturer	**Trolley name**	**Tray or platform**	**Mattresses included (mm)**	**Other mattress options (mm)**	**Standard Features**
Wardray	XRT	tray	50mm	memory foam and pressure relief mattress (no thickness included)	75cm lowest height. Tray suitable for portrait and landscape images
ArjoHuntleigh	Lifeguard50	platform	65 mm (2½") deep mattress pad with Lectrolite cover or 2-way stretch cover	Bi-Flex® Pressure Re-Distributing Mattress 150mm	56cm lowest platform height range
M.A.S	X-Ray Trauma Trolley	tray	76mm	No information	66cm lowest height. .Full length tracking x-ray cassette carrier
Stryker	Prime X	platform	70mm enhanced comfort mattress	100mm Enhanced Comfort mattress or 100mm or 130 mm Ultra Comfort Mattress	Full length tracking x-ray cassette carrier with film location indicators.
Seers Medical	SM0820	tray	Standard 80mm	100mm memory foam	Alignment guides make positioning the image receptor to the patient simple
Seers Medical	SM0830	tray	Standard 80mm	125mm memory foam	

The image receptor (IR) holder

Many imaging examinations of stretcher-bound patients cannot be acquired with the IR directly in contact with the patient due to the potential of exacerbating or inducing injuries. Such examinations include AP pelvis, AP spine(s) and AP supine chest projections. Consequently, the stretcher requires an IR holder (either a tray or platform) similar to an x-ray tabletop Bucky, to accommodate the IR and in some cases a stationary grid. The IR holder is commonly referred to as a stretcher cassette holder.[8] The design of the IR holder varies from one manufacturer to another with some designs restricting the angulation or rotation of the IR.

There are two different types of IR holders, one is designed similar to a Bucky mechanism as found under the x-ray tabletop and is referred to as a **tray** while the other type is referred to as a **platform** (or opening under stretcher). The stretcher tray is a device where the IR is placed in a drawer and slid into place prior to an exposure (Figure 1). The platform on the other hand is an opening under the stretcher which is parallel to the stretcher tabletop in order to accommodate the IR (Figures 2 and 3 show examples of two different platform designs). In comparison to the tray, the platform offers more flexibility especially when patients are not central to the stretcher or when the IR needs to be angled for patients that are not lying straight on the stretcher. The stretcher tray can therefore cause practical problems to radiographers since patients are rarely perfectly centralised on the stretcher and often lie obliquely across its central axis.[9] If the stretcher has a tray and the patient is not centralized it may require the patient to be moved to coincide with the axis of the tray; this can be a common reason for generating repeats due to anatomy cut-off.

Figure 1 – An illustration of a trolley with an image receptor tray beneath it (Lind permission of Wardray Premise Limited, LTD)

Figure 2 – An illustration of a trolley with a platform that does not elevate (Kind Permission of Prime X Stryker, Switzerland)

Figure 3 – An illustration of a trolley with platform underneath it which can be elevated with the red handles (Lifeguard 50 trolley, ArjoHuntleighs' Healthcare, Sweden)

It is important that the radiographer is able to visualize the position of the IR between the stretcher top and platform to ensure accurate alignment relative to the patient before making an exposure. Unfortunately this is not an entirely accurate method of assessing alignment, and this problem has been identified by Mutch and Wentworth, where radiographers within their study commented on the difficultly of aligning the IR and patient when using a tray mechanism in the incubator.[10] This situation is exacerbated when the tray or platform are used to store patient belongings e.g. clothing

thus further impairing visibility. On the x-ray tabletop there are physical and electronic indicators when the IR within the Bucky is aligned to the x-ray tube and therefore the issue of having to visually predict alignment is not a problem. There are some visual indicators on the stretcher as seen in Figures 2 and 3 to help align the IR but again these just help with predicting alignment. This issue of alignment on stretchers may potentially result in cutting off relevant anatomy.

Stretcher surface and mattress

Ideally, the entire length and width of the stretcher surface and mattress have to be uniformly radiolucent. According to Whitley et al. metal bars and hinges on the edges of the stretcher surface may cause image artifacts when using the tray or platform which would be exacerbated when angulation of the tube is required.[8]

The stretcher mattress is another important factor to consider. In comparison to the mattresses used on x-ray tabletops, stretcher mattresses tend to be thicker and constructed of different materials to meet standards associated with tissue viability, infection control and durability, since patients can remain on a stretcher for long periods of time.[11] In Canada, there have been concerns of patients lay on stretchers in the emergency department for long periods of time awaiting hospital beds.[12] This problem has also been noted in the UK which raises concerns over pressure ulcers.[13,14] Pressure ulcers are injuries that often develop in patients who remain in one position for prolonged periods. The elderly are particularly at risk in addition to those with injuries that limit mobility (e.g. suspected neck of femur fracture) are at even higher risk. [15] Due to this complication, patients are usually placed onto thicker [pressure redistributing] mattress on admission and consequently imaged on these mattresses.[16]

As seen in Table 2, mattress thickness varies between manufacturers. Manufacturers tend not to specify the density and construction of their mattresses however this may be available upon request. Most stretchers come with a standard mattress with most manufacturers, including Stryker, ArjoHuntleighs', and Seers offering a replacement thicker mattress to enhance patient comfort and to reduce the possibility of pressure ulcer development. For example ArjoHuntleighs standard mattress is 65mm in thickness and made of plain foam pads whereas their replacement Bi-Flex mattress (130mm) is constructed of pressure distributing foam (see Figures 4 and 5). Disappointingly, few studies are available which investigated the impact that these mattresses have on radiographic technique, image quality and radiation dose.

Figure 4 – An illustration of the Lifeguard 50 trolley with the standard 65mm mattress (Kind permission of ArjoHuntleighs Healthcare, UK)

Figure 5- An illustration of the Lifeguard 50 trolley with the Bi-Flex pressure redistributing mattress (Kind permission of ArjoHuntleighs Healthcare, UK)

An example where imaging has been considered before introducing a newly proposed mattress comes from the United Kingdom's National Institute for Health and Care Excellence (NICE).[17] NICE provided some information on the potential impact of this new warming mattress on radiation dose and image quality by comparing it to two other imaging mattresses which they termed as '*low-attenuating x-ray mattress*' and '*x-ray stretcher mattress'*. Comparisons were established by calculating the aluminium (Al) equivalent of the mattresses in order to determine their radiation

transmission capabilities. NICE estimated that the low attenuating x-ray mattress was 0.2mm Al equivalent whereas the x-ray stretcher mattress was 1.0mm Al equivalent. Surprisingly, NICE did not specify the make, type, or thickness of the mattresses used in their comparisons. It is therefore difficult to generalise and put this information into context since there are several commercially available mattresses for x-ray tabletops and stretchers on the market. In addition, manufacturers do not ordinarily specify the Al equivalent of their mattresses therefore it is also difficult to compare these estimations from the NICE guidelines to the mattresses described in Table 2. NICE comment that the mattress in question did not affect x-ray image quality or radiation dose however this was based on observations made by users confirming that clinical practice had not changed when using this new mattress. NICE conducted a small experiment to determine the effect of the new warming mattress on image quality, however there were no details on how image quality was assessed. The lack of scientific evidence for the assumptions made by NICE regarding the effect of the mattresses under question makes it difficult to interpret and transfer to clinical practice. This example above highlights that products can easily be deemed acceptable from an imaging perspective without rigorous empirical evidence to support it.

Another point to consider is that some radiology departments do not use mattresses on their x-ray tabletops and such is the case in many departments.[18] When manufacturers such as Siemens Healthcare and Philips Healthcare launch new x-ray rooms, the advertising images do not demonstrate a mattress. This is because radiographic mattresses are sold separately. This could mean that anatomically programmed radiography (APR) systems and exposure charts used in imaging departments are based on imaging techniques performed without the use of mattresses. Radiological surfaces are designed by manufacturers to be radiolucent and any mattress added to this would likely incur an increased patient radiation dose.[19] From an image quality and radiation dose perspective, acquiring images without a mattress is better. However a study by Everton et al. highlights the potential for the development of discomfort and pressure ulcers if patients remain on the tabletop for long periods of time without a mattress.[20] Everton et al. also demonstrated a significant difference in pain and comfort levels between the two imaging surfaces (a surface with and without a mattress) and therefore not using a mattress on tabletops may result in more patient movement caused by discomfort during imaging.

Unavailability of the AEC

For many radiography examinations the AEC is utilized as an x-ray exposure termination device.[21] AEC is considered to be a dose reducing and image quality standardising device since the exposure

terminates when the IR has received a threshold exposure level. It takes into account the thickness and density of the body part being imaged and this should reduce operator subjectivity / variability. [22] The use of the AEC is recommended by the American Society if Radiologic Technologists and the International Commission on Radiological Protection (ICRP) when imaging specific body parts such as the abdomen, pelvis and spine.[23,24] When imaging a patient on a stretcher, the AEC is not available and this situation requires the radiographer to set their own exposure factors. This can result in higher radiation doses than necessary and also the potential for dose creep to occur.[25] There have however been recent discussions exploring the idea of integrating an exposure control sensor (similar to the principles of the AEC) with signal detection into digital radiography in order to increase its flexibility and use. Some manufacturers have already started introducing this new technology.[26]

Geometric factors

The geometric factors that need consideration for stretcher imaging are predominantly SID and OID. SID was previously referred to as film to focus distance (FFD), or also more recently referred to as focus to receptor distance (FRD). It is the linear distance from the focal spot of the x-ray tube to the IR. According to the inverse square law it affects contrast and if doubled, the intensity of the x-ray beam will be reduced by one-fourth.[27] SID also affects magnification and distortion on the resultant image i.e. magnification will reduce if SID is increased. In clinical practice each projection has a suggested standard SID in order to reduce variability and provide consistency in image quality.[28,29] OID is the distance from the object being exposed to the IR. It is another factor that influences magnification and geometric unsharpness. The closer the object being imaged is to the IR (reduced OID), the less the magnification, and the better the detail and image resolution.[30,31] Carroll & Bowman recognised that there will always be a trade off when imaging on a stretcher where radiographers are often forced to choose which factors to sacrifice: a slight increase in unsharpness and magnification, a slight loss of contrast, some distortion of anatomy or the clipping of anatomy if SID is not appropriately increased.[32]

When the IR is placed in the stretcher IR holder, whether it is in the tray or on the platform, this will increase the OID (Figure 6). OID magnitude will depend on stretcher design and mattress thickness. Some manufacturers (e.g. Lifeguard 50, ArjoHutleighs; Figure 3) offer an elevating platform in order to reduce the OID to bring the IR closer to the patient. A stretcher tray on the other hand does not require elevation (Figure 1); there are also some stretcher platform designs, as seen by Stryker Prime

that do not require elevation (Figure 2).[2] As already discussed, stretchers also tend to have thicker mattresses, consequently OID is increased further. Carver and Carver support this notion and comment that OID is greater on a stretcher in comparison to the table Bucky setup.[9] By placing the IR in the holder beneath the stretcher and with the patient positioned on a thicker mattress this can considerably increase OID which increases magnification and geometric unsharpness. This is why it is an important feature on a stretcher that its height can be lowered in order to maintain the required SID and offset this magnification. This is especially important when undertaking a supine chest due to magnification of the heart.[33] This problem was identified in a study which explored the effect of increased OID owing to stretcher design on the magnification of the mediastinum during AP supine chest imaging.[34] Within the study, the thickness of stretcher mattresses and the IR holder was identified as problematic and OID varied between six commercially available stretchers. Although the stretcher can be lowered and SID increased to compensate for the increased OID, this is limited by the radiographer's height and restrictions within the x-ray room. The effect of increased OID for stretcher imaging needs explored further because increased OID not only increases magnification but it also results in geometric unsharpness which will reduce image detail.[8]

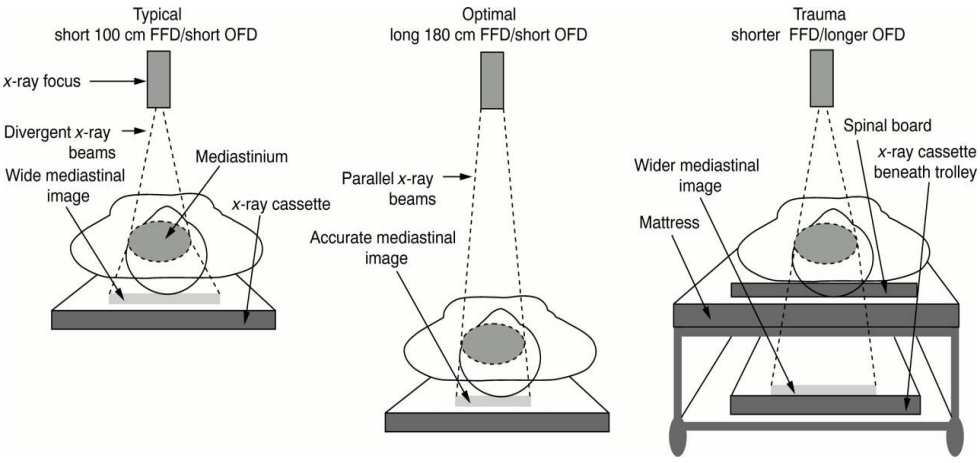


Figure 6 - Diagram demonstrating how changing SID and OID in various circumstances including on a trolley influence magnification (Gleeson, Spedding, Harding and Caplan, 2001)

An increase SID is required for an increase in OID not only to compensate for magnification but to ensure all require anatomy falls within the edges of the IR. Carroll and Bowman, recommends an increase in SID in this situation also to take advantage of beam divergence and hence bring in the collimation.[32] Increasing SID has previously been shown to reduce radiation dose to patient without impacting on image quality, however there is still controversy as to how to modify acquisition parameters for this situation. Carroll and Bowman suggested that for every 25cm increase in SID,

mAs needs to be adjusted by at least one third (35%). In addition, if adhering to the mathematics of the inverse square law, when 16mAs is used at a distance of 100cm as is subsequently increased by 25cm, it would require an increase of 9mAs (16mAs to 25mAs) which is more than one third. Yet again recent literature specifically exploring this increase in SID to reduce patient dose concluded that there was no visual impact on image quality when SID was increased for AP pelvis with the mAs kept consistent.[35-37]

Another consideration for stretcher imaging is the requirement for manual measurement of SID. When imaging on an x-ray table top using the Bucky, there are light indicators on the tube housing to confirm if the x-ray source and IR are aligned to the midsagittal plane and that the correct SID has been achieved. These are governed by sensors which illuminate and automatically notify the radiographer when there is correct alignment (source and IR) in all planes (long axis, short axis and distance) (Figure 7). These indicators are important to minimize the chance of excluding important anatomy, to avoid grid cut-off and also to ensure practice consistency.[38] However, for stretcher imaging the SID has to be measured manually using a measuring tape incorporated into the light beam diaphragm (LBD). This requires the radiographer to measure SID at the side of the stretcher and then re-position the x-ray tube over the patient (Figure 8). This has the potential to cause major inconsistency and accuracy issues with SID.[4]

Figure 7 - Source to image receptor alignment indicators illuminated on x-ray tube housing

Figure 8 – A radiographer demonstrating how they measure SID at the side of the trolley before centralising the x-ray tube

Grid selection

A secondary radiation grid can be used to reduce scattered radiation reaching the IR in order to improve image quality; they can be oscillating or stationary. An oscillating gird is incorporated into the x-ray tabletop Bucky and moves during an exposure in order to minimize the shadows of the gridlines on the resultant image. It is the most desirable type of grid as it helps minimize grid artifacts.[30] Nevertheless, this type of grid is unavailable for stretcher imaging and a stationary grid has to be used instead. A stationary grid does not move during an exposure and needs to be fitted to the IR prior to exposure. In comparison to an oscillating grid, the opaque strips found in a stationary grid are thin and close together such that the grid can remain stationary without the shadows of the strips being sufficiently visible to interfere with image detail (e.g. Lysholm grid). Different acquisition parameters may be needed, depending on the grid type.[8] This suggests that exposure factors used for the oscillating gird on the x-ray tabletop may not be directly transferable to a stretcher patient with a stationary grid.

Currently used grids are often focused with the lead strips are aligned in a slanted fashion towards a centering point. These grids have a minimum and maximum SID tolerance in order to avoid grid cut off.[8] The radiographer must therefore be accurate when measuring SID to avoid cut off artifact from misalignment causing visualisation of lead strips shadows on the resultant image.[27] The focus tolerance of the grid becomes problematic for certain examinations during stretcher imaging for two

reasons. Firstly, an increased SID may be required for stretcher imaging to compensate for the magnification caused by the mattress and position of the IR holder. The radiographer in this situation has to consider how much they can increase SID before gird cut off becomes apparent. Secondly, accurate measurement of SID can be difficult for stretcher imaging in comparison to x-ray tabletop imaging since it requires manual measurements of SID using a measuring tape. Recent literature on increasing SID to reduce patient dose have not visually experienced any image quality deterioration at increased SID over the recommended tolerance range of the grid.[35,39,40] However these studies have been conducted using oscillating grids on x-ray tabletops and therefore cautions needs to be taken before applying it to stationary girds. Further work would be beneficial to evaluate using an increased SID for stationary grids.

Previous published studies related to stretcher imaging

A comprehensive literature search was conducted to search for specific peer-reviewed articles on stretcher imaging. The search was performed using a systematic approach using several databases including Science Direct and Cochrane with several peer reviewed journals also individually searched including *Radiologic Technology, Radiation Protection Dosimetry, European Journal of Radiology, Radiology, American Journal of Roentgenology, British Journal of Radiology, Radiography*, *Journal of Medical Imaging and Radiation Sciences*, and *Medical Physics*. While undertaking a scope of the literature, relevant key words where used including *digital radiography, trolley, stretcher, optimisation, image quality* and *radiation dose.* Due to the limited literature found initially on stretcher imaging, no time restriction with regards to publication date was placed on the search in order to maximize the likelihood of finding relevant articles.

This comprehensive literature review revealed limited published work relating to imaging patients on stretchers, especially studies investigating the effects of the stretcher design on image quality and radiation dose. From this search strategy, only four studies were found that met the search criteria, with all of them being 10+ years old. The following section takes into consideration these prior studies however their publication date clearly reflects that stretcher imaging has not received much attention.

The first relevant study was a questionnaire-based study whereby radiographers across three district general hospitals in the United Kingdom were asked about their current working practices in association with stretcher imaging. The aim of this study was to explore whether there was variation in practise when imaging stretcher patients.[41] It was discovered that acquisition parameters used for

stretcher patients were based on APR values which are pre-programmed exposure techniques set on the control panel for average patients imaged on the x-ray tabletop but also on the radiographer's professional judgement. This study had a response rate of 65% which accounted for two thirds of the radiographers working within these hospitals. The results of this study demonstrated a considerable variation between radiographer's practice and their understanding of different variables when imaging a patient on a stretcher. One of the most important findings from this study was that more than 50% of radiographers increased their exposure factors from the recommended values on the APR system for stretcher imaging without any clear evidence to support this. The study demonstrated that 52% of radiographers either strongly agreed (n=3) or agreed (n=31) that an increase in mAs is necessary for imaging patients on a stretcher using the tray/platform beneath it while 26% (n=17) were undecided. This is especially worrying considering that after the introduction of digital systems in radiography a phenomenon called 'dose creep' became apparent and recognised by several authors.[25,42] The radiographer can increase dose quite a lot without degrading image quality; Ma et al went on to suggest that 'dose creep' can occur frequently in examinations where the AEC is not available and some radiographers may increase their mAs to ensure the image is acceptable on the first attempt.[25] This concept is worrying as the AEC is unavailable for stretcher imaging and there are no set protocols specifically related to this imaging technique.

Careful consideration must, however, be given to the results of this study as it cannot be assumed that the same variability and opinions exists in other x-ray departments. Also, this article was published in a radiography non peer reviewed magazine although it was still reviewed by an individual within the profession and can therefore still be deemed valid to reflect the current working practice in one area within the United Kingdom.

The second relevant study on stretcher imaging was conducted by Gleeson et al. in which supine chest imaging on stretchers and the impact of components such as the mattress and IR holder on magnification of the mediastinum was examined.[34] Gleeson et al. identified problems when imaging patients on stretchers and explored the effect stretcher imaging had on magnification in supine chest imaging. The problems identified by Gleeson et al. included the introduction of advanced trauma life support (ATLS) which sees patients being pre-packaged on spinal boards and placed on a stretcher with a thick mattress consequently inhibiting the placement of the IR directly behind the patient for imaging. The introduction of the spinal board, the thick mattress and the IR holder beneath the stretcher has therefore increased the distance between the *IR and the area being imaged*. Gleeson et al. wanted to explore this increased OID which has exacerbated magnification in order to determine its effect on the diagnosis of thoracic trauma when chest imaging. When

calculating magnification, Gleeson et al. compared the affect of six commercially available stretchers on mediastinal diameter however the name of the stretcher manufacturers were anonymous. The six stretchers caused different distances between the spinal board and the IR holder, ranging from 7.1 to 12.9 cm. This suggests a large manufacturer variation in stretcher design resulting in incomparable magnification level when imaging on different stretchers at identical SIDs. '*Radiographic techniques have to be adapted when imaging stretcher bound patients*' was one of the concluding statement made within this study; however, no recommendations were made regarding specific modification requirements for technique or acquisition parameters. In addition, this study by Gleeson et al. was carried out more than 10 years ago yet no follow up research study was found addressing the issues raised by this study. The impact of stretcher design on chest magnification was the only outcome measure evaluated for this study and therefore stretcher design and mattress plus geometric factors were not explored in terms of their effect on radiation dose and image quality.

One of the other studies found explored how different spinal boards affected image quality, radiation dose and the attenuation/transmission of radiation.[43] Although this article did not relate specifically to stretcher imaging, it does highlight some of the challenges of trauma imaging. It can also be assumed that patient who presents to the imaging departments on spinal board are on stretchers and therefore may remain on them for imaging. From an imaging perspective these boards need special consideration since they are an additional object placed in-between the patient and the IR and are therefore in the path of the x-ray beam. Linsenmaier and colleagues found that radiation transmission was similar for all boards but with dose areas product (DAP) differed by up to 59 %. This study did not however compare the difference in radiation transmission and DAP between the spinal boards and the absence of a spinal board. Five different spinal boards were compared to each other which helped to indicate the optimum spinal board to utilise for imaging rather than the impact different spinal boards have on image quality and radiation dose compared to imaging without the boards. Linsenmaier et al. demonstrated that the spinal boards' increased DAP and also had an impact on image quality due to image artifacts. Similar to Gleeson et al. the study did not consider whether and how acquisition parameters should be modified when imaging with the patient lay on a spinal board.[34]

One limitation when evaluating this article was that only the abstract was available in the English language as opposed to the full text that was originally written in German. Careful interpretation of the information provided is therefore required since the in-depth detailed description and analysis of the method and results are missing and there may also be inconsistencies between what has been reported in the abstract and what has been stated in the full paper.[44] Also this study was conducted

in Germany in 2001 where the use of spinal boards was still considered gold standard. Nevertheless, recent research has been conducted which questions the use of spinal boards. Log rolling the patient on to a spinal board should be avoided according to Conrad et al. as it can exacerbate injuries.[45] Theodore et al. demonstrated that patients had better neurological outcomes when spinal immobilization was not used.[46] Further studies have also demonstrated limitations to immobilization protocols such as delays in resuscitation, increased anxiety and pressure ulcer development.[47-51] Although the study by Linsenmaier et al. is outdated and does not specifically explore stretcher imaging, it does demonstrate that spinal boards (an object that lies in-between the patient and the IR) increases the radiation dose to the patients and can produce artifacts on the resultant images.[43]

Mutch and Wentworth explored a similar imaging situation to stretcher imaging.[10] The main aim of the study was to evaluate the effect of placing the IR in a dedicated slot within the incubator in comparison to the standard method of imaging which in Mutch and Wentworth's case was a direct exposure (IR placed directly behind the neonate).

Premature newborns are placed in incubators in order to maintain suitable environmental conditions. Neonates often require imaging where the radiographer acquires the images with the neonate remaining in the incubator. Similar to stretchers, there are a variety of different incubators available, each having their own design. Some incubators have a dedicated IR holder beneath them in order to reduce the risks associated with placing the IR directly behind the neonate. The difference between these two scenarios was investigated by Mutch and Wentworth.[10] They found that in comparison to placing the IR directly behind the neonate, the mattress and IR holder mechanism caused a 49% reduction in IR dose although this did not equate in a 49% increase in neonate dose. When allowing for the inverse square law, the difference in distances (OID) between a direct exposure and the IR placed in the IR holder would account for one-fifth of the reduction in IR dose. This means that the remaining reduction must have resulted from attenuation by the materials between these two imaging conditions. In addition, this large reduction in IR dose did not result in deterioration in image quality; there was minimal effect.

The results of Mutch and Wentworth's study are interesting and they demonstrate the potential impact of absorbing materials in the path of the x-ray beam on IR dose; however, these results should be carefully interpreted due to several methodological limitations. The radiation dose quantity used in their study was IR dose. This quantity is not a universally accepted dose quantity and has limited use in optimization studies. It is also not cited in radiation protection reports such as those from ICRP.[52] From a radiation protection perspective, IR dose does not consider the risk to the patient and it is also not fully understandable in terms of its correlation with image quality.[53]

Although significant IR dose reduction was found between the two scenarios presented within their study, there was no impact on image quality. Nevertheless, the method they used to evaluate image quality may have been limited. They used a Leeds Test Object which is a test phantom designed for routine quality control to quantify the degree of threshold contrast in each image using one of themselves as authors to observer and assess this. Not only could this introduce bias into the study but it can also introduce subjectivity due to the relaxed and unstructured nature of the visual evaluation. It would have been beneficial to use more than one independent observer to assess the images using stricter image criteria with repeated measurements taken at time intervals in order to ascertain intra and inter-observer variation. The importance of using multiple observers when evaluating image quality is highlighted by many studies. [54-56] In addition, a Leeds Test Object does not resemble patient clinical imaging and therefore this method may not always be suitable for evaluating different imaging systems or imaging techniques, since their contrast could behave differently to the contrast of clinically relevant details with a changing radiation quality. [57]

These four studies were found when specifically searching for studies focusing on stretcher imaging. Nevertheless, only the first two articles were directly related to the challenges associated with imaging on a stretcher whereas the latter two articles were only in-directly related and helps reinforce the challenges. They all highlight and emphasized the importance of studying imaging conditions and techniques that vary from standard imaging techniques in order to understand their effects on image quality and radiation dose. This is important because the APR system and exposure charts found in imaging departments are programmed for standard clinical examinations and do not take into consideration these modifications in clinical practice e.g. increased OID and objects placed in the path of the primary beam. Although, the APR system and exposure charts should only be used as a guide to help the radiographer's clinical judgment as to the appropriate exposure factors required for each examination.[58] It is the radiographer's responsibility to modify these parameters when necessary; however, this can be challenging if there is no empirical evidence to suggest or support how and when modification is necessary. This limited empirical evidence can result in a wide variation in exposure factors across a variety of examinations since clinical judgment is highly subjective but may contribute to the dose creep phenomenon.

Summary

When patients present on a stretcher to the imaging department, transferring the patient onto the x-ray tabletop is a difficult decision. Transferring patients can cause them further harm however it is standard practice to image patients on the dedicated x-ray table. If the patient remains on the stretcher for imaging, many factors need to be considered before acquisition can take place. These

factors have been discussed in detail in this article and they include grid usage, stretcher and mattress design, IR holder, exposure factors owing to the unavailability of the AEC and geometric factors (SID/OID). Optimisation of image quality and radiation dose for stretcher imaging is of paramount importance because there are currently no specific guidelines for radiographers when having to adapt technique for imaging stretcher patients. This review highlights upon the limited evidence available for stretcher imaging hence why some old seminal references have occasionally been used. This is clearly a fundamental issue which needs further understanding and recognition.

References

1. Lee C, Porter K. The prehospital managment of pelvic fractures. *Emerg Med J*. 2007; 24(2): p. 130-133.

2. Stryker. *Stryker Prime X Imaging Stretcher: Image Quality. Access. Mobility*. Switzerland: Stryker.

3. Beebe R, Myers J. Professional Paramedic, Vol III: *Trauma Care and EMS Operations*. 1st ed. New York: Cengage Learning; 2012.

4. Carlton R, Adler A. *Principles of Radiographic Imaging: An Art and a Science*. 5th ed. Melbourne: Cengage Learning ; 2013.

5. Radiologists TRCo. *Standards of practice and guidance for trauma radiology in severly injured patients.* London: RCR; 2011.

6. ArjoHuntleigh. *Lifeguard trolley ranges brochure*. Sweden: ArjoHuntleigh Getinge Group; 2014.

7. Carter P, Paterson A, Thornton L, Hyatt A, Milne A, Pirrie J. *Chesneys' Equipment for Student Radiographers*. 4th ed. London: Blackwell Scientific; 1994.

8. Whitley S, Jefferson G, Holmes K, Sloane C, Anderson C, Hoadley G. *Clark's positioning in radiography*. 13th ed. London: CRC Press; 2015.

9. Carver E, Carver B. *Medical Imaging: Techniques, Reflection and Evaluation*. 2nd ed. Philadelphia: Churchill Livingstone; 2012.

10. Mutch S, Wentworth S. Imaging the neonate in the inbubator: an investigation of the technical, radiological and nursing issues*. Br J Radiol*. 2007; 80: p. 902-910.

11. Dawkins S. Impact Assessment on a Newly Implemented Service Utilising Recovery Nurses as Transfer Nurses, Incorporating a Literature Review of Pressure Ulcer Reduction Strategies, i.e. Mattress and Overlay Types, for Patients on Hospital Trolleys. *British Journal of Anaesthetic and Recovery Nursing*. 2012; 13(3-4): p. 58-64.

12. Taylor, P. *Why must ER patients wait so long for a hospital bed? [*Online]; Mar. 16, 2016 2:45PM. Available from: http://www.theglobeandmail.com/life/health-and-fitness/health-

advisor/why-must-er-patients-wait-so-long-for-a-hospital-bed/article29260307/ [Accessed 23.8.16]

13. Donnelly L, Sawer P. *Number of patients waiting on stretchers in A&E triples.* The Telegraph; November. 29, 2014. Available from: http://www.telegraph.co.uk/news/health/news/11262541/Number-of-patients-waiting-on-stretchers-in-AandE-triples.html [Accessed 10.6.16]

14. Parry, L. *War hero, 89, left on a hospital stretcher in A&E for 34 hours*. Wales Online ; January. 19, 2015. Available from: http://www.dailymail.co.uk/health/article-2916821/War-hero-89-left-hospital-stretcher-E-34-hours-turning-couldn-t-appointment-GP-FIVE-days.html#ixzz4Vds4rlRw [Accessed 23.10.16]

15. Haleem S, Heinert G, Parker M. Pressure sores and hip fractures. *Injury*. 2008; 39(2): p. 219-223.

16. Vickery D. The use of spinal board after the pre-hospital phase of trauma managment. *Emerg Medi J*. 2001; 18: p. 51-54.

17. (NICE) NifHaCE. *Inditherm patient warming mattress for the prevention of inadvertent hypotherimia*. London: NICE; 2011.

18. Angmorterh S. An investigation into interface pressure (IP) risk of healthy volunteers on modern medical imaging and radiotherapy tables. Manchester: Univeristy of Salford , Degree of Doctor of Philosophy (PhD); 2016.

19. Everton C, Bird S, Brito W, Colle P, Franco A, Lutjber S, et al. Review article – The effects of clinical support surfaces on pressure as a risk factor in the development of pressure ulcers, from a radiographical perspective: a narrative literature review. In Hogg P, Lanca L. *Radiation dose and image quality optimisation in medical imaging*: Erasmus Intensitve Program OPTIMAX. Lisbon, Portugal; 2014.

20. Everton C, Bird S, Brito W, Colle P, Franco A, Lutjber S, et al. Experimental article – An experimental study to compare the interface pressure and experience of healthy participants when lying still for 20 minutes in a supine position on two different imaging surfaces. In Hogg P, Lanca L. *Radiation dose and image quality optimisation in medical imaging*: Erasmus Intensive Programme OPTIMAX. Lisbon, Portugal ; 2014.

21. Manning-Stanley A, Ward A, England A. Options for radiation dose optimisation in pelvic digital radiography: a phantom study. *Radiography*. 2012; 18: p. 256-263.

22. Jones K. Using Automatic Exposure Control in Digital Radiography. Houston, Texas: *The American Association of Physicists in Medicine Annual Meeting*; 2008.

23. Herrmann T, Fauber T, Gill J, Hoffman C, Orth D, Peterson P, et al. Best practices in digital radiography.[White Paper] *Radiologic Technology*. 2012; 84. Available from: http://asrt.org/docs/whitepapers/asrt12_bstpracdigradwhp_final.pdf

24. Protection IcoR. The 2007 recommendations of the ICRP on radiological protection, publication 103. *Annals of ICRP. 2007*; 37(2-4).

25. Ma W, Hogg P, Tootell A, Manning D, Thomas N, Kane T, et al. Anthropomorphic chest phantom imaging the potential for dose creep in computed radiography. *Radiography*. 2013; 19(3): p. 207-211.

26. Agfa Healthcare. DX-D Retrofit Solution. [Online].Available from: http://www.agfahealthcare.com/he/global/en/binaries/DX-D_Retrofit_flyer_tcm541-167185.pdf [Accessed 16.01.17]

27. Carroll Q. *Radiography in the Digital Age: Physics, Exposure and Radiation Biology*. 2nd ed. Illinois: Charles C Thomas; 2014.

28. Bontrager K, Lampignano J. *Textbook of radiographic positioning and related anatomy*. 8th ed. Missouri: Mosby; 2014.

29. Fauber T. *Radiographic Imaging and Exposure*. 4th ed. Missouri: Mosby Inc; 2013.

30. Bushong S. *Physics, Biology, and Protection. Radiologic Science for Technologists*. 10th ed. Missouri: Elsevier; 2013.

31. Fosbinder R, Orth D. *Essentials of Radiologic Science*. Philadelphia: Lippincott Williams and Wilkins; 2011.

32. Carroll Q, Bowman D. *Adaptive Radiography with Trauma, Image Critique and Critical Thinking*. International ed. New York: Cengage Learning; 2013.

33. McConnall J. *Index of Medical Imaging*. Chichester: Wiley and Sons; 2011

34. Gleeson C, Spedding R, Harding L, Caplan M. The mediastinum – is it wide? *Emerg Med J.* 2001; 18: p. 183-185.

35. Tugwell J, Everton C, Kingma A, Oomkens D, Pereira G, Pimentinha D, et al. Increasing source to image distance for AP pelvis imaging – impact on radiation dose and image quality. *Radiography*. 2014; 20(4): p. 351-355.

36. Farrell K, Abbott C, Round K, Willis S, Yalden R, Knapp K. Pelvic projection radiography: increasing source to image distance provides diagnositc images at reduced dose. In UK radiological congress; 2008; Manchester: *British Institute of Radiology*. P. 16.

37. Woods J, Messer S. Focusing on dose. *Imaging and Therapy Practice*. 2009, September: p. 16-20.

38. Papp J. *Quality Management in the Imaging Sciences*. 4th ed. St.Louis: Mosby; 2010.

39. England A, Evans P, Harding L, Taylor E, Charnock P, Williams G. Increasing source-to-image distance to reduce radiation dose from digital radiography pelvic examinations. *Rad Tech*. 2015; 86(3): p. 246-56.

40. Heath R, England A, Ward A, Charnock P, Ward M, Evans P, et al. Digital pelvic radiography: increasing distance to reduce dose. *Rad Tech*. 2011; 83(1): p. 20-28.

41. Tugwell J. Here comes a trolley: Imaging the trolley bound patient – current working practices and experience. *Imaging and Therapy Practice*. 2014, September.

42. Uffmann M, Schaefer-Prokop C. Digital radiography: the balance between image quality and required radiation dose. *Eur J Radiol*. 2009; 72(2): p. 202-208.

43. Linsenmaier U, Krötz M, Kanz KG, Russ W, Papst C, et al. Evaluation of spine boards for X-Ray diagnostics. *Rofo*. 2001; 173(11): p. 1041-7.

44. Lang TA. *How to Write, Publish, & Present in the Health Sciences: A Guide for Clinicians & Laboratory Researchers*. Philadelphia: American College of Physicians; 2010

45. Conrad B, Rossi GD, Horodyski M, Prasarn M, Alemi Y, Rechtin G. Eliminating log rolling as a spine trauma order. *Surg Neurol Int*. 2012; 3(3): p. 188-197.

46. Theodore N, Hadley M, Aarabi B, Dhall S, Gelb D, Hurlbert J, et al. Pre-hospital Cervical Spine Immobilization After Trauma. Neurosurgery. 2013; 72: p. 22-34.

47. Lance S, Pons P, Guy J, Chapleu W, Butler F, McSwain N. Prehospital Spine Immobilization for Penetrating Trauma – Review and Recommendations From the Prehospital Trauma Life Support Executive Committee. *J Trauma*. 2011; 71(3): p. 763-770.

48. Vanderlan W, Tew B, McSwain N. Increased risk of death with cervical spine immobilization in penetrating cervical trauma. Injury. 2009; 40(8): p. 880-883.

49. Brown J, Bankey P, Sangosanya A, al e. Prehospital spinal immobilization does not appear to be beneficial and may complicate care following gunshot injury to the torso. *J Trauma*. 2009; 67(4): p. 774-778.

50. Kwan I, Burns F. Spinal immobilization for trauma patients (Cochrane Review). *Cochrane Review*. 2009; 11.

51. Hauswald M. A re-conceptualisation of acute spinal care. *Emerg Med*. 2013; 30: p. 720-723.

52. Petoussi-Henss N, Bolch W, Eckerman K, Endo A, Hertel N, Hunt J, et al. Conversion coefficients for radiological protection quantities for external radiation exposures. *Annals of the ICRP*. 2010; 40(2-5): p. 1-257.

53. Mattsson S, Soderberg M. Dose Quantities and Units for Radiation Protection. In Mattsson S, Hoeschen C. *Radiation Protection in Nuclear Medicine*. Berlin: Springer; 2013.

54. Ma WK, Hogg P, Norton, S. Effects of kilovoltage, milliampere seconds, and focal spot size on image quality. *Rad Tech*. 2014; 85(5): 479-485

55. Burgess, A. Visual Perception Studies and Observer models in Medical Imaging. *Seminars of Nuclear Medicine.* 2011; 41: 419-436. DOI:10.1053/j.semnuclmed.2011.06.005

56. Krupinski, EA. Current perspectives in medical image perception. *Attention Perception and Psychophysics.* 2010*;* 72(5). Doi:10.3758/APP.72.5.1205.

57. Kupinski, MA. *Evaluation and Image Quality in Radiation-Based Medical Imaging*. In C. Grupen, I. Buvat (Eds.), Handbook of Particle Detection and Imaging (pp. 1083-1093). Berlin: Springer-Verlag; 2012. DOI. 10.1007/978-3-642-13271-1_43

58. Herrmann, T.L., Fauber, T.L., Gill, J., Hoffman, C., Orth, D.K., Peterson, P.A., Prouty, R.R., Woodward, A.P., & Odle, T.G. (2012). Best practices in digital radiography. *Radiological Technology*, 84, 83-89

Quiz questions

1. **What is the purpose of the Automatic Exposure Control (AEC):**

a) Reduce contrast

b) Improve image sharpness

c) Reduce operator variation

d) Terminate exposure when DRL has been exceeded

2. **Magnification is influenced by.....when imaging on a stretcher:**

a) Grid specification

b) Mattress material

c) Object to receptor distance (OID)

d) The un-availability of the AEC

3. The function of an oscillating grid is to:

a) Reduce radiation dose to patient

b) Eliminate grid lines

c) Reduce magnification

d) To be used for thicker body parts

4. In comparison to a lower grid ratio, a higher grid ratio.....

a) Absorbs more scatter

b) Requires lower mAs

c) The lead strips are cross-hatched

d) Requires higher kV

5. Focused grids have:

a) Angled lead strips

b) A focal distance of 110cm

c) Varying width of the interspace

d) A Set mAs value

6. Patients on stretchers should be transferred onto the x-ray tabletop for imaging:

a) For all x-ray cases

b) If under 20 stone

c) Dependent upon patient condition

d) Only for examinations using the AEC

7. When using a stretcher image receptor tray.....

a) You cannot angle the image receptor

b) You can only use a specified SID

c) You can use the AEC

d) You cannot use a grid

8. Thicker mattresses are used on stretchers in order to:

a) Reduced likelihood of pressure ulcers

b) Absorb excess blood

c) Enable patients to remain on them for days

d) Help patients sleep

9. What does APR stand for.....

a) Anatomical Precision Recording

b) Auto-selected peak radiation

c) Automatic Positioning Radiography

d) Anatomically Programmed Radiography

10. A major problem with exposure index (EI) is:

a) Variability among manufacturers

b) There are no set ranges, they are purely numbers

c) Influenced by positioning technique

d) They provide feedback on estimated exposure used

2.4 - PAPER 4

A systematic review of incubator-based neonatal radiography – what does the evidence say?

Tugwell-Allsup JR, England A.

Abstract

Objectives: This systematic review aimed to explore the impact of incubator design (canopy, mattress, and mattress support) on neonatal imaging in terms of imaging technique, radiation dose and image quality.

Key Findings: A systematic literature review was performed by searching multiple healthcare databases. Following study selection and extraction, 7 articles were deemed eligible and included within the study. Of these 7 studies, six were experimental phantom based with the remaining one being a retrospective analysis. Four studies reported a percentage reduction in beam attenuation for incubator components ranging from 12%-72% with one other study reporting a reduction but with no numerical data. This wide variation in radiation beam attenuation from the incubator components was correlated with image quality within five studies, two suggesting reduced image quality when using the incubator tray under the mattress support whilst the other three found no significant difference. Although the seven studies reported that incubator components reduced X-ray beam intensity, there was limited evidence on whether this required an increase in exposure factors. Only one study suggested increasing exposure parameters to accommodate for the increase in beam attenuation when using an incubator tray.

Conclusion: The literature clearly demonstrates that with existing incubator designs, there is considerable beam attenuation between placing the image receptor directly behind the neonate as oppose to the incubator tray. However, this radiation beam attenuation is not well correlated to neonatal radiation dose or image quality effects and therefore is very confusing when considering clinical implementation.

Implications for practice: This review highlights the need for standardisation and further optimisation work to ensure best practice for this vulnerable patient group.

Introduction

Newborn babies in the Neonatal Intensive Care Unit (NICU) often require numerous radiological examinations during their first weeks of life.[1] Due to the increased sensitivity of newborns to ionising radiation, it is important to reduce the radiation dose where possible without compromising image quality. NICU is one of the most critical areas for dose optimisation, as it has the youngest patients, who often require multiple imaging exams.[2] Neonates are maintained in the incubator and warmer systems to ensure a well-regulated, stable and protective environment, which also reduces the chance of infection. Carver and Carver suggested that opening the incubator may change temperature within the incubator which can adversely affect the neonate.[3] To perform radiographic imaging of neonates, a mobile radiography system is used together with an image receptor (IR). The radiographer can place the neonate directly onto the IR or use the built-in tray/slot; both these methods have their benefits and limitations[4]. Placing the neonate directly onto the IR results in an image with minimal magnification and allows for simple positioning and collimation checks. In addition, there are no objects between the neonate and the IR resulting in limited additional attenuation from other structures. However, placing the IR in the tray eliminates 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 an infection control perspective. When the IR is placed within the tray, it makes judgements regarding collimation and alignment more difficult, and also the radiation beam must pass through the extra thickness of the mattress and the IR holder, which reduces beam attenuation and consequently detector dose. [1, 2, 5, 6] A further variable is the presence or removal of the incubator canopy (lid). This is typically left in place, but provides further reduction in beam attenuation and consequently, it is necessary according to Rizzi and colleagues, to increase the exposure factors.[6]

As seen above, issues with incubator imaging are often acknowledged within the literature. However, limited evidence is available to allow standardisation of this type of imaging. Little is known about the effect of incubator design on image quality and radiation dose. Many assumptions are made regarding the need for modification of acquisition parameters to compensate for placing the IR within the tray.[6] A review of current literature is required to explore the optimal methods for imaging a neonate within an incubator and the consequences of incubator design on image quality and radiation dose.

Method

A systematic review was carried out following guidance provided by the Cochrane Collaboration[7].

Eligibility criteria

Articles were included if they were written in English and explored radiation dose and/or image quality in relation to neonatal incubator imaging. If studies explored neonatal incubator imaging but did not consider or make reference to incubator design and the consequential effect on technique (attenuation, tray, mattress) then they were excluded. In other words, the effect of the incubator on imaging must be the primary focus of the included studies. All relevant study designs were permissible with the exclusion of ideas, opinions, case studies and editorials. Only studies published after 2004 were included, that was due to technological advancement both in radiographic equipment and incubator design.

Sources

To ensure all relevant published studies were identified, a wide range of databases were searched including: Medline via Ovid (2004 to present), Pubmed (2004 to present), Science Direct (2004 to present), Cumulative Index to Nursing and Allied Health (CINAHL) (2004 to present) and the Cochrane Library Database (2004 to present). In addition, the reference list of each relevant article was searched for additional publications in accordance to the eligibility criteria.

Search strategy

A search strategy was performed for each individual database, this included keyword terms, synonyms, and the AND/OR qualifiers. The "Medical Subject Heading" (MeSH) was used to help identify related keywords which enabled the development of the key terms for searching (**Table 1**)

Table 1. Summary of keywords searched in the systematic literature review.

1st term		2nd term
Neonate OR Neonatal OR Infant OR Newborn OR Incubator OR	AND	Optimisation OR Dose reduction OR Image quality OR Optimise OR Imaging OR X-ray

Study selection and data extraction

Following the search strategy, duplicates were removed and the remaining studies were screened by two independent reviewers using the title and abstract in conjunction with the eligibility criteria. Both reviewers met to compare findings; any differences in reviewers' judgements were resolved through discussions until a consensus was reached. The included papers were then screened for full text inclusion against the eligibility criteria by the same two independent reviewers. The quality of each study was assessed using modified questions (to account for phantom studies) from the Critical Appraisal Skills Programme Oxford UK (CASP) diagnostic checklist.[8]

The CASP diagnostic checklist was then applied to all eligible studies for assessing the quality and presence of bias in the included papers. Each article was provided with a score from 0-7. If the answer to a question was '*yes'* it was scored 1, but if the answer to a question was '*cannot tell'* or '*no'* a score of 0 was awarded for that question. The result of this second phase of screening was the same as previously where the two reviewers debated until consensus was reached.

Due to the limited literature identified on incubator imaging during the search strategy, all studies identified were included within the review regardless of quality scoring. This was to ensure that all relevant literature was included. The quality of these studies were, however critically evaluated with their outcomes heavily scrutinised within the review analysis.

Results

The PRISMA flow chart (**Figure 1**) summarises the literature review search results.[9] Following the initial search, 84 studies were identified, 24 were duplicates with the remaining 60 proceeding for screening. Following screening, 25 papers qualified for full text review and confirmation of eligibility **(Figure 1)**. Upon extraction, both reviewers agreed that on closer inspection that 18 of the papers did not meet the inclusion criteria. Although these 18 papers explored image quality and/or radiation dose of neonates within incubators, they did not consider the impact of incubator design on image quality and radiation dose. Two of the remaining seven articles were conference abstract papers and following deliberation between the reviewers, these were included as they did meet the inclusion criteria.

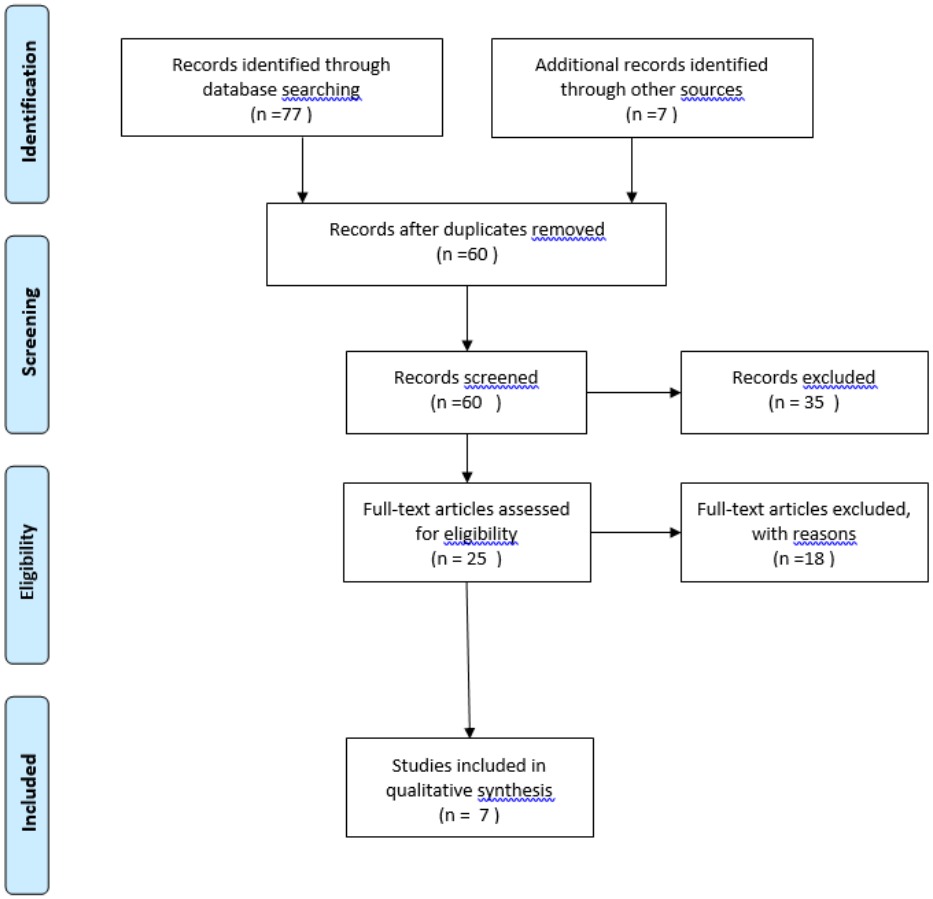


Figure 1 – figure demonstrating the different phases of the literature review search results.

Overall, seven relevant articles were included within the review. The studies were of average quality with CASP scores ranging from 2-5 out of a possible 7 (**Table 2**). The reviewers had no disagreements with the scoring of article quality. Five of the seven papers were published within the last 10 years, with the remaining two papers published between 10-15 years. These seven papers accounted for 99% of the studies found within the search of literature (only 1 study was identified prior to 15 years).

Table 2 - Characteristics of the seven articles in the systematic literature review

Lead author	Year	Patients/Phantom	Country	CR/DR	Quantities	Quality score (0-7)
Del Rio Part 1[1]	2016	Gammex Phantom for radiation dose, TOR for image quality (n=n/a)	Italy	Not specified	EDS, IAKp, IAKd	2
Del Rio Part 2[11]	2016	patient (retrospective) + Gammex	Italy	Not specified	E	2
Jiang[2]	2016	5cm acrylic phantom	USA	CR	DED, CNR	5
Mutch[5]	2007	acrylic 5cm for dose/LEEDS TOR CR for IQ	UK	CR	spatial resolution / detected inserts (subjective)	4
Rattan[10]	2013	Gammex Phantom	USA	CR	EI, no dose unit	3
Rizzi[6]	2014	acrylic 5cm for dose/LEEDS TOR CR for IQ	Italy	CR	ESD, E, spatial resolution / detected inserts (subjective)	3
Slade[12]	2005	Patients (retrospective)	UK	Not specified	VGA, no dose	2

EI= exposure index; ESD= entrance surface dose; IAKp = Incident air kerma on phantom, IAKd, incident air kerma on detector; DED = detector entrance dose, CNR = contrast to noise ratio; CR = computed radiography; DDR = direct digital radiography; VGA = visual grading analysis

All studies identified were different in terms of research question and the methodology used; therefore comparison of outcome measures was difficult. There was wide variation between the attenuation values recorded for different incubator components, however this was expected owing to methodological differences in how attenuation was calculated in terms of units used as well as which incubator components were considered (**Table 3**).

Table 3 – Study methodology and results

Study	**Radiation dose measurement**	**Image quality assessment**	**Number of incubator designs used**	**Incubator attenuation**	**CR/DR used**	**Key conclusions**
Del Rio et al. 2016[1] (Part 2)	IAKp, IAK d, ESD	Contrast sensitivity and spatial resolution using observers	3 x unspecified incubators	No figures but comments on influence on radiation dose and IQ	N/A	The different attenuation features of incubator design have significant influence on image quality and ESD.
Del Rio et al. 2016[11] (Part 3)	ESD, E	Not considered	3 x unspecified incubators	No figures but comments on influence on radiation dose and IQ	N/A	Incubator features such as attenuation and SID have an impact not only on IQ and radiation dose but on cancer risk
Jiang et al. 2016[2]	DEE	CNR	3 x specified incubators	16-60%	CR	Increase detector dose and image quality when comfort pads removed and variation in image quality and radiation dose found amongst different incubator designs
Mutch and Wentworth 2007[5]	Dose measured at the surface of each component (no metric specified	Contrast sensitivity and spatial resolution using observers	6 X specified incubators	62-79%	CR	Incubator components significantly reduce the radiation dose reaching IR, without significant impact on IQ.
Rattan and Cohen 2013[10]	EI used as indicator of beam attenuation	Not considered	4 x comfort pads only	12-75%	CR	Removal of comfort pads can be a simple way of reducing radiation exposure to babies
Rizzi et al. 2014[6]	Dose measured at the surface of each component (no metric specified	Contrast sensitivity and spatial resolution using observers	1 x unspecified incubator	15-32%	CR	Incubator canopy and cassette holder does not degrade image quality
Slade et al. 2005[12]	Not measured	VGA (using 2 x observers)	Unknown	Not measured	Not specified	Image quality is equivalent between direct and tray imaging, and therefore tray imaging should be advocated to reduce handling of neonate

DEE; detector entrance exposure, IAKp; incident air kerma, CNR; contrast to noise ratio, EI; exposure index, CR; computed radiography, ESD; entrance surface dose; VGA; visual grading analysis

Jiang and colleagues[2] considered the attenuation of the mattress and mattress support individually but not the canopy, whereas Mutch and Wentworth[5] along with Rizzi and colleagues[6] explored the attenuation of the canopy and then the mattress and mattress support combined (but not individually). Rattan and Cohen[10] compared the attenuation of four different comfort pads/mattresses but did not consider the incubator canopy nor mattress support. Both studies from Del Rio[1, 11] considered attenuation and made reference to the reduction in radiation dose reaching the IR, however no information was provided on which incubator components were considered and no numerical values were available regarding the stated reduction. This was due to the studies being conference abstracts. Slade and co-workers[12] did not consider attenuation values but instead retrospectively explored differences in image quality between direct exposure and tray exposure which indirectly reflects attenuation impact. Owing to the above methodological differences, there was a wide variation in recorded attenuation values for incubator components ranging from 12%-72%. These values are influenced by methodology differences but also they are influenced by the make and manufacturer of the incubator, however this was difficult to quantify as only two studies specified the type of incubator used.[2,5] In addition, the studies whom provided attenuation values for various different components of incubator design (individual components and combined) calculated the percentage difference or percentage reduction between a direct exposure (without any attenuator) in comparison to exposures with various different incubator component in-between the X-ray tube and image receptor. These calculations were obtained at the surface the image receptor or phantom for each scenario using different units such as ESD[1,11] and exposure index[10] and therefore it is difficult to compare these attenuation values reliably due to these methodological variations.

Six of the seven studies were phantom based studies who all found that incubator components reduced beam energy hence the amount of radiation reaching the IR if placed in the incubator tray **(Table 3)**. This reduction was correlated with image quality in five studies, with Del Rio and Jiang[1,2] suggesting reduced image quality when using the incubator tray in comparison to Mutch and Wentworth, Rizzi et al. and Slade et al. [5,6,12] who found no significant difference in image quality. Three of the five studies used a Leeds Test Object TOR phantom[1,5, 6] which is designed for routine quality control to quantify the degree of threshold contrast in each image. A Leeds Test Object does not resemble clinical imaging and therefore this method may not always be suitable for evaluating different imaging systems or imaging techniques, since their contrast could behave differently to the contrast of clinically relevant details with changing acquisition parameters[13].

Jiang et al.[2] on the other hand used an objective measure of image quality which was contrast to noise ratio (CNR). CNR has been used successfully as a measure of image quality in various optimisation studies. [14-17] In comparison to SNR, CNR takes into consideration the effect of noise on our ability to distinguish objects within the image because visibility depends on contrast (the difference between signals). A highly exposed image may have a high SNR but show no useful information on that image.[18] According to the study by Jiang et al.[2], CNR increased by 28-36% when removing the mattress and support tray from the primary beam but whether this increase in CNR would impact visual image quality using human observers is unknown. It must also be remembered that CNR does not include the display and observation steps of the imaging process and therefore does not truly reflect clinical processes. The study by Slade et al.[12] was the only study to use visual grading analysis (VGA) with a criteria-based scoring system on actual neonatal chest images. However, this study did not consider radiation dose and was limited by numerous confounding variables such as radiographer practice variation, equipment variation, neonatal size and weight variation which is seen by the fact that most X-ray examinations performed using incubator tray for the study were on very premature neonates in comparison to direct exposures performed on larger neonates. This means that comparisons within this study were flawed.

The effect of incubator components on image quality has been considered previously, however consideration must be given to radiation dose. Although the seven studies reported that incubator components reduced/absorbed X-ray beam intensity, there was limited evidence on whether this required an increase in exposure factors. The report by Rizzi and colleagues[6] was the only study which suggested increasing exposure parameters to accommodate for the increase in beam attenuation when using an incubator tray, however this recommendation was based on an assumption rather than evidence of any correlation with image quality.

Balancing radiation dose and image quality is the forefront of optimisation as sufficient image quality is required for the lowest possible radiation dose. National legislation exists[19] together with national and international guidelines [20-22] recommending the importance of reducing radiation dose whilst maintain image quality. These national and international guidelines predominantly focus on traditional methods of imaging and do not expand to more unconventional imaging situations such as incubator imaging. When considering radiation dose there are many methods (direct and indirect) which can be used to estimate radiation dose (examples DAP, IAK, ESD, E). Within the studies reviewed, three used detector dose or radiation dose at the surface of each incubator component in order to assess attenuation. [2,5,6] Detector entrance exposure (DEE) unit is not a universally accepted dose quantity and has limited use in optimisation studies. It is also not cited in radiation protection reports such as those from the International Commission on Radiological

Protection (ICRP).[22, 23] From a radiation protection perspective, detector dose does not consider the risk to the patient and it is also not fully understandable in terms of its correlation with image quality therefore it must be carefully interpreted. The study by Rattan and Cohen[10] used exposure index as a metric to reflect attention and dose reduction but again exposure index is a controversial quantity due to its lack of standardisation and needs to be considered carefully especially in terms of how it translates into clinical practice. Only one from the seven articles calculated effective dose[11] which considers the associated risk of the exposure to the neonate and yet this was the study by Del Rio and colleagues whereby only the abstract was available and therefore did not disclose any numerical data/statistics to support the assumption that using the incubator tray as oppose to a direct exposure increases radiation risk.

Another factor that makes it very difficult to compare the studies under review is the acquisition parameters used within them (**Table 4**). A variety of different tube potentials and current time product combinations were used as well as various SIDs. Currently there are no set guidelines for neonatal chest imaging within an incubator, with the exception of the European Commission[20], however, they do not consider neonatal incubator components and design and were also based on film-screen. The studies under review have therefore either used parameters based on local current practice or have followed the recommendations of the European Commission despite their limitations. Although the European Commission did not consider incubator components and the difference between direct and tray exposure when recommending acquisition parameters, they have within the same document made a generic statement regarding the importance of using low attenuating materials for imaging to allow for reduction in patient dose for example table tops and grids[20]. This is reinforced by work from Mutch and Wentworth[5] and Jiang and colleagues[2] who also recommend within their studies that manufacturers need to consider the thickness and construction of incubator support, mattress and canopy and to consider alternative materials that are more radiolucent to ensure minimal beam attenuation. Yet again as suggested by Tugwell and colleagues[24], manufacturers tend not to specify the density and construction of the materials and components used for various medical equipment which makes it difficult to compare and explore this issue further. Mutch and Wentworth found that construction and material across incubators are similar with most of the attenuation caused by the mattress support.[5] However, Jiang argues that the attenuation of comfort pads vary between different makes of incubator, even by the same manufacturer[2]. These conflicting findings may be based on the method used to evaluate image quality as small changes in image quality may be more apparent in objective measures such as CNR in comparison to visual changes witnessed by human observer. [25,26]

Table 4 – Study acquisition parameters

Study	Method	Exposure factors	SID
Del Rio Part 1	Experimental Phantom	Different exposure parameters (not specified)	
Del Rio Part 2	Experimental Phantom		
Jiang	Experimental Phantom	3 different; 65kV/2mAs, 60kV/0.96mAs, 55kV/1.2mAs	102cm (40inch)
Mutch	Experimental Phantom	60kV/1mAs	Varied but FSD kept at 90cm
Rattan	Experimental Phantom	3 different; 66kV/1mAs, 56kV/1mAs, 76kV/1mAs	102cm (40inch)
Rizzi	Experimental Phantom	Pre Optimisation; 55kV/3.2mAs, Post optimisation; 60kV/1mAs	Varied. Maximum SID 80-110cm (min-max)
Slade	Retrospective IQ analysis (tray v direct)	Average 53kV/2mAs (ranges: 48-60kV; 2-3mAs)	Not specified

IQ; image quality, SID; source to image distance, FSD; focus to surface (of phantom) distance

Discussion

An informative systematic review has been performed identifying seven articles that consider incubator design and their influence on image quality and radiation dose when imaging neonates. Although the quality of the studies varied owing to methodological flaws in each piece of work, the findings within these studies are still important and highlight an unconventional area of imaging requiring further standardisation and optimisation. All studies found a reduction in beam energy reaching the IR however there was considerable variation in terms of how much attenuation and the impact this reduction had on image quality and radiation dose risk to patients. This reduction in beam energy reaching the IR *will* have an impact on image quality as there is a reduction of photons reaching the IR, however, whether this is significant and impacts on visual image quality is a question yet to be fully answered. All studies failed to correlate their findings with visual image quality in addition to data on the radiation risk associated with incubator imaging. Perhaps the limited evidence on visual image quality relates to most studies using a physics phantom for image quality evaluation instead of either an anthropomorphic neonatal phantoms or control clinical trials which would evaluate clinical practice more accurately. The seven studies therefore are limited in their practical implications in terms of translation into clinical practice.

Another factor to consider when synthesising the results of this review is that imaging equipment has changed over recent years due to healthcare demands, technological advances and safety regulations and therefore it is important to conduct experimental work that not only simulates clinical practice but uses up to date and current technology employed in clinical practice. None of the seven studies within the review used direct digital radiography; only CR was used and therefore this needs to be explored further using technology that is becoming wide spread in clinical practice.

When taking into account incubator design and components, and how these features impact/differ between direct exposure and tray exposure, attenuation is not the only factor to consider. The difference in object to image distance (OID) will also vary as seen for trolley imaging.[24] None of the seven articles explored this increase in OID and calculated the difference or evaluated impact on magnification and geometric unsharpness. Mutch and Wentowrth did however make an assumption based on the inverse square law that the difference in OID between direct exposure and tray exposure may have accounted for one-fifth of the reduction see in IR dose within their study.[5] In theory, the closer the object being imaged is to the IR (reduced OID), the less the magnification, and the better the geometric sharpness.[27, 28] To overcome this issue, a slight increase in SID is required which will reduce magnification but also reduce radiation dose to the patient[29]. However, this may not always be possible for incubator imaging as there are restrictions to increasing SID e.g. incubator height, radiographer height and the portable machine design. [24, 30] Tugwell et al. also highlights the importance of the radiology department being involved in the procurement stages when considering and purchasing new imaging equipment such as incubators.[24] It is important that incubator height can be lowered to ensure maximum SID can be achieved which also allows for collimation to be closed to the area of interest as more area is covered with increased SID due to beam divergence.

Limitations

Owing to the limited studies identified on incubator imaging from the search strategy, the study quality threshold was potentially compromised and therefore both lower quality studies and conference abstracts were included within the review. The aim of this systematic review was to identify all evidence relevant to the research questions and this may sometimes necessitate the inclusion of 'grey literature' and those of lower quality. Even though these articles may be deemed of lower quality, their findings are still relevant but need to be considered more carefully. A clearly defined search strategy was established prior to review and the decision to include conference abstracts was based on recommendations within the literature. [33,34] Conference abstracts potentially contain a lot of information and when considering the limited literature on this subject,

the inclusion of this information was both important and justified. Furthermore, the potential contributions of grey literature to systematic reviews are becoming increasingly more apparent. The safety of the neonate when comparing direct and tray X-ray exposures was not explored within any of the included studies and therefore no conclusions were drawn as to the non-radiological benefits of these techniques. Previous, historic studies, have demonstrated hypoexemia[31] and bradycardia[12,32] when moving and handling neonates but this needs to be explored further, especially in terms of its relationship with radiographic imaging.

Conclusion

The literature clearly demonstrates that with existing incubator designs, the X-ray beam is attenuated considerably when the image receptor is placed in the incubator tray as oppose to directly behind the neonate. However, this attenuation is not well correlated with both the radiation dose risk to the neonate and the resultant image quality .This is confusing and poses challenges when defining best clinical practice. Within the literature there is also limited visual evaluation of image quality using anthropomorphic phantoms together with limited evidence on effective dose and the risk associated with the exposure of a neonate within an incubator. Current studies on incubator imaging have been radiology led, with a focus on radiation dose, attenuation and image quality. However, there needs to be a more holistic multi-disciplinary approach to investigating the numerous factors that could affect neonates during radiographic imaging. A larger clinical study is required that considers not only the radiological aspect of incubator imaging but also the safety considerations from a nursing perspective (moving and handling, infection control) together with the medical aspect e.g. diagnostic yield. What is optimal from a radiology perspective may be outweighed by other associated risks/benefits. Within radiology, an anthropomorphic phantom-based study estimating effective dose as well as evaluating visual image quality is warranted to more fully explore the numerous variables/factors associated with incubator imaging.

References

1. Del Rio V, Satta L, Fanti V. Radiologic imaging of the newborn inside the incubator. Radiation dose and image quality. Abstracts of the 9th National Congress of the Associazione Italiana di Fisica Medica. Physica Medica 2016; 3: e71–e96

2. Jiang X, Baad M, Reiser I, Feinstein K, Lu Z. Effect of comfort pads and incubator design in neonatal radiography. Pediatr Radiol *2016* 46(1): 112-118

3. Carver E, Carver B. Medical Imaging: Techniques, Reflection & Evaluation. 2nd ed. Philadelphia: Churchill Livingstone; 2012

4. Ehrlich R, Coakes D. Patient Care in Radiography: With an Introduction to Medical Imaging. 9th ed. Missouri: Mosby; 2016

5. Mutch SJ, Wentworth SD. Imaging the neonate in the incubator: an investigation of the technical, radiological and nursing issues. Br J Radiol *2007;* 80: 902–910

6. Rizzi E, Emanuelli S, Amerio S, Fagan D, Mastrogiacomo F, Gianino P, Cesarani F. Optimization of Exposure Conditions for Computed Radiology Exams in Neonatal Intensive Care. Open Journal of Radiology 2014; 4: 69-78. doi: 10.4236/ojrad.2014.41009

7. Higgins JPT, Green S, editors. Cochrane handbook for systematic reviews of interventions version 5.1.0 [updated September 2018]. The Cochrane Collaboration; 2018. Available from: http://handbook.cochrane.org [accessed 11.10.18].

8. Critical Appraisal Skills Programme (CASP). 2013. CASP Diagnostic Checklists. Available from: https://casp-uk.net/casp-tools-checklists/[Accessed January 2019]

9. Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 2009; 6(7): e1000097. doi:10.1371/journal.pmed1000097

10. Rattan AS, Cohen MD. Removal of comfort pads underneath babies: a method of reducing radiation exposure to neonates. Acad Radiol *2013;* 20: 1297–1300

11. Del Rio V, Satta L, Fanti V. Radiologic imaging of the newborn inside the incubator. part

3: risk estimation . Abstracts of the 9th National Congress of the Associazione Italiana di Fisica Medica *In: Physica Medica 2016; 32, e71–e96.* http://dx.doi.org/10.1016/j.ejmp.2016.01.259

12. Slade D, Harrison S, Morris S, Alfaham M, Davis P, Guildea Z, Tuthill D. Neonates do not need to be handled for radiographs. Pediatric Radiology 2005; 35(6):608-11. DOI: 10.1007/s00247-005-1414-x

13. Kupinski, MA. *Evaluation and Image Quality in Radiation-Based Medical Imaging*. In C. Grupen, I. Buvat (Eds.), Handbook of Particle Detection and Imaging (pp. 1083-1093). Berlin: Springer-Verlag; 2012. DOI. 10.1007/978-3-642-13271-1_43

14. Hess, R., & Neitzel, U.Optimizing image quality and dose for digital radiography of distal pediatric extremities using the contrast-to-noise ratio. *Rofo*, 2012; 184(7): 643-9. doi: 10.1055/s-0032-1312727

15. Mori M, Imai K, Ikeda M, Iida Y, Ito F, Yoneda K, Enchi Y. (2013). Method of measuring contrast-to-noise ratio (CNR) in nonuniform image area in digital radiography. *Electronics and Communications in Japan,* 96(7), 32--41. DOI: 10.1002/ecj.11416

16. Goenka AH, Herts BR, Dong F, Obuchowski N, Primak AN, Karim W, Baker M. Image Noise, CNR, and Detectability of Low-Contrast, Low-Attenuation Liver Lesions in a Phantom: Effects of Radiation Exposure, Phantom Size, Integrated Circuit Detector, and Iterative Reconstruction. Radiology: Volume 280: Number 2—August 2016

17. Kim H, Park Ch, Chae H, Lee SM, Goo JM. Impact of radiation dose and iterative reconstruction on pulmonary nodule measurements at chest CT: a phantom study. Diagn Interv Radiol. 2015 Nov-Dec; 21(6): 459–465

18. Vladimirov, A. Comparison of image quality test methods in computed radiography. (MSc Thesis), University of Tratu, Estonia. 2010; Retrieved from: http://dspace.utlib.ee/dspace/bitstream/handle/10062/15191/Vladimirov_Anatoli.pdf;jsessionid=80A1A82F275CF25DA0B99383FFB3DACB?sequence=1

19. Ionising Radiation((IR)[ME](MedicalExposure)). (2018). The ionising radiation (medical exposure) regulations 2000.Statutory instrument. Available from:

20. European Commission (1996) European guidelines on quality criteria for diagnostic radiographic images in paediatrics , Report EUR 16261EN

21. International Atomic Energy Agency. (2009). Justification of Medical Exposure in Diagnostic Imaging. Proceedings of an International Workshop. September. Brussels: IAEA. Retrieved online from: http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1532_web.pdf

22. International Commission on Radiological Protection (ICRP). (2007). The 2007 recommendations of the ICRP on radiological protection, publication 103. *Annals of ICRP*, 37(2-4), 1-332.

23. International Commission on Radiological Protection. (2005). Basis of dosimetric quantities used in radiological protection'. Draft for discussion by Task Group of ICRP Committee 2. Available from: http://www.icrp.org/docs/physics_icrp_found_doc_for_web_consult.pdf

24. Tugwell-Allsup J, England A, Hogg P, Legg JS. Challenges Associated With X-ray Imaging of Stretcher-Bound Patients. Radiol Technol 2017;89(2):159-172.

25. De Crop A, Smeets P, Van Hoof T, et al. Correlation of clinical and physical-technical image quality in chest CT: a human cadaver study applied on iterative reconstruction. *BMC Med Imaging* 2015;15:32. doi:10.1186/s12880-015-0075-y

26. A. Meijer, A, Buissink C, Hogg P. Radiation dose, image quality optimisation, the use of new technology y in medical imaging. (OPTIMAX 2017) Oslo, Norway; 2017. Retrieved from: http://usir.salford.ac.uk/id/eprint/46104/7/OPTIMAX%202017%20ed.pdf [Accessed 12/06/2019]

27. Bushong S. *Physics, Biology, and Protection. Radiologic Science for Technologists*. 10th ed. Missouri: Elsevier; 2013.

28. Fosbinder R, Orth D. *Essentials of Radiologic Science*. Philadelphia: Lippincott Williams and Wilkins; 2011.

29. England A, Evans P, Harding L, Taylor E, Charnock P, Williams G. Increasing source-to-image distance to reduce radiation dose from digital radiography pelvic examinations. Rad Tech 2015; 86(3): 246-56.

30. Gleeson C, Spedding R, Harding L, Caplan M. The mediastinum – is it wide? *Emerg Med J.* 2001; 18: p. 183-185.

31. Long JG, Philip AG, Lucey JF.) Excessive handling as a cause of hypoxemia. Pediatrics 1980; 65:203–207

32. Danford DA,Miske S, Headley J et al. Effects of routine care procedures on transcutaneous oxygen in neonates: a quantitative approach. Arch Dis Child 1983; 58:20–23

33. Paez A. Gray literature: An important resource in systematic reviews. J Evid Based Med 2017; 10(3):233-2.

34. mahood Q, Van-Eerd D, Irvin E. Grey literature in systematic reviews: a practical approach to searching and including in systematic reviews. In: Bero L, Montgomery P, Robinson K, Pigott T, Krause K. Bringing Evidence-Based Decision-Making to New Heights. Abstracts of the 2010 Joint Colloquium of The Cochrane and Campbell Collaborations; 2010 18-22 Oct; Keystone, USA. John Wiley & Sons; 2010.

2.5 - PAPER 5

Imaging neonates within an incubator – a survey to determine existing working practice

Tugwell-Allsup JR, England A.

Abstract

Introduction: There is limited and confusing evidence within the literature regarding the optimal techniques when imaging neonates within incubators; in particular, whether to place the image receptor directly behind the neonate or in the incubator tray. For this reason, radiology departments across Wales and North West England were surveyed to explore existing working practice with regards to incubator imaging.

Method: A self-designed survey was developed using a systematic approach. The survey was sent to 31 radiology departments across Wales and North West England whom had a neonatal unit in order to assess existing techniques used when imaging neonates within the incubator. The survey was split into three main domains: 1) general/demographics, 2) exposure factors and technique, and 3) incubator design.

Results: Nineteen departments responded (64%) demonstrating a wide variation in practice for incubator imaging. The minimum and maximum exposure factors used for neonatal chest x-ray imaging varied from 55kV to 65kV and 0.5mAs to 2mAs. Fifty-eight percent of departments used the incubator tray as standard practice with the remaining forty two percent not using the tray for various reasons including, image quality, artefacts and misalignment. Sixty-three percent of departments use the maximum achievable SID for incubator imaging which demonstrates wide variability as the SID would be dependent upon: incubator design, portable machine and radiographer height.

Conclusion: The survey demonstrates a wide variation in existing practice for neonatal incubator imaging.

Implications for practice: This study supports the need for standardisation and further optimisation work to ensure best practice for this vulnerable patient group.

Introduction

Every year, 100,000 neonates are cared for in the neonatal unit in the United Kingdom (UK)[1] and often require many radiological examinations during their first weeks of life[2]. These radiological examinations are predominantly chest x-rays (CXR) with the smallest birth-weight neonates potentially receiving multiple examinations to monitor their condition[3]. Due to the increased sensitivity of neonates to long-term risk of radiation exposure, it is important to reduce the radiation dose where possible without compromising image quality[4, 5]. Although imaging a neonate within an incubator is a common requirement [2], limited evidence is present within the literature recommending the most optimal imaging technique. Many radiographic challenges exist when imaging a neonate within an incubator; the location of the image receptor (IR) whether directly behind the neonate or in the incubator drawer/tray. From a technical radiological perspective, placing the IR directly behind the neonate is assumed optimal as the beam is not required to travel through any additional attenuating material before reaching the IR and magnification and geometric unsharpness is kept to a minimum. In addition, there are no misalignment issues and collimation can be easily visualised on the darker background of the IR[6]. From a safety perspective, placing the IR behind the neonates can disrupt an already vulnerable neonate with the risk of accidentally displacing tubes and lines[7]. Neonates are also maintained in the incubator and warmer systems to ensure a well-regulated, stable and protective environment which reduces chances of infection. Opening the incubator to place the IR may also change the internal temperature and cause further problems with neonates being susceptible to noise and vibration[8].

With the above issues in mind, limited evidence is reported within the literature to aid identification of the most optimal techniques for imaging neonates within incubators. Phantom based studies on neonatal incubator imaging have demonstrated that when the IR is placed in the incubator tray, a greater reduction in detector dose is evident, with attenuation varying between 12% and 72%[2, 8-11]. This reduction implies that less image forming photons reach the IR and therefore will reduce image quality unless exposure parameters are adjusted accordingly to compensate. However, these studies have failed to successfully correlate their study findings with visual image quality changes and provide definitive evidence as to whether an increase in exposure factors is necessary to compensate for this reduction. For this reason, many assumptions are made with regards to the practical implication of such findings e.g. an increase in exposure factors is required for acquiring adequate diagnostic images. In addition, the methods used in these studies vary considerably in terms of which variables were evaluated (e.g. X-ray equipment, incubator design and components, exposure factors, source to image distance (SID)) and the units used to calculate radiation dose,

image quality and attenuation of incubator components. Owing to this lack of consistency, recommendations within the literature on neonatal-incubator imaging are difficult to translate into clinical practice. To plan further optimisation studies, it would be useful to have baseline data to support what is currently standard clinical practice. It is, therefore, the aim of this study to explore the existing working practices for neonatal incubator imaging across Wales and North West of England to provide a better understanding of what techniques are currently being employed.

Method

This study was granted an exemption from formal ethics committee approval by the Institutional Review Board. Consequently, it was reviewed and approved by the Quality Assurance Team and Service Evaluation Committee (Ref 18/248).

Survey design

A systematic and previously reported approach was used to design and develop the survey[12,13]. Firstly, a literature review was undertaken to scope current evidence regarding neonatal incubator imaging. The literature reviewed was carried out in conjunction with a small focus group, this aided in the identification of themes/items for the survey[14,15]. The focus group was an informal open discussion led by a paediatric radiographer relating to the imaging of neonates within an incubator within one radiology department. Seven general radiographers, of varying levels of experience but all involved in neonatal imaging, were invited to participate in the focus group. The purpose of the focus group was to explore the issues surrounding the imaging of neonates within an incubator and to help to determine what type of information should be included in the questionnaire, the presentation of the questionnaire, the language used and the format. The focus group was audio-recorded and comments made by participants were also written on a whiteboard and recorded. Following the literature review and focus group, the initial survey questions were developed. Two staff members from the R&D department and two university lecturers with previous experience in questionnaire development were asked to review the content and face validity of the draft survey in addition to providing comments on its readability and comprehensibility. The survey along with a copy of the research proposal was distributed to each reviewer via e-mail, from this they were asked to review the survey to ensure questions were accurate, free from item construction problems and grammatically correct. The reviewers, to the best of their ability, ensured that the questions did not contain content that may be perceived as biased to a particular subgroup of respondents[16]. Based on their feedback changes were made in order to improve consistency and to ensure the aims of the

study were adequately met. The final version of the survey was three pages long, with three main domains (see **Supplementary Information**).

Survey content

Following survey development and testing, the final electronic survey consisted of 17 questions which were split into three main domains: demographic/general (n=6), exposure factors and technique (n=5), and incubator design (n=6). Question format included fixed multiple responses with five questions having a '*please explain'* comment box following the multi-response to allow for additional information to be included if respondents needed to expand or clarify answers. This allowed additional responses to emerge from the data that were not included in the formulated answers.

Survey distribution

A list of all public neonatal units across Wales and the North-west of England was established using data available from the Infant Journal[17]. 31 radiology departments across Wales and the North-west of England were identified and contact details of these institutions were retrieved from their websites. The survey was consequently distributed via email to the radiology service manager or equivalent at each of the 31 departments. A covering letter was attached explaining the purpose of the study. Within this email the recipient was asked to forward the survey request to the most appropriate staff member for completion. A read receipt was activated for all e-mails sent in order to identify any potential participants who may have left the organisation. All e-mails were sent in September 2018 with a reminder e-mail sent in January 2019 to all departments whom were yet to respond with a deadline for responses being February 2019. Each department was allowed to submit only one response as a reflection of their existing departmental working practice. Once the survey was completed, each department was given the option of sending the completed survey back via e-mail or by pre-paid postal envelope. Completion of the survey constituted informed consent and all responses were kept confidential.

Statistical Analysis

Data received from completed questionnaires were inputted into SPSS Version 14.0 (IBM Inc, Armonk, NY) for analysis. Basic descriptive statistics were obtained for each question. Cumulative frequency and percentage values for all responses were calculated.

Qualitative data were analysed using basic thematic analysis, which means the narrative comments were coded and themes were generated to provide meaningful interpretation of the data[18]. These

themes were consequently converted into simple descriptive counts in order to reflect frequency of theme occurrence[19]. To reduce bias, the data from this study was coded and analysed by an independent researcher.

Results

From the 31 departments invited to participate in the study, 19 (61%) responded. All twelve radiology departments with a neonatal unit in Wales responded. Of the 19 departments who responded, 18 (95%) were district general hospital departments (acute) with the remaining department being in a specialised paediatric hospital. From the responding departments, only three (16%) had a dedicated specialised radiographer for paediatric imaging (with one of these three based in the specialised paediatric hospital), but fourteen (74%) had a specialist paediatric radiologist.

Twelve departments (63%) stated that they acquired mobile neonatal X-rays daily, six (32%) declared it was a weekly occurrence and one (5%) stated monthly. The department who stated monthly was one of four hospitals considered as a Level 1 neonatal unit and therefore would not have neonates with extremely low birth weights or complications which would be more likely to require more frequent imaging[20].

To acquire images of neonates in incubators, three departments (16%) used CR and all other responding sites had access to mobile DR image. Eleven (58%) sites indicated that they had access to both CR and DR technologies. Variations in the exposure factors used for neonatal CXRs in incubators across the nineteen departments are reported in **Table 1**. When asked about using imaging accessories within the incubator, eleven (58%) departments did not use any accessories. Seven (38%) disclosed they used lead rubber to assist with radiation protection and/or with collimation. Two (11%) departments used 15^{o} positioning sponges to reduce lordosis; although one (5%) department did imply they angled the tube to reduce lordosis. Twelve (63%) of the responding departments suggested they used the maximum achievable SID to acquire neonatal CXRs. Seven (37%) departments used a 'standard distance', however only three out of the seven departments specified this distance (100 cm). In terms of incubator design, as seen in **Figure 1**, Draeger appears to be the most common incubator choice amongst the nineteen sites, especially the Caleo design with the GE giraffe being second.

Table 1 – Variation in exposure factors used in relation to type of mobile X-ray machine used

				Average (min-max)					
Modality	**CR**				**DR**				**Both**
Exposure Factors									
kVp	62 (60-63)				61 (60-65)				60 (55-62)
mAs	1.5 (1.2-2)				1 (0.5-1.5)				1.2 (0.5-1.6)
Incubator	**Drager**	**GE**	**Atom**	**Hill Rom**	**Drager**	**GE**	**Atom**	**Hill Rom**	
kVp	61 (55-63)	62 (60-65)	60 (n/a)*	60 (n/a)*	60 (55-65)	62 (60-65)	60 (n/a)*	60 (n/a)*	
mAs	1.2 (1.0-2.0)	1 (0.6-1.6)	1 (n/a)*	1 (n/a)*	0.95 (0.5-1.6)	0.9 (0.5-1.2)	1 (n/a)*	1 (n/a)*	
(n/a)* - data from a single incubator only.									

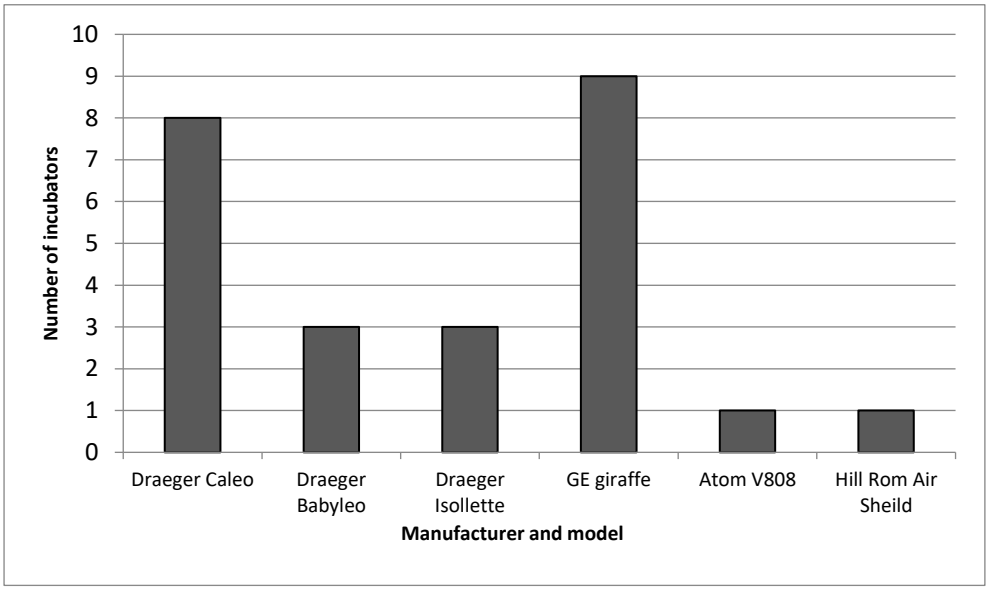


Figure 1. A bar chart illustrating the most common incubator design (make and manufacturer) within the responding institutions.

Eleven (58%) of the departments used the incubator tray as standard practice, two (11%) did not use it, and the remaining six (32%) answered '*variable'*. Qualitative data from this question suggests that all of those who answered '*variable'* preferred not to use the tray but felt that in some circumstances it may be unavoidable. Unavoidable circumstances were similar amongst departments and included if the neonate's condition was unstable, if they had multiple lines, or very premature/low birth weight. Interestingly, three of the departments who did not advocate the use of the incubator tray disclosed that they had conducted internal research or audit on incubator imaging. They found image quality deterioration and artefacts from using the incubator tray which

subsequently affected their decision to use a direct exposure approach, where possible. Reasons for not using the incubator tray are highlighted in **Figure 2**.

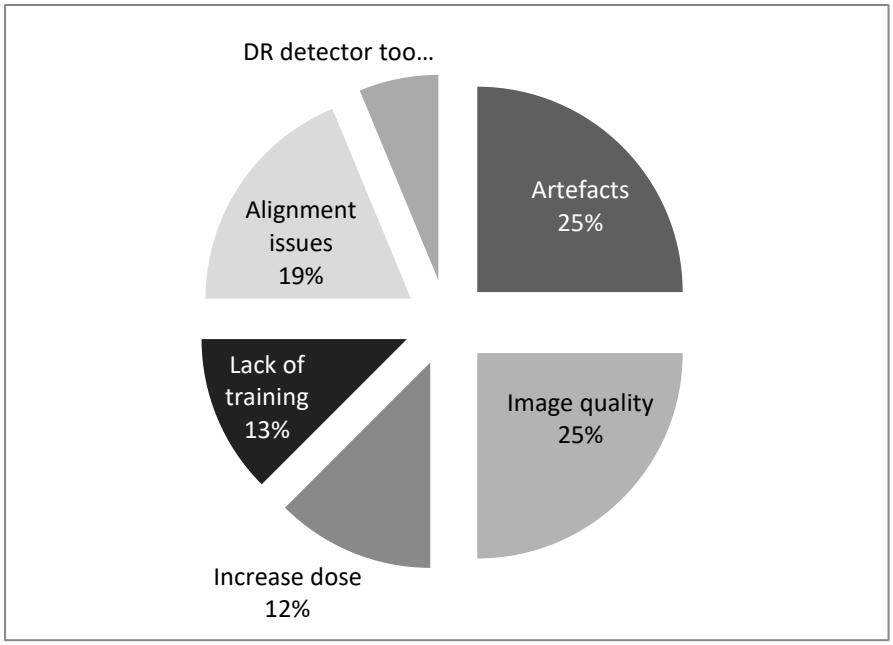


Figure 2. A pie chart illustrating the reasons for not using the incubator tray for imaging.

When using the incubator tray, 13 (68%) of respondents believed that no increase in exposure factors are required. Two of the respondents (11%) answered '*Yes'* with three (16%) answering '*variable'*, however, no additional information was provided to explain this practice.
Fourteen departments (74%) did not open the incubator canopy, with many suggesting that certain modern incubator designs did not allow for this, with only the sides of the incubator being the access point. Five (26%) departments did however comment that they did open the canopy when it was possible with further qualitative data suggesting that this was only if staff felt the neonate was stable as "*opening the incubator reduces the temperature and increases infection risk*".
The final question regarding artefacts also highlighted issues with the incubator canopy, with three respondents (16%) suggesting that some incubators have a port hole which could potentially project over the area of interest when imaging. Further artefacts were elaborated upon within the comment box with ECG leads, wires, nappy, blanket and mattress being the most common listed artefacts. Two respondents also commented that artefacts are exacerbated by the increased sensitivity of DR.

Discussion

This study sought to explore the variation in current working practices between hospitals who image neonates within an incubator. Considerable variation is seen in practice amongst departments as to the standard imaging methods used. These variation ranges from 1) where to place the image receptor, 2) what accessories should be used, 3) the optimal SID and 4) the optimal exposure factors. Imaging protocols are further complicated by differences in incubator design and the range of mobile X-ray machines and acquisition modalities used within clinical practice.

A wide variation in the exposure factors used for neonatal CXRs within an incubator was evident. These results are not surprising owing to the wide variation in imaging techniques which are likely to influence the selection of exposure factors. In addition, there is limited and potentially confusing evidence within the literature as to the optimal kVp and mAs for different birth weights and acquisition modalities (CR/DR). Many studies reported in the literature still advocate the use of a low kV and relatively high mAs values as standard practice[3,9,21], although Rizzi et al[9] did conclude after an optimisation study that higher kV and lower mAs can reduce the radiation dose and still provide the same image quality (60kV/1mAs). Another attempt was made[22] to systematically search the literature for paediatric radiography exposure techniques and subsequently develop an updated paediatric exposure chart. This study concluded that the optimal exposure factors for a neonate (0-6months) were 63 kVp and 1.6mAs which is still much higher than the average exposure factors found within the current study.

Considering the issue of variation in exposure factors for incubator imaging, it is important to firstly address the technical variation seen in practice for incubator imaging as these may influence exposure factor selection. The uncertainty and variation when using the incubator tray is one aspect that needs to be addressed, especially owing to the wide variation within previous studies as to the effect of incubator deign on X-ray beam attenuation and hence detector and patient dose[2,8-11]. This confusion is highlighted by the findings of this study where several departments who advocated the use of the incubator tray increased exposure factors whilst other department who also used the tray did not modify exposure factors. Rizzi and colleagues stated that the radiation beam must pass through the extra thickness of the mattress and the image receptor holder system, possibly incurring attenuation and alteration of the energy spectrum requiring an increase in exposure parameters[9]. Yet 68% of the respondents of this current survey believed no increase in exposure factors are necessary when using the incubator tray. Interestingly, the three departments who did not advocate using the incubator tray had conducted unpublished research projects to inform local practice. They found that the tray affected image quality and occasionally caused artefacts. They

also used lower mAs compared to all other hospitals. However, the projects conducted by these hospitals were not in the public domain and therefore it was difficult to assess their robustness, reliability and validity and hence their wider generalisability.

Other variables need to be considered when interpreting the average exposure factors of each responding hospital such as the make and manufacturer of the incubator and the acquisition modality of the portable machines (CR/DR). Incubator make and model did not seem to influence exposure factor selection within this study, however there was a reduction in mAs for those who acquired CXRs on neonates using DR. Neonatal size and weight is another consideration when selecting exposure factors yet Cohen and colleagues suggested that radiographers do not routinely check a baby's weight prior to exposure[24]. This study[24] also found that the majority of exposures for CXRs were within a narrow spectrum on a range of different size babies suggesting some hospitals do not modify exposure factors between neonatal weight variations. This was reinforced by some exposure charts having only one recommended kV and mAs for neonates aged 0-6 months[22].

Seven (37%) of the responding departments used a set SID for acquiring CXRs on neonates within the incubator, however only three specified this distance (100cm). Over half of the remaining responding departments used the maximum achievable SID for imaging the neonatal chest within incubators. This maximum distance would vary significantly depending on: incubator design, X-ray machine make and model, and, the height of the radiographer conducting the examination[7]. Consequently, this would cause significant variation in magnification and this may be problematic if a neonate was to have multiple X-rays to monitor a condition. On the other hand, using the maximum achievable SID would ensure a reduction in radiation dose to the neonate and a reduction in magnification in comparison to a standard SID[24-26]. With the above variations in mind and the possible consequences of SID on image quality, radiation dose and magnification, more studies are needed to explore this issue. This is further emphasised when considering the 30 cm variation in SID found in one study between incubator heights (80 to 110 cm)[9]. This means that responding departments who uses the maximum achievable SID may have a wider variation in SID than 30cm; this is worrying considering that dose reduction can be found with as little as 5 cm SID changes[26].

A number of limitations were apparent within our study. Owing to the nature of our study, the questionnaire did undergo robust development and testing. We do, however, accept that further validity and reliability checks could have been made using more sophisticated methods of analysis, for example Cronbach's alpha.

Although consideration was given to the variation in exposure factor selection and the different acquisition technologies (CR v DR) used, this could have been explored further in terms of the specification of mobile X-ray units as this may influence exposure factor selection. In addition, neonatal body weight was not considered as part of the same question, although a few studies on exposure charts and neonatal exposures[21,22] along with guidelines form the European Commission[29] do not separate exposure parameters between neonates of different body sizes. It must be noted that only a single response was extracted from each department and was used as the best judge of existing working practices. This unfortunately does not consider the potential variation amongst individual radiographers, a feature reported within previous radiographic studies[27,28]. Nevertheless, the findings of this study provide baseline data on imaging techniques used for neonatal imaging within incubators across Wales and the North-west of England. Furthermore, the study supports the need for standardisation and further optimisation work to ensure best practice for this vulnerable patient group.

Conclusion

This study found considerable variation in current working practice between public hospitals in Wales and the North-west of England when imaging neonates within an incubator. This is not surprising considering the limited evidence within the literature for standardising and optimising this type of imaging. Further work is required to understand the implications of various factors highlighted within this study that affects incubator imaging by ensuring radiation dose is kept as low as reasonably practical, image quality is of diagnostic quality and that the neonate's safety is at the forefront of each radiographic examination.

References

1. Neonatal Data Analysis Unit (NDAU). (2017). NDAU 2016 report. [online] Available at:

https://www.imperial.ac.uk/media/imperial-college/medicine/dept-medicine/infectious-diseases/neonatology/NDAU-2016-Report-v1.1-(002).pdf [Accessed 10 April 2019]

2. Del Rio V, Satta L, Fanti V. Radiologic imaging of the newborn inside the incubator. Radiation dose and image quality. Abstracts of the 9th National Congress of the Associazione Italiana di Fisica Medica. Physica Medica 2016; 3: e71–e96

3. Edison P, Chang PS, Toh GH, et al. Reducing radiation hazard opportunities in neonatal unit: quality improvement in radiation safety practices.BMJ Open Quality 2017;6: doi:10.1136/ bmjoq-2017-00012

4. Datz H, Ben-Shlomo A, Bader D, Sadetzki S, Juster-Reicher A, Marks K, et al. The additional dose to radiosensitive organs caused by using under-collimated X-ray beams in neonatal intensive care radiography. Radiat Prot Dosimetry 2008;130(4):518–24. doi: 10.1093/rpd/ncn090

5. Armpilia CI, Fife IA, Croasdale PL. Radiation dose quantities and risk in neonates in a special care baby unit. Br J Radiol 2002;75(895):590–5.

6. Ehrlich R, Coakes D. Patient Care in Radiography: With an Introduction to Medical Imaging. 9th ed. Missouri: Mosby; 2016

7. Carver E, Carver B. Medical Imaging: Techniques, Reflection & Evaluation. 2nd ed. Philadelphia: Churchill Livingstone; 2012

8. Mutch SJ, Wentworth SD. Imaging the neonate in the incubator: an investigation of the technical, radiological and nursing issues. Br J Radiol *2007;* 80: 902–910

9. Rizzi E, Emanuelli S, Amerio S, Fagan D, Mastrogiacomo F, Gianino P, Cesarani F. Optimization of Exposure Conditions for Computed Radiology Exams in Neonatal Intensive Care. Open Journal of Radiology 2014; 4: 69-78. doi: 10.4236/ojrad.2014.41009

10. Jiang X, Baad M, Reiser I, Feinstein K, Lu Z. Effect of comfort pads and incubator design in neonatal radiography. Pediatr Radiol *2016* 46(1): 112-118

11. Rattan AS, Cohen MD. Removal of comfort pads underneath babies: a method of reducing radiation exposure to neonates. Acad Radiol *2013;* 20: 1297–1300

12. Timmins F. Survey and questionnaire in nursing research...Art and Science Research Series: Part 16. Nursing Standard *2015;* 29(42): 42. **doi:** 10.7748/ns.29.42.42.e8904

13. Bradburn NM. Understanding the question-answer process. Survey Methodology 2004, 30(1): 5-

14. McLeod P, Meagher T, Steinert Y, Boudreau D. Using Focus Groups to Design a Valid Questionnaire Acad Med 2000; 75: 671.

15. Nassar-McMillan SC, Borders LD. Use of focus groups in survey item development. The Qualitative Report, 2002 7(1). Available from http://www.nova.edu/ssss/QR/QR7- 1/nassar.html. [Accessed 12 Jan 2019]

16. Tsang S, Royse CF, Terkawi AS. Guidelines for developing, translating, and validating a questionnaire in perioperative and pain medicine. Saudi J Anaesth 2017; 11(Suppl 1): S80–S89. doi: 10.4103/sja.SJA_203_17

17. Infant Journal. (2019). *Neonatal Unit Guide*. [online] Available at: http://www.infantjournal.co.uk/nicu_list.html [Accessed 15 May 2019].

18. Lichtman M. *Qualitative research in education. A user's guide*. 3rd ed. London: SAGE; 2013.

19. Chang Y, Voils CI, Sandelowski M, Hasselblad V, Crandell JL. Transforming verbal counts in reports of qualitative descriptive studies into numbers. West J Nurs Res 2009; 31(7):837-52. doi: 10.1177/0193945909334434

20. Care Quality Commission. Neonatal core service framework V 5 (Published on internet July 2016) https://www.cqc.org.uk/sites/default/files/20160713_NHS_specialist_core_service_inspection_framework_neonatal_services.pdf [Accessed 23/02/2019]

21 Hinojos-Armendariz VI, Mejía-Rosales SJ, Franco-Cabrera MC. Optimisation of radiation dose and image quality in mobile neonatal chest radiography. Radiography 2018; 24: 104-109

22. Knight SP. A paediatric X-ray exposure chart. J Med Radiat Sci 2014; 61(3): 191–201.

23. Cohen MD, Markowitz R, Hill J, Huda W, Babyn P, Apgar B. Quality assurance: a comparison study of radiographic exposure for neonatal chest radiographs at 4 academic hospitals. Pediatr Radiol 2012; 42: 668. https://doi.org/10.1007/s00247-011-2290-1

24. Heath R, England A, Ward A, Charnock P, Ward M, Evans P, et al. Digital pelvic radiography: increasing distance to reduce dose. *Rad Tech* 2011; 83(1): 20-28.

25. England A, Evans P, Harding L, Taylor E, Charnock P, Williams G. Increasing source-to-image distance to reduce radiation dose from digital radiography pelvic examinations. Rad Tech 2015; 86(3): 246-56.

26. Tugwell J, Everton C, Kingma A, Oomkens D, Pereira G, Pimentinha D, et al. Increasing source to image distance for AP pelvis imaging – impact on radiation dose and image quality. *Radiography* 2014; 20(4): 351-355.

27. Tugwell J. Here comes a trolley: Imaging the trolley bound patient – current working practices and experience. Imaging and Therapy Practice 2014; September

28. Darcy S, Rainford L, Kelly B, Toomey R. Decision Making and Variation in Radiation Exposure Factor Selection by Radiologic Technologists. Journal of Medical Imaging and Radiation Sciences, 2015, 46(4): 372-379, https://doi.org/10.1016/j.jmir.2015.09.003.

29. European Commission (1996) European guidelines on quality criteria for diagnostic radiographic images in paediatrics , Report EUR 16261EN

2.6 - PAPER 6

Optimising image quality and radiation dose for neonatal incubator imaging

Tugwell-Allsup JR, Morris RW, Hibbs R, England A.

Abstract

Introduction: Neonates often require imaging within incubators however limited evidence exists as to the optimal method and acquisition parameters to achieve these examinations. This study aims to standardise and optimise neonatal chest radiography within incubators.

Methods: A neonatal anthropomorphic phantom was imaged on two different incubators under controlled conditions using a DR system. Exposure factors, SID and placement of image receptor (direct v tray) were explored whilst keeping all other parameters consistent. Image quality was evaluated using absolute visual grading analysis (VGA) with contrast-to-noise ratio (CNR) also calculated for comparison. Effective dose was established using Monte Carlo simulation using entrance surface dose within its calculations.

Results: VGA and CNR reduced significantly ($p < 0.05$) whilst effective dose increased significantly ($p < 0.05$) for images acquired using the incubator tray. The optimal combinations of parameters for incubator imaging were: image receptor directly behind neonate, 0.5 mAs, 60 kV at 100 cm SID, however, if tray needs to be used then these need to be adapted to: 1 mAs at maximum achievable SID. Effective dose was highest for images acquired using both incubator tray and 100 cm SID owing to a decrease in focus to skin distance. There is significant increase ($p < 0.01$) in VGA between using 0.5 mAs and 1 mAs but an apparent lack of increase between 1 and 1.5 mAs.

Conclusion: Using the incubator tray has an adverse effect on both image quality and radiation dose for incubator imaging. Direct exposure is optimal for this type of examination but if tray needs to be used, both mAs and SID need to be increased slightly to compensate.

Implications for practice: This study can help inform practice in order to both standardise and optimise chest imaging for neonates in incubators.

Introduction

When neonates are born prematurely or have health concerns, they are commonly placed within an incubator or warmer system. During this period, they are likely to require mobile chest radiography (CXR) to diagnose and monitor their condition, whilst remaining within their incubators.[1] During such examinations the radiographer will need to consider whether to place the image receptor directly beneath the neonate or in a dedicated tray/drawer. These two scenarios have advantages and disadvantages in relation to infection control, magnification, attenuation differences, collimation and alignment, which all impact on image quality, safety and the radiation dose to the neonate.[1-4] Two recent studies [1,5] have shown considerable variation in neonatal imaging protocols and have highlighted the need for standardisation and optimisation. Previous optimisation studies are limited and have either focused only on one or two acquisition parameters or have failed to correlate the additional attenuation of the incubator design with the increased risk associated with the radiation dose or with any decline in visual image quality. [3,4,6,7]

This study advances work from a recent systematic review [2] and a clinical practice survey [5] on neonatal incubator imaging. Within these reports the lack of empirical evidence and wide variability in radiographic technique was evident. This is a concern since neonates are more sensitive to the effects of radiation owing to their rapid development. A neonate's life expectancy is also theoretically longer meaning that there is more time for the harmful effects of radiation to manifest.[8] This project aims to build on previous knowledge to standardise and optimise neonatal CXR within incubators. This study will assess how each component of the incubator design and choice of acquisition parameters affects image quality and radiation dose.

Method

Imaging equipment and technique

Quality assurance testing was conducted prior to commencing the study in accordance with IPEM Report 91 [9], and results were within accepted tolerances. Images were acquired using a DR Samsung GM85 mobile and a 25 x 30cm wireless, lightweight S-Detector™ (MIS Healthcare, London, UK). To allow for multiple exposures under consistent conditions, the commercially available Gammex 16 neonatal anthropomorphic phantom was used (Rothband LTD, Haslingden, UK) to simulate a 1 - 2 kg neonate. For comparison purposes, images were acquired using two different

neonatal incubators, both had an integrated X-ray tray: 1) Drager Caleo and 2) GE Giraffe and both are commonly used incubators. [5]

The phantom was positioned for a standard supine anteroposterior (AP) chest examination, ensuring the median sagittal plane was coincident with, and at right angles to the incubator tabletop and tray beneath.[10] The centering point was fixed in the midline at the level of the sternal angle (between the nipples), the collimation was adjusted to include the lung apices, lateral margins of both lungs, cardiophrenic and costophrenic sucli in accordance with radiographic textbooks.[10,11] This area of clinical interest was marked with tape in order to maintain a fixed collimation size for all exposures **(Figure 1).**

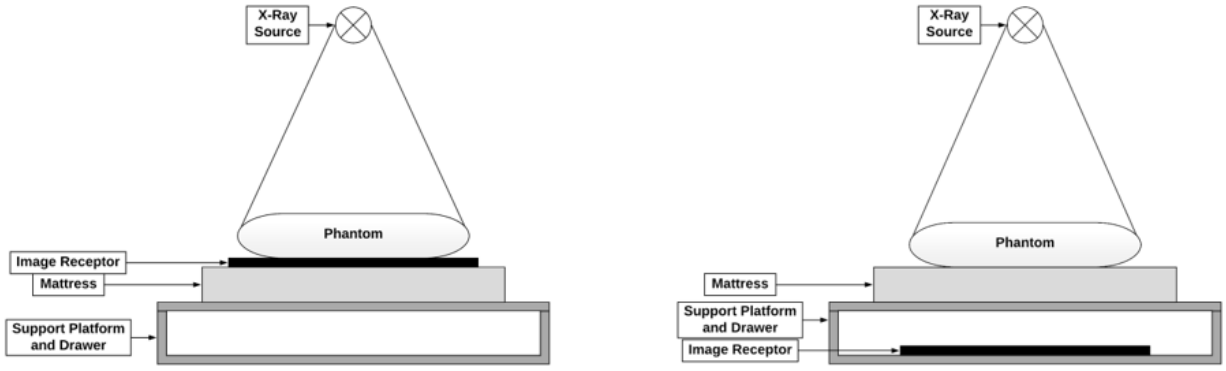


Figure 1 – figure demonstrating experimental set up for direct and tray exposure

Study acquisition parameters were based on local clinical protocols and those reported in the literature [2-7,12] Various acquisition parameters were changed in this factorial study design. The main independent variables for the study were: 1) image receptor position *(direct v tray)*, 2) incubator design *(Caleo v Giraffe*), 3) mAs *(0.5, 1, 1.5)*, 4) kV *(60, 65)* and 5) source-to-image distance (SID) *(100cm, max).* For tray exposures, the mattress, SID and object-to-image to distance (OID) were measured using both a tape measure and ruler. The mattresses of both incubators were identical in terms of thickness (3.5cm) and the distance from the phantom. The OID was 6cm for the Drager Caleo and 7cm for the GE giraffe. The maximum achievable SID, with the incubator at the lowest height setting and X-ray tube in the highest achievable position, is described in **Table 1**.

All other acquisition parameters were kept consistent and according to those typically employed in clinical practice and within the literature. [4-6] These included a small focus (0.6mm) and 3.2 mm Al total filtration.

Table 1. Independent variables within the experimental study

Type	Parameter	
Independent Variables	Incubator	Drager Caleo
		GE Giraffe
	Image receptor	Direct
	position	Tray
	kV	60
		65
	mAs	0.5
		1
		1.5
	FRD	100cm
		Maximum achievable ; Drager direct = 119cm / Drager tray = 128cm /GE Giraffe direct = 117cm/ GE Giraffe tray = 125cm

Visual image quality evaluation

All images were displayed on a high quality 24.1 inch NEC (EA243WM) monitor with a resolution of 5 megapixels. The images were evaluated using the ViewDEX computer software.[13] ViewDEX is a Java based program developed to display images in a random order, without any acquisition data, with the facility of providing a direct assessment of image quality via options displayed on the screen. Images were analysed independently by two radiologists, two reporting radiographers and two general radiographers with more than 5 years clinical experience. All six observers were blinded to the acquisition parameters used to acquire the images. Images were evaluated using an absolute visual grading assessment (VGA) method whereby each observer rated their opinion on the visibility of specific features within the various acquired images. Image quality criteria were taken from Uffmann et al.[14] Martin et al.[15], Ladia et al.[16] and the European Commission criteria[17]. Numerous criteria were 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). Some adjustments were made to terminology in order to reflect more closely anatomy within the phantom. Overall seven criteria were evaluated for each image **(Table 2).**

Table 2 - Image quality criteria and rating scale used to assess chest X-ray image quality

Chest criteria	**Rating scale used to assess image quality**
1. Reproduction of the lung pattern in the displayed lungs 2. Reproduction of the trachea and proximal bronchi 3. Reproduction of the diaphragm and costo-phrenic angles 4. Reproduction of the spine through the heart shadow 5. Reproduction of the mediastinum and heart borders 6. Overall levels of noise within the image 7. 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).

Contrast-to-Noise Ratio (CNR)

CNR was also calculated by placing a region of interest (ROI) on two contrasting homogeneous structures within the acquired images **(Figure 2).** The ROI was placed in the same position for all acquired images in accordance with Bloomfield et al. [18] The Image J software (National Institutes of Health, Bethesda,MD) was used to calculated CNR whereby the mean pixel values (signal) and the standard deviation (noise) for the ROI was determined by the following equation.[19]

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

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

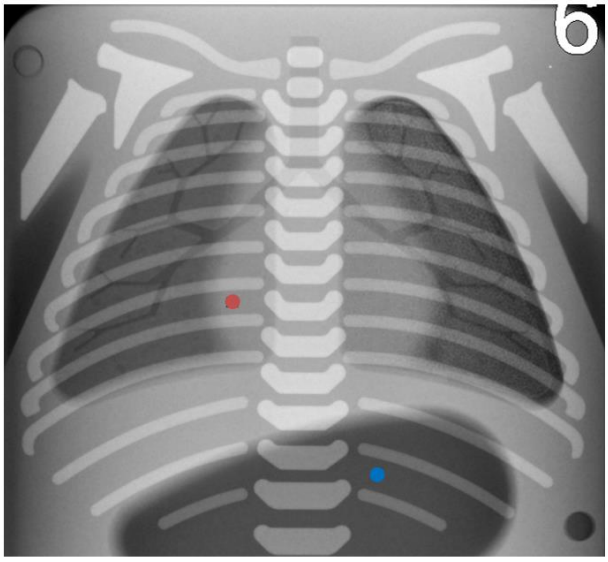


Figure 2 – ROI position to calculate CNR; ROI1 (red circle) and ROI2 (blue circle)

Radiation dose assessment

Entrance surface dose (ESD), including backscatter, was measured at the surface of the phantom at the centre of the collimation field using an Unfors Mult O-Meter 407L detector (Unfors Equipments, Billdal, Sweden). In order to reduce random error, three repeated exposures were performed and then averaged.

Effective dose was estimated using PCXMC 2.0 (STUK, Helsinki, Finland)and tissue weighting factors from the ICRP Publication 103. [20] The software has a phantom representative of a 1kg newborn. Entrance surface dose (ESD) was used in this estimation along with the respective acquisition parameters.

Statistical analysis

All data were inputted into Excel 2007 and transferred to GenStat (GenStat version 13.3, VSN International Ltd) and SPSS software package (PASW Statistics 18: version 18.0.2, SPSS Inc., Chicago,

IL) for analysis. For the visual image quality data, inter-observer variability was evaluated using the Intra-Class Correlation Coefficient (ICC). An ICC >0.75 is indicated as excellent, 0.40-0.75 as fair to good and <0.40 poor.[21] Image quality data (both visual and physical) and radiation dose data were analysed in a multi-factorial 2^4x3 design (2 incubators, 2 image receptor positions, 2 kV, 2 SID, 3 mAs). This was achieved with 6 repetitions (observers) using the general ANOVA model with observer as the blocking factor and a significance level of $p<0.05$ (95%). Pearson's r correlation was also generated to determine correlation between visual image quality and CNR.

Results

On average, there was good consistency amongst the six observers when evaluating visual image quality, with an ICC of 0.73 (CI 95% 0.59-0.83); with agreement being stronger for images that were scored very low or very high. In addition, visual image quality and CNR had a moderately good positive correlation r=0.65 which can also be seen from the ANOVA coefficients (**Tables 3** and **4**)

Of the 48 experimental images, as expected, the images with the highest image quality also had the highest radiation dose. However, in order to ensure optimisation, these results have to be explored further for optimal combinations. Interestingly, there was a statistically significant difference in visual image quality and CNR between 0.5mAs and the other mAs values of 1 and 1.5 (**Tables 3** and **4**). However, there is an apparent lack of an increase in visual image between 1 and 1.5 mAs. It is estimated that when using the incubator tray in comparison to direct exposure, visual image quality decreases slightly by 0.15 (3%) and yet was statistically significant ($p<0.05$). This means that an increase in mAs from 0.5 to 1 is required to achieve identical VIQ when using tray. Using a non-tray exposure and 100cm SID with 0.5mAs and 60kV, resulted in above average visual image quality (3 and above) and high CNR with a lower effective dose; making them the most suitable combination for optimisation.

For most variables explored within this study, a significant increase in image quality meant a significant increase in effective dose and vice versa. For example, the Drager incubator had significantly lower image quality than the GE Giraffe but also allowed images to be acquired at a significantly lower dose (**Tables 3** to **5**). The same was seen for SID, where there was a significant increase in both visual image quality and CNR for 100cm SID compared to maximum achievable SID yet there was also a significant increase in effective dose. From the 48 experimental images, the images acquired using the tray at 100cm SID resulted in the highest effective dose (**Figures 3** and **4**). This is not surprising as the OID when using the tray for the Drager and Giraffe incubator were 6cm

and 7cm, respectively. This meant that when using an SID of 100cm, with the tray, the source to skin distance was shorter compared to a direct exposure (has no OID)

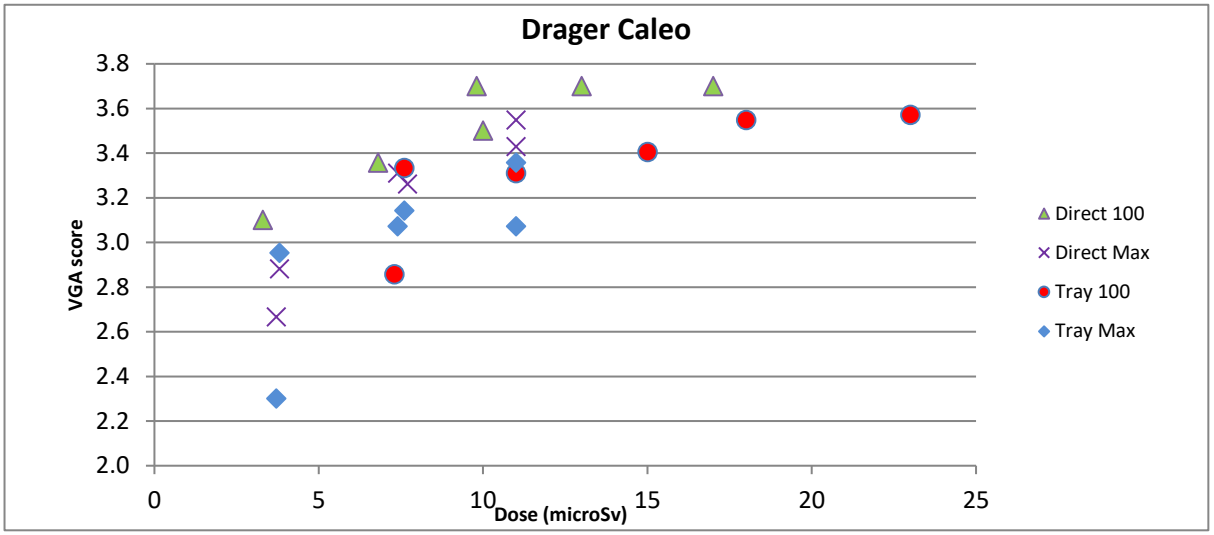


Figure 3 –Visual image quality versus effective dose for the different variables used on the Drager incubator

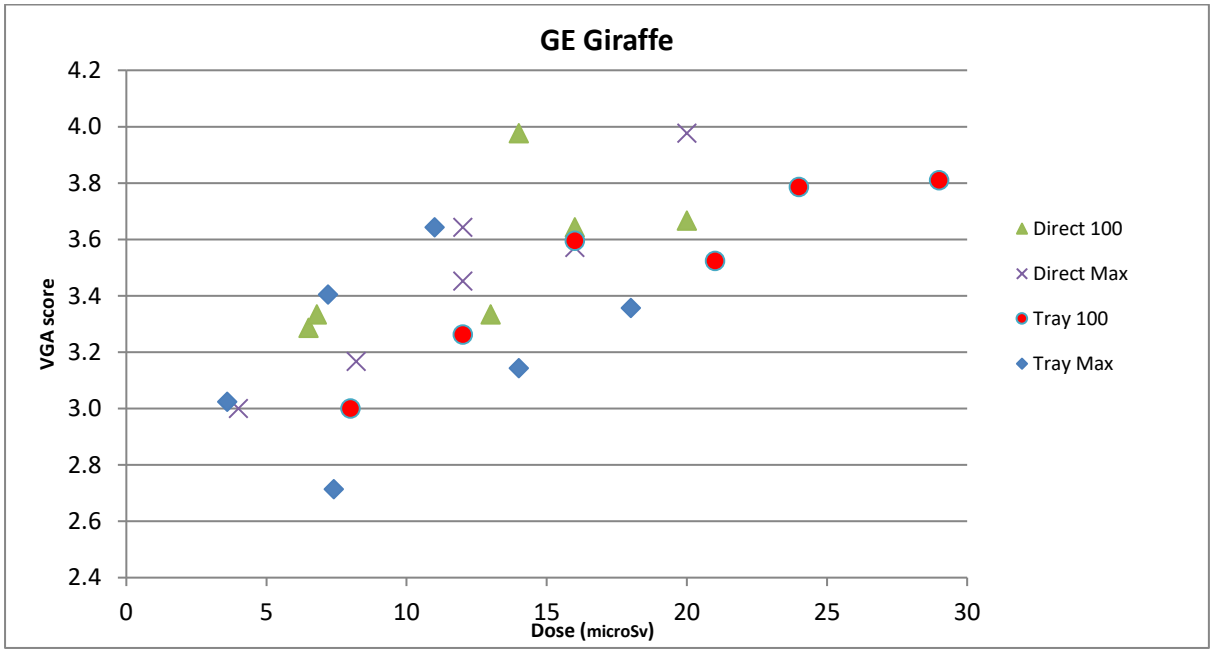


Figure 4 - Visual image quality versus effective dose for the different variables used on the Giraffe incubator

The only independent variable where the inverse correlation seen above (increase dose = increase image quality) was not present was for direct verses tray exposures. Both VIQ and CNR were significantly decreased for tray exposure but at significantly higher doses to a direct exposure (**Tables 3** to **5**). This means that the tray had an adverse affect on both image quality and radiation for incubator imaging.

Table 3 - Results of the ANOVA for visual image quality.

Visual image quality	Coefficient	Confidence Interval 95%	p-value
Intercept (Visual image quality when kV=65, mAs=0.5, FRD max, no tray, Giraffe)	3.34		
kV=60	-0.15	(-0.25, -0.05)	p=0.003
mAs=1	0.45	(0.36, 0.54)	p<0.001
mAs=1.5	0.55	(0.46, 0.64)	p<0.001
FRD=100	0.26	(0.16, 0.36)	p<0.001
location=tray	-0.17	(-0.27, -0.07)	p=0.01
Incubator=Drager	-0.18	(-0.28, -0.08)	p<0.001

Table 4 - Results of the ANOVA for CNR

CNR	Coefficient	Confidence Interval 95%	p-value
Intercept (CNR when kV=65, mAs=0.5, FRD max, no tray, Giraffe)	22.18		
kV=60	-2.38	(-3.37, -1.4)	p<0.01
mAs=1	6.22	(5, 7.43)	p<0.01
mAs=1.5	9.94	(8.73, 11.15)	p<0.01
FRD=100	3.94	(2.95, 4.92)	p<0.01
location=tray	-4.84	(-5.83, -3.85)	p<0.01
Incubator=Drager	-1.59	(-2.58, -0.61)	p=0.002

Table 5 - Results of the ANOVA for effective dose

Effective Dose	Coefficient	Confidence Interval 95%	p-value
Intercept (Dose when kV=65, mAs=0.5, FRD max, no tray, Giraffe)	5.94		
			p=
kV=60	-2.37	(-3.73, -1.01)	0.001
mAs=1	5.35	(3.68, 7.02)	p<0.01
mAs=1.5	10.97	(9.3, 12.64)	p<0.01
FRD=100	4.4	(3.04, 5.76)	p<0.01
location=tray	1.86	(0.5-3.22)	p=0.01
Incubator=Drager	-3.7	(-5.06, -2.34)	p<0.01

From an image quality perspective, 0.5mAs should not be used in combination with maximum SID and/or with incubator tray as both SID and tray decreased image quality and hence 0.5mAs is not sufficient to ensure optimal image quality for these variables (**Figures 2** and **3**).

Discussion

Results from our study indicate that when imaging neonates within incubators, numerous variables affect image quality and radiation dose. Most findings were expected in terms of the relationship between effective dose and increases in VIQ and CNR. However, when optimising an imaging technique, a balance is required to ensure optimal image quality at lowest radiation dose. Overall, the optimal protocol for incubator imaging came from images acquired with the image receptor directly behind neonate, with a 100cm SID (60kV and 0.5mAs) for both incubator designs. These combinations produced images above average image quality with a very low effective dose. However, in clinical practice, it is not always feasible to image a neonate using a direct exposure as it requires the positioning and movement of an already vulnerable neonate. Although use of the incubator tray has been shown to increase beam attenuation, many studies [6,7,22] still advocate the use of the incubator tray when imaging neonates as it reduces the risk of cross infection and displacing lines and tubes without any significant impact on image quality. Also, historical studies have demonstrated that handling neonates can be associated with bradycardia and hypoxia. [22-24] In addition, 58% of respondents within Tugwell et al's study [5] used the tray as standard practice, with 32% using it only in unavoidable circumstances such as when the neonate's condition was unstable,

if they had multiple lines, and/or very premature/low birth weight. It is therefore important to also consider the optimal acquisition parameters and technique when using the incubator tray. From all acquisitions using tray, the current study found that the optimal acquisition parameters to be 60kV, 1mAs at maximum achievable SID.

Unlike previous studies, our work did not attempt to calculate the attenuation properties for the various components of both incubators used. The difference in image quality and radiation dose would reflect this and thus be more clinically relevant. The Drager incubator had significantly lower image quality but had significantly lower effective dose too. Incubator design would be a reasonable explanation for this. Both OID and SID when at maximum achievable height was different for both incubators with the Drager unit having larger OID and SID. This means the distance from the tube to tray is larger for Drager which would result in a reduction in radiation dose according to the inverse square law and similar trends found in SID related studies. [25-27] In addition, the materials/construction of the incubator may have added additional attenuation and influenced radiation dose and image quality between both incubators. It was noticed that for direct exposures at 100cm SID, DAP for both incubators were identical but the ESD at the surface of phantom was not, which means that the canopy for Drager seemed to absorb more primary radiation; this could also contribute to the differences seen between both incubators for the study.

Some additional findings within this study became apparent. It is already noted within the literature that differences occur between incubator designs such as the attenuation of various components such as the canopy, support tray and mattress. [3,4,6] The above experiment aimed to explore the radiology aspects of imaging a neonate within an incubator by considering the impact of various variables on image quality and radiation dose. However, in order to make a more informed holistic decision as to the optimal parameters/method to image the neonate, other factors need to be considered. It was noted, that during the experiments, in order to place the image receptor within the incubator tray for the GE Giraffe, the incubator side panel needed to be open. This means that the temperature within the incubator could be compromised. One of the main purposes of an incubator is to ensure a stable warm environment for the neonate [10] and therefore the use of the tray in this instance does not eliminate all of the disadvantages associated with a direct exposure. Another design feature noted for the Drager Caleo was the tray could only be accessed from one side of the incubator, which is not flexible. In addition, the tray/drawer for this incubator is large and the image receptor seemed to move considerably when opening and closing into position which meant it could easily be misaligned for imaging. The drawer was large and yet it still cannot accommodate a large DR image receptor. This was also found in other studies [1,5] where the use of

the tray was limited by the size of the image receptor as a 35x43cm receptor would not fit into the incubator drawer. It is therefore important that each imaging department, when purchasing new DR portable equipment, should consider purchasing a small image receptor if undertaking neonatal imaging. Lastly, as already discussed, the distance of the tray/drawer from the surface of the mattress can also be a variable that increases effective dose and reduces image quality. Radiology should be consulted when designing such equipment similar to that seen for trolley imaging.[28]

There are several limitations in our study. Using an anthropomorphic phantom is not fully representative of the human body since it lacks anatomical and pathological variation. Furthermore, the study was conducted using only a single DR system and therefore needs to be confirmed using other portable DR equipment. Although the thickness of both incubator mattresses were identical, the full composition of mattress specification was unknown and therefore future studies need to consider this especially with the introduction of warming gel mattresses for incubators. The statistics used for this study found significant difference between each variable and acquisitions parameters, however this statistical significance may not be clinically important.. Although image quality may have significantly deteriorated using some combination of parameters/technique, these images may still be of diagnostic quality. None of the images scored below two meaning that none of the observers deemed any of the images as unacceptable for diagnostic purposes and thus requiring a repeat exposure. Based on the findings of this study, the recommended technique for chest imaging for neonates in incubators is summarised in **Table 6**. Consideration should however be determined by the clinical question and the technique should be evaluated at each hospital, using their own equipment.

Table 6. Recommendations for practice for both incubators used within the study based upon using a Samsung portable machine

	FRD	**kV**	**mAs**
Neonatal chest x-ray with direct exposure*	100cm	60	0.5
Neonatal chest x-ray in the incubator tray**	Maximum achievable	60	1

*A direct exposure should only be used if the neonate is stable and under the guidance of the nurse in charge

**The tray is advocated especially to reduce movement of neonate

Conclusion

This study has highlighted how different conditions and acquisition parameters used for neonatal chest imaging in incubators can influence both radiation dose and image quality. The main finding within this study was that image quality decreased whilst radiation dose increased when the images receptor was placed in incubator tray for imaging as oppose to directly behind the neonate. For the purpose of optimisation, direct exposure favoured a lower dose at higher image quality, however, from a holistic clinical perspective, it is not always feasible to move the neonate and therefore this study also gives recommendations on the optimal combination of acquisitions parameters if the incubator tray was to be used.

References

1. Gunn C, O'Brien K, Fosså K, Tonkopi E, Lanca L, Martins CT et al. A multi institutional comparison of imaging dose and technique protocols for neonatal chest radiography. Radiography 2019, In Press: https://doi.org/10.1016/j.radi.2019.10.013.
2. Tugwell-Allsup J, England A. A systematic review of incubator-based neonatal radiography – What does the evidence say? Radiography 2019, In Press https://doi.org/10.1016/j.radi.2019.09.009.

3. Jiang X, Baad M, Reiser I, Feinstein K, Lu Z. Effect of comfort pads and incubator design in neonatal radiography. Pediatr Radiol 2016; 46(1):112-8.
4. Rattan AS, Cohen MD. Removal of comfort pads underneath babies: a method of reducing radiation exposure to neonates. Acad Radiol 2013; 20:1297-300.
5. Tugwell-Allsup J, England A. Imaging neonates within an incubator – A survey to determine existing working practice. Radiography 2020; 26(1): 18-23 https://doi.org/10.1016/j.radi.2019.07.005.

6. Rizzi E, Emanuelli S, Amerio S, Fagan D, Mastrogiacomo F, Gianino P, et al. Optimization of exposure conditions for computed radiology exams in neonatal intensive care. Open J Radiol 2014;4:69e78. https://doi.org/10.4236/ojrad.2014.41009.
7. Mutch SJ, Wentworth SD. Imaging the neonate in the incubator: an investigation of the technical, radiological and nursing issues. Br J Radiol 2007;80: 902-10.
8. Khong P, Ringertz H, Donoghue V, Frush D, Rehani M, Appelgate K, et al. ICRP publication 121: radiological protection in paediatric diagnostic and interventional radiology. Ann ICRP 2013;42(2):1-63.
9. IPEM. Report 91: recommended standards for the routine performance testing of diagnostic X-ray systems. 2005. York, http://hdl.handle.net/10454/6424.

10. Carver E, Carver B. Medical imaging: techniques, reflection & evaluation. 2nd ed. Philadelphia: Churchill Livingstone; 2012.
11. Whitley SA, Jefferson G, Holmes K, Sloane C, Anderson C, Hoadley G. Clark's positioning in radiography. 13th ed. London: CRC Press; 2015

12. Del Rio V, Satta L, Fanti V. Radiologic imaging of the newborn inside the incubator. Radiation dose and image quality. In: Abstracts of the 9th National Congress of the Associazione Italiana di Fisica Medica. Phys Med 2016; vol 3; e71-96.
13. Håkansson M, Svensson S, Zachrisson S, Svalkvist A, Båth M, Månsson LG. Viewdex: an efficient and easy-to-use software for observer performance studies. Radiat Prot Dosimetry 2010; 139:42–51
14. Uffmann M, Schaefer-Prokop C. Digital radiography: the balance between image quality and required radiation dose. European Journal of Radiology 2009; 72(2): 202-208.

15. Martin L, Ruddlesden R, Makepeace R, Robinson L, Mistry T, Starritt H. Paediatric x-ray radiation dose reduction and image quality analysis. Journal of Radiological Protection 2013; 33(3), 10.1088/0952-4746/33/3/621

16. Ladia AP, Skiadopoulos SG, Kalogeropoulou CP, Zampakis PE, Dimitriou GG, Panayiotakis GS. Radiation Dose and Image Quality Evaluation in Paediatric Radiography. International Journal of New Technology and Research (IJNTR) 2016; 2(3): 09-14
17. European Commission. European guidelines on quality criteria for diagnostic radiographic images in paediatrics. 1996. Report Eur 16261EN.
18. Bloomfield C, Boavida F, Chabloz D, Crausaz E, Huizinga E, Hustveit H, et al. Experimental article e reducing effective dose to a paediatric phantom by using different combinations of kVp, mAs and additional filtration whilst maintaining image quality. In: Hogg P, Lanca L, editors. Erasmus intensive programme OPTIMAX; 2014. Lisbon, Portugal
19. Sun Z, Lin C, Tyan Y, Ng KH. Optimization of chest radiographic imaging parameters: a comparison of image quality and entrance skin dose for digital chest radiography systems. Clinical Imaging 2012; 36(4): 279-86.

20. International Commission on Radiological Protection (ICRP). (2007). The 2007 recommendations of the ICRP on radiological protection, publication 103. *Annals of ICRP*, 37(2-4), 1-332.

21. Rosner B. Fundamentals of biostatistics. 7th ed. Boston: Cengage Learning; 2010.
22. Slade D, Harrison S, Morris S, Alfaham M, Davis P, Guildea Z, et al. Neonates do not need to be handled for radiographs. Pediatr Radiol 2005; 35(6):608-11. https://doi.org/10.1007/s00247-005-1414-x.

23. Long JG, Philip AG, Lucey JF. Excessive handling as a cause of hypoxemia. Pediatrics 1980; 65:203-7.
24. Danford DA, Miske S, Headley J, et al. Effects of routine care procedures on transcutaneous oxygen in neonates: a quantitative approach. Arch Dis Child 1983;58:20-3.
25. Tugwell J, Everton C, Kingma A, Oomkens D, Pereira G, Pimentinha D, et al. Increasing source to image distance for AP pelvis imaging e impact on radiation dose and image quality. Radiography 2014;20(4):351e5.
26. Heath R, England A, Ward A, Charnock P, Ward M, Evans P, et al. Digital pelvic radiography: increasing distance to reduce dose. Radiol Technol 2011;83(1): 20e8.
27. England A, Evans P, Harding L, Taylor E, Charnock P, Williams G. Increasing source-to-image distance to reduce radiation dose from digital radiography pelvic examinations. Radiol Technol 2015;86(3):246e56.
28. Tugwell JR, England A, Hogg P. Antero-posterior (AP) pelvis x-ray imaging on a trolley: Impact of trolley design, mattress design and radiographer practice on image quality and radiation dose. Radiography 2017; 23: 242-48

3. OPTIMISING IMAGE QUALITY AND RADIATION DOSE.

The papers presented within this thesis focus on two main variables: geometry and attenuation, with the aim of optimising image quality and radiation dose for AP pelvis (tabletop and trolley) and neonatal chest imaging. In order to achieve this, firstly, it is important that the basic principles of optimisation are understood, especially in terms of recognising the impact of geometry and attenuation on image quality and radiation dose (ICRP, 2007; Malone et al., 2012).

Organisations such as the ICRP and International Atomic Energy Agency (IAEA) along with authors including Martin (2007) have strived to define the principles of optimisation, providing recommendations and guidance for reducing radiation dose, whilst evaluating methods for exploring these concepts further. This has led to widespread attempts at optimisation, under controlled experimental conditions, for a variety of imaging examinations and variables. However, there remain many areas of radiographic practice not yet explored with continued disparity in the methods used, especially surrounding those used to evaluate image quality and radiation dose. During the conduction of the six papers presented, it was evident that this disparity causes difficulties when translating findings into clinical practice, but also causes confusion when comparing findings of similar studies.

The following two sections will appraise the research methods available for evaluating both image quality and radiation dose in order to justify their use in the experimental studies presented within this thesis. Any new findings, ideas or approaches established during this research journey, as well as observations which enhance the understanding within this area, will also be discussed.

3.1 – VISUAL AND OBJECTIVE MEASURES OF IMAGE QUALITY

The purpose of medical imaging is to demonstrate patient anatomy and pathology adequately to enable reliable and accurate diagnosis (Morrell, 2006). A variety of methods are available for measuring image quality, some involve the use of physical objective measures whilst others involve the participation of human observers. Both observer evaluations and objective physical measures were used for the experimental studies presented within this thesis (Papers 1, 2 and 6) to reinforce findings and to also establish their correlation since conflicting evidence was, and still is evident within the literature regarding their relationship (Al-Murshedi et al., 2020; Alzyoud, Hogg, Snaith, Flintham, & England, 2019; Moore, Wood, Beavis, & Saunderson, 2013; Samei, 2009; Sandborg & Önnerth, 2004).

3.1.1 OBJECTIVE MEASURES

For Paper 1, signal to noise ratio (SNR) was used to objectively measure image quality owing to its simple reproducible calculation and its effectiveness in denoting the quantity and proportion of signal to noise present within the image (Krupinski, 2010). Mraity, England & Hogg (2014) also found a positive correlation between SNR and visual image quality when optimising AP pelvis using the same anthropomorphic phantom. Following further reflection and critique of existing literature (Lanca et al., 2014; Mori et al., 2013; Sun, Lin, Tyan & Ng, 2012), contrast to noise (CNR) ratio, as oppose to SNR, was selected for the remaining two experimental studies (Paper 2 and 6). This is because CNR takes into consideration the effect of noise on our ability to distinguish between structures within an image since visibility depends on contrast (the difference between signals). A highly exposed image may therefore have a high SNR but have limited contrast. The primary quality-related features within radiographic images are contrast, sharpness and noise, and therefore CNR reflects upon two of these factors related to image quality (Hess & Neitzel, 2012; Martin, 2007; Mori et al., 2013). In addition, Paper 6 explored chest imaging as oppose to pelvis, and therefore the point made above is even more pertinent as the chest has a large range of densities requiring good contrast between different structures including the lungs, heart and spine (Mori et al., 2013). In hindsight, the use of both SNR and CNR may have been useful for Paper 2 in order to explore their relationship and to correlate both to the visual image quality scores. This would have been interesting since AP pelvis is a bony structure and ensuring contrast between different densities may not be as important. The use of CNR for AP pelvis could therefore be deemed unsuitable since the background region of interest (ROI) is placed in an area not of diagnostic interest (Lyra, Kordolaimi & Salvara, 2010; Vldimirov, 2010). There remains consistency, reliability and validity issues related to these objective measures in terms of their reproducibility and correlation to visual image quality, which requires further exploration; this will be discussed further in section 2.1.3.

3.1.2 OBSERVER PERFORMANCE (SUBJECTIVE MEASURE)

Although SNR and CNR are reproducible, they do not reflect on the entire imaging chain (from image acquisition to display to interpretation) and therefore do not simulate clinical practice. Medical imaging involves the subjective assessment of image quality using qualified professionals such as radiologists. This is why many optimisation studies have opted for observer performance methods (Allen, Hogg, Ma & Szczepura, 2013; Ma et al., 2013; Mekis, Entee & Stegnar, 2010; Mraity et al., 2014) and why visual grading analysis (VGA) was used as the main outcome measure for evaluating image quality within Paper 1, 2 and 6. VGA methods are pragmatic, sensitive to small changes in image quality, and are characterised by attractive simplicity and powerful discriminating properties (Månsson, 2000). Identifying small changes in image quality was deemed especially useful for the

experimental studies presented within this thesis since acquisition parameters were modified using small increments. Such small increments may allow for reduction in radiation dose for examinations without visually compromising image quality. The drawback associated with VGA is that human observers are subject to agreement inconsistency, not only when using multiple observers, but when re-testing the same observer (intra and inter variability). This is why statistics such as Intraclass Correlation Coefficient (ICC) are useful to measure and assess observer reliability. It must be noted that the subjective nature of this method also reflects that of daily clinical practice within radiology (Sandborg et al., 2015). Although such variability associated with VGA cannot be removed, there are methods that can be used to reduce them. These include having a sufficient number of observers as suggested by Burgess (2011) and Ludewig, Richter and Frame (2010), defining the image quality criteria and scale, provide observer instructions, and restricting some aspects of post processing and image manipulation (Mantiuk, Tomaszewska & Mantiuk, 2012). These factors were taken into consideration for each experimental study, however, following further research and experience within this area, together with developments within the literature (Ma et al., 2013; Mantiuk et al., 2012; Mraity, 2015), aspects of the method for each subsequent study evolved, including the image quality criteria, the type of observers used, and the statistics used to define results. These will be considered in more detail in the below sections.

3.1.2.1 ABSOLUTE VERSUS RELATIVE VGA

VGA can be applied using an absolute or relative method. For absolute VGA, experimental images are evaluated in isolation, as standalone images, using criteria and a Likert scale with wording such as 'the structure is not reproduced' or 'very well reproduced'. With a relative VGA, a comparison image is used whereby all experimental images are compared to a reference image. There are advantages and disadvantages to using a reference image, and for Paper 1 and 2, the advantages outweighed the limitations. These advantages included reducing inter-observer variation since the reference image acts as a reference point (as per its name) for the interpretation of image quality as opposed to the observer's own pre-conceived subjective impression of image quality (Månsson, 2000; Tapiovaara, 2006). In addition, relative VGA can provide much more consistent results and less decision variability in comparison to absolute VGA (Tingberg et al., 2004). However, these advantages are only evident if there is a clear justification for selecting the reference image such as an already established technique used in clinical practice. This is supported by Precht, Hansson, Outzen, Hogg, and Tingberg (2019) who suggests that the advantage of relative VGA is to optimise a technique against an already known current technique. For Paper 1, the reference image was selected based on standard current technique for AP pelvis used within local clinical practice and in accordance with the literature

(Manning-Stanley, Ward and England, 2012; Whitley et al., 2015, Williams, 2012). For Paper 2, the same reference image was used since one of the aims was to explore whether standard AP pelvis acquisition parameters were transferable to AP pelvis on trolleys. Tugwell (2014) had also demonstrated that current local acquisition parameters used for trolley imaging were those adopted from standard AP pelvis used in clinical practice. This allowed for a definitive conclusion in Paper 2, that acquisition parameters used for imaging AP pelvis on the tabletop were not directly transferable to trolley imaging.

For Paper 6, an absolute VGA was selected as no standard techniques for neonatal chest imaging was evident. This decision was reinforced by the variation in current working practice found in Paper 5. The only guidelines currently available for neonatal imaging are from the CEC (1996a) which were developed for film/screen. The ACR (2014) adapted guidelines for digital systems however they do not provide specific details on selecting optimal acquisition parameters. Instead, they provided vague statements such as *'kVp should be selected to provide adequate contrast'* without recommending specific exposure parameters or SID to achieve this. This lack of clear guidance meant that selecting a reference image would have been difficult and complex to justify for Paper 6. The use of absolute VGA also meant the study reflected more closely clinical practice since reporting practitioners evaluate images in isolation with no comparator.

3.1.2.2 IMAGE QUALITY CRITERIA

In order to perform VGA, image quality criteria are used. The criteria consists of items or statements regarding anatomical structures of different radiographic examinations and are subsequently scored on a Likert scale. By providing observers with a set of items/criteria, it reduces bias, variability and subjectivity, as it focuses their attention upon specific features within images (Dobbins, 2000; Thornbury, Fryback, Patterson & Chiavarini, 1977; Vucich, 1979). Until recently, the CEC (1996b) was responsible for the only published criteria for visual image quality assessment and therefore have been utilised in many studies including Allen et al. (2013), Davey and England (2015), Chan and Fung (2014) and Mekis et al. (2010). Nevertheless, the CEC quality criteria were developed for film/screen radiography, with many of the criteria inapplicable to digital imaging, or inversely, important aspects of image quality relating to digital imaging are not included. For Paper 1 and 2, a newly developed psychometric image quality scale for AP pelvis was used (Mraity, 2015).Owing to the scales novelty hence limited use in optimisation studies prior to conducting Paper 1, some additional criteria were added in accordance with prior work to aid clarity (Allen et al., 2013; Davey & England, 2014; Chan & Fung, 2015); see Table 1 and Table 2.

One limitation associated with a relative VGA is the potential for not using the entire Likert scale if the reference image is of higher quality to the experimental images (Lanca et al., 2014; Mohammed Ali, Hogg, Abuzaid, & England, 2019; Mraity 2015). This limitation was considered and deemed possible for Paper 2 since the reference image was acquired on the x-ray tabletop with the experimental images acquired on a trolley where additional geometry and attenuation are present. To help overcome this and to also ensure relatability to clinical practice, Paper 2 incorporated an additional, un-validated criterion to the VGA to establish whether overall image quality was sufficient for diagnostic purpose in accordance to similar studies (Davies, Manning-Stanley, Hughes & Ward, 2020; Keating & Grange, 2011; Tesselaar, Dahlström & Sandborg, 2015). This is because an image with a relatively low VGA score could still be deemed diagnostic. The addition of such criterion is also supported by Precht et al. (2019) whom highlights its benefits in adding clinical relevance to task based radiography.

As this final criterion for Paper 2 was not validated as part of the psychometric scale developed by Mraity (2015), and also used a different scale (binary as oppose to a 5-point Likert), it was analysed separately when deriving inter-observer reliability. Interestingly, the ICC for this item had a low positive agreement of 0.41 compared to the rest of the scale (ICC of 0.84). This meant that reliability was high amongst observers when evaluating the reproduction of anatomical landmarks but much lower when deciding on whether image quality was acceptable for diagnostic purpose. Similar observations were recently made within a study that used a similar criteria relating to diagnostic image quality for AP pelvis and reported a low ICC for inter-observer reliability (Davies et al., 2020). A reasonable explanation for this may be due to observers having to decide on the diagnostic quality of images without knowing the clinical indication. For AP pelvis, the indication may be traumatic or post-operative follow up; both which may require different levels of image quality (Chang & Fung, 2015; Harding et al., 2014; Uffman & Schaefer-Prokop, 2009). Clinical indication can influence observer decision making as some clinical indications require greater anatomical detail (Chan & Fung, 2015). A similar criterion was however used for Paper 6, but with the terminology altered to 'overall image quality', excluding the terms 'diagnostic purpose', and used the same Likert scale, in order to limit the problem encountered in Paper 2.

As previously discussed, defining image quality can be complex and the intention of the image should be considered since the quality of an image is dependents upon its adequacy in answering the clinical question. Following the limitations and variability encountered with the last criterion in Paper 2, it is suggested that VGA should incorporate a qualitative aspect to its method within future studies. An

open comment box following the grading of images would allow observers to elaborate on their decision making, simulating that of a radiology report in clinical practice (Kumar, 2014). A local reporting radiographer is currently conducting a Masters level project pursuing this idea. The project aims to explore radiographer's threshold when accepting or rejecting clinical images, and whether clinical indication or level of experience and role (reporting radiographer and diagnostic radiographer) influences these decisions. The project is currently at the data analysing stage.

The image quality criteria used for Paper 6 was derived using numerous previous scales (Ladia et al., 2016; Martin et al., 2013; Uffmann & Schaefer-Prokop, 2009), as well as the CEC criteria (1996a). Numerous criteria were 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). Some adjustments were made to terminology in order to reflect more closely anatomy within the phantom (Table 3). Prior to commencing the VGA task for Paper 6, observers were provided with a demonstration of the VGA software in order to familiarise themselves with the image quality scale and set up, and to also allow them to see five different experimental images with varying level of image quality (based on CNR values) (Mantiuk et al., 2012). This also helped reduce the limitations associated with absolute VGA, specifically to having pre-conceived ideas of image quality as previously discussed. The limited problems and excellent understanding of observers during the image quality task reinforced the simplicity and decision to change the wording of these criteria. Overall seven criteria were evaluated for each image. A qualitative aspect was considered for this VGA task as recommended in Paper 2, however the software available did not allow for free text responses, and the other method considered to capture such responses had issues in terms of ensuring observer anonymity. There is therefore scope for software platforms such as ViewDex (Hakansson et al., 2010) and 2AFC (Hogg & Blindell, 2012) to incorporate such function into its software. Some of these issues have recently been addressed with a current study on neonatal imaging and copper filtration having incorporated a qualitative aspect to its visual image quality evaluation (see section 8).

TABLE 1 - IMAGE QUALITY CRITERIA AND SCALE USED FOR PAPER 1

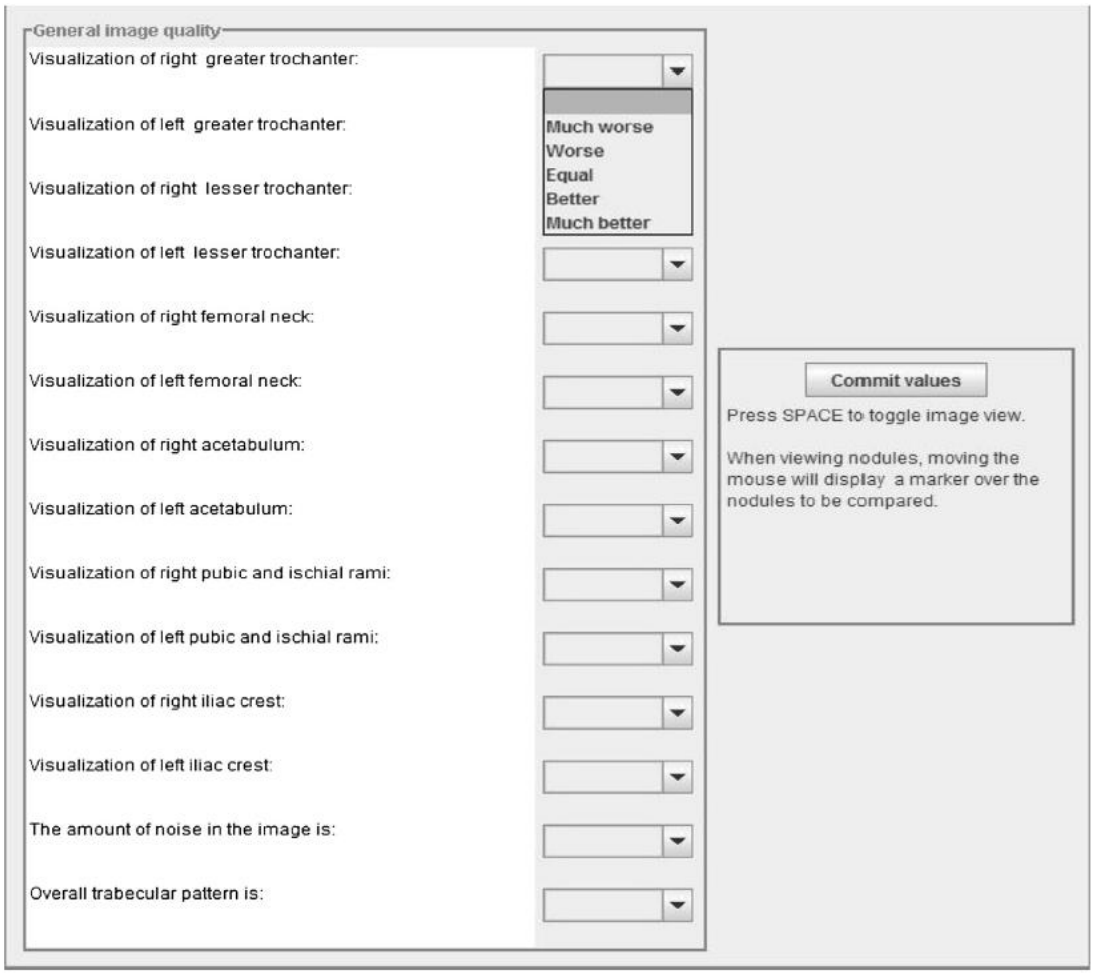


TABLE 2 - DEMONSTRATING THE CRITERIA AND SCALE USED FOR PAPER 2.

Image quality criteria for AP pelvis developed by Mraity et al. (2016).[24]

	Item
Anatomic region	1. The right lesser trochanter is visualised
	2. The right hip joint is visualised
	3. The right iliac crest is visualised
	4. The right greater trochanter is visualised
	5. The left hip joint is visualised
	6. The left lesser trochanter is visualised
	7. The left iliac crest is visualised
	8. The left greater trochanter is visualised
	9. The pubic and ischial rami are visualised
	10. The proximal femora are demonstrated
	11. The left femoral neck is visualised
	12. The right femoral neck is visualised
	13. Both acetabula are visualised clearly
	14. The body of L5 is sufficiently visualised
	15. The exposure factors are sufficient
Diagnostic accuracy	16. This image is sufficient for diagnostic purposes

TABLE 3 – CRITERIA AND SCALE USED FOR PAPER 6

Image quality criteria and rating scale used to assess chest X-ray image quality.

Chest criteria	Criteria rating scale
1. Reproduction of the lung pattern in the displayed lungs	(5) *excellent image quality* (no limitations for clinical use)
2. Reproduction of the trachea and proximal bronchi	(4) *good image quality* (minimal limitations for clinical use)
3. Reproduction of the diaphragm and costo-phrenic angles	(3) *sufficient image quality* (moderate limitations for clinical use but no considerable loss of information)
4. Reproduction of the spine through the heart shadow	(2) *restricted image quality* (relevant limitations for clinical use, clear loss of information)
5. Reproduction of the mediastinum and heart borders	(1) *poor image quality* (image must be repeated because of information loss).
6. Overall levels of noise within the image	
7. Overall Image Quality	

3.1.3 THE USE OF OBJECTIVE MEASURES TO CORRELATE WITH VGA

For Paper 1, 2 and 6, objective measures were used in conjunction with VGA as a means of validating the visual data and to explore their correlation. This was deemed important as numerous studies tend to use either objective measures (Del Rio, Satta & Fanti, 2016; Freitas et al., 2020; Jiang et al., 2015; Mori et al., 2013; Rizzi et al., 2014; Sun et al., 2012) or subjective methods (Keating & Grange 2011; Ma et al., 2013 & Reis et al., 2014), which does not allow for assessment of their correlation, but also makes studies difficult to compare and subsequently challenging when striving to implement into clinical practice. The relationship found between objective measures and VGA within the experimental studies for this thesis was variable. This is not surprising owing to the lack of consistency

between the methods used in each study e.g. CNR, SNR, absolute and relative VGA. Only visual relationship between VGA and SNR was considered for Paper 1, with no correlation statistics used. For the purpose of this thesis and to support the above statement regarding variability, retrospective analysis was conducted on the data for Paper 1, and on average a correlation of r= 0.64 was identified; this is considered moderate correlation (Rosner, 2017). The variability seen across the three experimental studies is similar to other studies that found different levels of correlation between visual image quality and SNR/CNR; from strong correlation (Alzyoud et al., 2019; Moore et al., 2013; Mraity et al., 2014) to those who reported low correlation (Al-Murshedi, et al., 2020).

This variation in correlation seen between SNR/CNR and VGA within the experimental studies for this thesis, and within the literature, could also be the result of methodological differences used within their calculations. These differences include: the equation used to derive SNR and/or CNR (Al-Murshedi et al., 2020; Freitas et al., 2020), the size, shape and location of the ROI (Alzyoud et al., 2019; Mori et al., 2013; Sun et al., 2012), the number of ROI included within calculations (Lanca et al., 2014; Mraity et al., 2014) and the interpretation of the strength of correlation (Alzyoud et al., 2019; Bloomfield et al., 2014). In addition, specifically for the experimental studies within this thesis, the modification to SID, hence magnification level within an image, may have also influenced SNR/CNR results. This has not been explored or acknowledge within prior studies and therefore requires further consideration. Attempts were made to calculate and adjust the size of the ROI for Paper 1 and 2 to ensure consistent coverage of anatomy when placing the ROI. This was achieved by calculating the % increase in magnification factor for each image and increasing ROI accordingly. This method was generated ad-hoc and not in accordance with any other method identified within the literature which may have limited its reliability and validity. It was however felt that using the same size ROI for all images would induce a level of inaccuracy to the SNR/CNR measurements since the anatomy sampled within that ROI would vary depending on the magnification level of the image. The decision to discontinue this method (vary ROI size) for Paper 6 was due to the continued lack of standardisation and uncertainty in calculating CNR within the literature and given that only two different SID were used.

It is also important to consider that when correlating SNR/CNR to visual image quality, variation in the VGA methods would also contribute to disparity when determining their correlation. Owing to the complex nature of this subject, and with continued uncertainty and variation within the literature (Al-Murshedi et al., 2020; Alzyoud et al., 2019; Freitas et al., 2020), it is an area the author will re-visit. A study is already in motion to explore the variation induced when using various different method of

calculating SNR/CNR with the aim to develop and standardise these objective measures. This should enhance our understanding to the impact that small methodological changes has on the outcomes, which in time may allow reliable comparison between future studies especially in terms of their correlation to visual image quality and how they may relate to clinical practice.

To summarise, evaluation of image quality within optimisation studies requires careful consideration and scrutiny to ensure a balance between reproducibility and the simulation of clinical practice. The methods used within each of the experimental papers evolves, being influenced by the findings and limitations from each subsequent study along with developments within the literature, to ensure a pragmatic approach to optimisation. These modifications and developments do however contribute to the significant variation problem found within methods used to measure image quality, both objectively and when using observer performance methods, making it difficult to reliably compare outcomes of similar studies. This may consequently prohibit the evidence and findings from such studies to be adopted into clinical practice. Further studies need to be conducted to explore the methods used to derive SNR and CNR, to allow for their standardisation but also to establish their correlation with visual image quality. Lastly, in order to strengthen the VGA method and its relatability to clinical practice, this work recommends either validating a criteria to assess overall image quality for diagnostic purpose or/and incorporate a qualitative aspect to the evaluation, allowing observers to elaborate on their decision making.

3.2 – MEASURING RADIATION DOSE FOR OPTIMISATION STUDIES

The methods used to evaluate image quality for the experimental studies are considered above; this next section aims to evaluate critically the methods used to calculate/estimate radiation dose for these studies.

Within optimisation studies, numerous dose quantities and calculations have been identified, all of whom strive to reflect the radiation dose and risk of the exposure to the patient. In radiology, evaluating radiation dose delivered to the patient is important for two main reasons. Firstly, it provides a means of setting and checking standards of good practice, certifying compliance with regulatory requirement. This means that documented doses can be used to compare against DRLs, identify whether a dose greater than required was delivered to the patient, and to evaluate different techniques/equipment (RCR, 2015). Secondly, radiation dose estimation can be utilised to determine and assess the associated risk to the patient from the imaging exposure (Wall et al., 2006).

In order to record and monitor this radiation received by the patient from medical imaging, and to ensure they are as low as reasonably practical, there must be a means of measuring the radiation dose. There are three interrelated measures of radiation - exposure, absorbed dose, and equivalent dose/effective dose. Within optimisation studies, effective dose seems to be the favoured approach (Allen et al., 2013; Alzyoud et al., 2019; Chan & Fung, 2015; Davey & England, 2015; Ma et al., 2013) as it takes into account the type and amount of exposed tissue and the relevant tissue weighting factors (how sensitive a particular area in the body is to radiation). It is an indicator of the risk of inducing stochastic effects (ICRP, 2007; Harrison & Lopez, 2015). Tissues within the body have different sensitivities to radiation which means a dose applied to one area of tissue within the body carries a higher risk than the same dose applied to another. This allows comparisons of the risks associated with different imaging techniques or modalities (Tootell, Szczepura & Hogg, 2014). The estimation of effective dose can be made with commercially available computer programs such as the PC based Monte Carlo (PCXMC) program (STUK, Helsinki, Finland). The utilisation of this software is supported by a vast body of literature including Allen et al., (2013), Chan and Fung (2015), Helmrot, Pettersson, Sandborg and Altén (2007) and Ma et al., (2013) which have shown that PCXMC results agree well with dose measurements and calculations with other phantom models. The application of effective dose for Papers 1, 2 and 6 was useful as it allowed comparison of the imaging techniques using a combination of parameters and provided data that allowed decision making during the referral, justification and the optimisation process. Effective dose has however come under scrutiny over the past decade, mainly due to its misuse and lack of understanding to its intended purpose (Fisher & Fahey, 2017). When using effective dose, it must be appreciated that it is applied to reference person and calculated using one set of tissue weighting factors meaning that the risk per Sv might underestimate risks for younger ages. This also is dependent upon the organs irradiated within the x-ray field (Martin, Harrison & Rehani, 2020; Tootell et al., 2014). The means by which tissues weighting factor are derived is also a cause for debate. Nevertheless, optimisation studies continue to use this quantity as it provides useful comparative data in order to guide everyday decisions about patient imaging and helps to promote best practices for radiation protection purpose (Martin et al., 2020).

The use of effective dose in Papers 1, 2 and 6 was predominately influenced by the fact that most optimisation studies use this quantity and therefore the findings from this work could be reliably compared to other studies. However, on further reflection and recent analysis, the time implications associated with deriving effective dose from PCXMC could have been spared. For the intended purpose of the studies, the use of ESD alone would have been optimal as the studies used the same phantom, the same modality for the same examination. Effective dose is most useful when comparing

different body areas with different sensitivities or when comparing different modalities e.g. chest x-ray for neonates' versus CT chest for neonates. It can therefore be argued that translating ESD to effective dose for Paper 1, 2 and 6 was time consuming with no added value for the purpose of the studies. In order to reinforce this, further analysis was recently conducted to evaluate the correlation between ESD, DAP and effective dose. Near perfect correlation was found between ESD and effective dose for the three studies, with even a strong correlation seen for DAP and effective dose (See Appendix 1). Subsequent studies such as Tugwell-Allsup et al. (2020) have therefore not used effective dose as part of the methodology as decision making in terms of finding optimal combination of acquisition parameters can be made with ESD alone.

To summarise, the understanding of different radiation dose measures in optimisation studies is important to ensure their correct use and interpretation; especially effective dose. Although the use of effective dose for the experimental studies (Paper 1, 2 & 6) within this thesis may have been unwarranted owing to comparing the same phantom and technique, it does allow comparison to other optimisation studies ensuring meaningful interpretation of findings.

4. OPTIMISING GEOMETRIC FACTORS

Whilst exploring and striving to optimise image quality and radiation dose for the six papers within this thesis, geometry was the primary focus. This included, source to image distance (SID), object to image receptor distance (OID) and magnification. Increasing SID was the initial focus (Paper 1) owing to its effectiveness in reducing radiation dose whilst maintain image quality (Brennan et al., 2004; Farrell et al., 2008; Heath et al., 2011) but also the ease to which it can be modified by radiographers within clinical practice. Paper 1 considered the effect of increasing SID on image quality and radiation dose for AP pelvic imaging, including its effect on magnification. The subsequent five papers on trolley and incubator imaging continued to explore SID and magnification but with additional geometry consideration in terms of the increased OID from the mattresses and image receptor holder.

Focal spot size is another factor that affects geometry and was initially considered but later disregarded as an independent variable to explore. For Paper 1, the experimental images were acquired with both fine and broad focal spot size (0.6mm and 1.2mm), however, during the pilot study, no visual differences were noted between these images. This was in line with previous studies who also found focal spot size's limited impact on image quality and radiation dose to the patient (Gorham & Brennan, 2010; Ma, Hogg & Norton, 2014; Mraity, England & Hogg, 2018)

The following section considers the findings and/or impact of SID, OID and magnification on the six published papers, with any contribution to knowledge critically discussed.

4.1 - SOURCE TO IMAGE DISTANCE (SID)

SID is defined as the distance between the focal spot and the image receptor (Fauber, 2016). The distance between the x-ray tube (focal spot) and image receptor affects magnification, distortion and beam intensity in accordance with the inverse square law. It is therefore important to consider all of these factors to achieve optimal SID, since increasing distance reduces image magnification and distortion but at the same time deceases beam intensity (the amount of image forming photons reaching the image receptor) (Whitley et al., 2015). Standard SIDs have traditionally been used in clinical practice adhering with the recommended ranges within the CEC (1996b). A 100cm SID is the universally accepted distance for the majority of direct x-ray table-top examinations (Brennan, et al., 2004; Carver & Carver, 2012) and has been used as baseline SID for AP pelvic imaging by authors such as Heath et al. (2011) and more recently Buissink et al. (2020). A 180cm SID is advocated for chest x-rays to reduced magnification (Carver and Carver, 2012) however this is rarely achieve during supine portable chest imaging owing to environmental constraints.

Previous studies have shown that increasing SID for various x-ray examinations can reduce patient radiation dose whilst maintaining images of diagnostic quality (Brennan et al., 2004; Heath et al, 2011; Woods & Messer, 2009). However, limited evidence existed to the impact increasing SID has on magnification, especially for AP pelvic imaging. In addition, gaps in knowledge from previous findings required further evaluation and consolidation including the use of fixed mAs as oppose to the AEC, and the potential for dose reduction at smaller SID increments. Paper 1 found that using a fixed mAs, as opposed to AEC, achieved much greater radiation dose reduction whilst maintaining images of diagnostic quality, when increasing SID from 100cm to 140cm. Previous studies (Grondin et al., 2004; Heath et al., 2011; Poletti & McLean, 2005) have predominantly utilised the AEC, or increased mAs, when increasing SID to maintain a consistent detector dose. However, a constant detector dose may not always be required for digital radiography due to its high dynamic range and post processing capabilities (Seibert, 2009). Jones, Ansell, Jerrom and Honey (2015) scrutinised studies for using methodologies that focuses on achieving consistent number of photons (signal) reaching the detector, and suggested that digital radiography has different energy response which does not require a fixed detector dose. Paper 1 was also the first study to quantify FHD to demonstrate the effect of increasing SID on image magnification (see section 3.2 for additional information). In addition, SID was modified using very small increments (5cm) to explore the potential for dose reduction even with a slight change in distance (see Table 4). Although increasing SID to reduce radiation dose was the primary focus of Paper 1, shorter distances were also explored to identify a trend in the data i.e. shorter distances results in increased ESD and effective dose. This finding of increased radiation dose at shorter distances with limited impact on image quality was the main reason for not including shorter distances within Paper 2 and 6.

An important finding across all of the optimisation studies (Papers 1, 2 and 6) was that most of the experimental conditions, at increased SID, resulted in reduced effective dose without significantly compromising image quality. This meant that an increase in SID was advocated for almost all examinations explored. For certain parameter combinations, whereby SID was increased at very low mAs, a significant reduction in image quality was evident and therefore a corresponding increase in mAs was recommended e.g. for trolley imaging and neonatal chest imaging using the tray. This increase in mAs at higher distances still results in radiation dose reduction since the x-ray beam intensity decreases with the square of the distance from the source, so the ESD decreases even with higher exposure factors (Starc & Makis, 2016). An exception to this recommended increase in SID was found for direct neonatal imaging whereby the optimal combination of parameters were evident if SID was maintained at 100cm with a lower mAs of 0.5. This is interesting and warrants further

exploration as shorter SIDs at lower mAs is rarely explored. Using the maximum achievable SID with 0.5mAs for Paper 6, significantly reduced visual image quality hence was not recommended. This might be attributed to the effects of the inverse square law as demonstrated in Table 5. For tray exposure within Paper 6, 1mAs is recommended when combined with maximum achievable SID, which seems reasonable especially since the additional attenuation from the image receptor holder is not considered within the calculations seen in Table 5. Only two SID increments were explored for Paper 6 (100cm and maximum achievable) which were informed by the findings of Paper 5. It would however be interesting for future studies to explore SID increments in-between 100cm and maximum achievable distance especially since Paper 1 found dose reduction with as little as 5cm increase in SID (see Table 4). Interestingly, these findings for Paper 6 in terms of the recommended SID for both direct and tray exposure contradicts some recommendations made by Cook, Shaw and Witwit (2015) within Clark's positioning radiographic textbook. They advocate maximum SID for direct neonatal imaging but also proposes that the image receptor holder should not be used as routine to avoid magnification and exposure increase. An exposure increase may not however be required as this would depend upon what exposure parameters are already being used within different hospitals for direct neonatal imaging. This could therefore be misinterpreted especially since it is not supported by recommended acquisition parameters. Paper 5 also found that some hospitals use 1mAs for direct neonatal imaging using DR meaning that these parameters would not require a corresponding increase when using the incubator tray.

TABLE 4 – TABLE DEMONSTRATING THE IMPACT OF SMALL SID INCREMENTS ON EFFECTIVE DOSE FROM VARIOUS DIFFERENT SCENARIOS FOR PAPER 1-2 (PAPER 6 EXCLUDED AS ONLY 2 SID USED WHICH VARIED DEPENDING UPON INCUBATOR USED)

SID(cm)	**Effective Dose (µSv)**		**Effective Dose (µSv)**			
	Paper 1 (mAs of 16)	%change	Paper 2 (standard)	Paper 2 (Bi-Flex)	Average	%change
110	0.11		0.12	0.15	0.14	
115	0.09	-13.6	n/a	n/a		
120	0.08	-27.3	0.1	0.11	0.11	-21.4
125	0.07	-36.3	n/a	n/a		
130	0.07	-36.3	0.08	0.09	0.09	-35.7

Note - data using reference acquisition parameter, with tray elevated for all trolley data
n/a = data not acquired (10cm increments)

TABLE 5 – TABLE DEMONSTRATING THE PRINCIPLES OF THE INVERSE SQUARE LAW FOR PAPER 6 SCENARIOS

Scenario	SID(cm)	Distance increased (cm)	Increase mAs required if inverse square law applied**	mAs required to achieve same exposure at image receptor as 100cm SID
Standard SID	100			
Maximum SID (direct exposure)	119*	19	0.2mAs	0.7mAs
Maximum SID (tray exposure)	128*	28	0.4mAs	0.9mAs

*Drager incubator distances

For Paper 1, 2 and 6, the maximum achievable distance was explored and used, however, this distance may vary considerably depending upon numerous factors including equipment manufacturer and design, for both the portable radiographic equipment and the trolley /incubators, plus the radiographer height. Paper 1 used SID increments of up to a 140cm, however, with trolley imaging, 130cm was the maximum achievable distance. This was likely due to the different x-ray room used but also the height of an x-ray tabletop can perhaps be lowered more than trolleys. For Paper 6, the maximum achievable SIDs were slightly different between the incubators owing to their height adjustment variability and incubator tray design. The above factors are important to consider when translating results to clinical practice especially considering the height adjustment range of newer incubators or trolleys that may allow for greater SIDs to be achieved. In addition, the maximum achievable distances within Paper 6 can only be attained if radiographers ensure that the incubator is lowered to its minimum height prior to exposure. Anecdotal evidence suggests that this might not be considered within clinical practice, and even though Paper 5 demonstrates that maximum achievable distances are already used within existing working practice for different incubators, none of the respondents specified these distances for comparison. This variation in maximum achievable SID is also highlighted by England et al. (2014) whose maximum achievable distance ranged between 135-144cm for the same equipment, with the variation attributed to radiographer height.

Using maximum achievable distance for different examinations will reduce patient radiation dose, however, it will also cause standardisation problems owing to the numerous factors that can affect this distance as discussed above. In addition, increasing SID at consistent OID reduces image magnification as seen in Paper 1 whilst an increase in OID increases image magnification. A decision must therefore be made on a departmental level whether to use maximum achievable SID to achieve lowest possible dose, or an SID that is achievable for all situations/equipment to ensure

standardisation. The former has the benefit of dose reduction, however, the latter ensures reproducible images in terms of magnification. This is especially important when imaging the same person on multiple occasions where comparison of previous images may be necessary. It must however be noted that guidelines such as those provided by the CEC (1996a) and (1996b) in terms of recommended SID may often be ranges (e.g. 100-150cm) as oppose to a single factor, which add to the difficulty in ensuring standardisation. To overcome the variation issue, following this work, local radiographers have been instructed, for both trolley and neonatal incubator imaging, to annotate on the images the SID used and whether the image receptor holder was used (see Appendix 2 for an example). This aids the observers when comparing previous images and to account for any difference in magnification. This also provides additional data when evaluating and auditing clinical practice as this was not previously available. Prior to conducting Papers 2 and 3, within local clinical practice, it was not possible to differentiate between AP pelvis conducted on a trolley to on the x-ray tabletop, and the same was true for neonatal imaging; no indication existed to distinguish between a direct and tray exposure as the name tag on the radiology system were identical. This made retrospective comparative evaluation of images quality and radiation dose impossible for these exanimations.

Increasing SID reduces patient radiation dose, however, its effect on image quality must also be considered. Previous studies (Brennan et al., 2004; England et al., 2015; Heath et al., 2011) have found that when increasing SID, images quality remains of diagnostic quality. However, these prior studies have used the AEC, resulting in an increase in mAs to achieve consistent detector dose. In addition, their method of evaluating image quality differs and thus may affect what is deemed 'diagnostic' (as already critically discussed throughout section 2). Paper 1, 2 and 6 explored the use of a fixed mAs, not only to explore the potential for further dose reduction, but also because the AEC is not feasible (e.g. metallic hip implant) or available for trolley and incubator imaging. This is an important consideration for clinical practice as selecting manual mAs, as oppose to relying on the AEC, involves further operator skill and understanding of detector response, requiring radiographers to be more aware of the relationship between mAs and SID.

Paper 1 and previous literature (Brennan et al., 2004; Grondin et al., 2004; Heath et al., 2011; Poletti & McLean, 2005; Woods & Messer, 2009) have explored increasing SID to reduce radiation dose for standard radiographic examinations. However, the additional geometry associated with trolley and incubator imaging warranted further consideration to ensure images of diagnostic quality at reduced dose. The primary purpose of a trolley and incubator is for treatment and transportation benefits of the patient, with imaging a secondary consideration. This means that some of their design features may adversely affect radiation dose, image quality and magnification. These include different

mattresses of varying thickness and material, and the image receptor holder; both which increases OID. In addition, this work found that for trolley imaging, increasing SID to compensate for the increased OID hence magnification was essential in ensuring the required anatomy was captured on the image receptor. One of the experimental conditions for trolley imaging had an OID of 25cm resulting in the greater trochanters falling outside of the image receptor boundaries if a 110cm SID was used (See Table 6 and Figure 2).

To summarise, the six papers presented within this thesis demonstrate that increasing SID reduces radiation dose for all examinations explored. Currently, there are no guidelines or literature that recommends the optimal SID for trolley and neonatal imaging (Paper 3 and 4). This may be why a significant variation exists in current working practice for these examinations as identified within Paper 5 and Tugwell (2014). Increasing SID also reduced magnification, ensuring that for AP pelvis on a trolley, all required anatomy fell within the borders of the image receptor. It was however evident that SIDs at much greater distances can reduce visual image quality which may require a corresponding increase in mAs or that shorter distances are used with lower mAs. This needs to be carefully considered clinically, as the decrease in image quality at increased SID may be sufficient for clinical purpose depending upon the clinical question and thus the level of image quality necessary. It must also be appreciated that the decrease in visual image quality seen at increased SID, especially for trolley and incubator imaging, may not be due to the increase in SID alone. Additional attenuating materials are present and therefore may have also impacted upon visual image quality (discussed in section 4).

4.2 – OID AND MAGNIFICATION

OID is the distance between the object being imaged and the image receptor. The closer the object/anatomy is to the image receptor, the less the magnification and distortion. When undertaking imaging examinations', there will always be some level of OID present for various body parts as it is impossible to have an anatomical region with zero OID. It is however possible to reduce OID by ensuring the area of interest is as close to the image receptor as possible. OID has a direct relationship with magnification; the larger the OID, the more the magnification. SID also impacts on magnification; this is why a chest x-ray is acquired at 180cm SID to allow for a more accurate cardiac-thoarcic ratio assessment.

For Paper 1, AP pelvic images were acquired on the x-ray tabletop to make use of the incorporated Bucky, AEC and oscillating gird. There will inevitably be an OID present for this imaging scenario, however, it was not considered for Paper 1. This was because the OID did not vary from standard AP pelvic imaging (the reference image) and remained consistent for all experimental images. To the

contrary, numerous factors influenced OID for both trolley and incubator imaging including the image receptor holder and the mattresses used; see Table 6. Due to limited available resources, only one trolley manufacturer was used for Paper 2, however it had two different mattresses available and an elevating platform which meant OID varied significantly even for one trolley (See Table 3.3). For Paper 6, two different incubators were used which meant variability existed between OID for direct and tray exposure as well as between the design of both manufacturers (Table 6).

TABLE 6 – TABLE DEMONSTRATING THE GEOMETRY FOR DIFFERENT IMAGING SCENARIOS FROM PAPER 2 AND 6.

Scenario	Image receptor position	SID (cm)	OID(cm)	SOD(cm)	Magnification Factor (SID/SOD)	%Magnification
Reference x-ray tabletop	Bucky	110	11.5	98.5	1.12	112%
Trolley, standard mattress, platform elevated	Tray /Platform	110	12.5	97.5	1.13	113%
Trolley, standard mattress, platform down	Tray /Platform	110	18.5	91.5	1.20	120%
Trolley, Bi-Flex mattress, platform elevated	Tray /Platform	110	19	91	1.21	121%
Trolley, Bi-Flex mattress, platform down	Tray /Platform	110	25	85	1.29	129%
Drager incubator	Direct	100	0*	100	1.00	100%
Drager incubator	Direct	119	0*	119	1.00	100%
Drager incubator	Tray	100	7	93	1.08	112%
Drager incubator	Tray	128	7	121	1.06	110%
GE incubator	Direct	100	0*	100	1.00	100%
GE incubator	Direct	117	0*	117	1.00	100%
GE incubator	Tray	100	6	94	1.06	110%
GE incubator	Tray	125	6	119	1.05	108%

*OID is considered 0cm for direct neonatal imaging

(Note that for the above calculations, magnification may be underestimated owing to OID being calculated from the posterior surface of the phantom hence SOD denoting source to posterior object distance).

As seen from Table 6, considerable OID exists for the various scenarios when imaging on a trolley. Theoretically, this increase in OID adversely affects geometric unsharpness and distortion (Whitley et al., 2015) however Paper 2 found a contradictory finding. From 48 experimental images acquired on the trolley, three had equal or higher visual image quality scores to the reference image (standard x-ray tabletop). These three images were acquired using the Bi-Flex mattress, platform lowered and an SID of a 110cm; conditions resulting in the largest possible OID hence image magnification. This raises the question of whether magnification influenced the visual image quality scores, as the VGA criteria evaluates how well structures are visualised. Manning , Ethell and Donovan (2004) suggests that visual image quality is influenced by more than just the sharpness of anatomical outlines and image noise, but also by the size and complexity of structures. The visibility of an object is proportional to its area, with contrast, noise, object size and shape all affecting our ability to extract visual information from an image (Vladimirov, 2010). No statistical difference was identified for CNR when comparing the mattresses and platform position which also suggests that observers may be influenced by more than contrast and noise. The use of the air gap to improve image quality was also considered as an explanation for this finding, however, air gap is used instead of a grid to reduce the amount of scatter (noise) reaching the image receptor, which would have also been reflected within the CNR results.

4.2.1 OID AND QUANTIFYING MAGNIFICATION

Both SID and OID affect magnification, however, previous literature on AP pelvis and SID (Farrell et al., 2008; Grondin et al., 2004; Heath et al., 2011; Poletti & McLean, 2005) have not quantified this impact. For Paper 1 and 2, magnification was calculated by measuring FHD of the acquired images. This provided numerical data in order to validate assumptions made within previous studies regarding magnification (Brennan et al., 2004; Heath et al., 2011; Poletti & McLean, 2005). For Paper 1, where only SID varied, FHD decreased by an average of 2mm per 10cm SID increment, which means if you increase the distance from 110cm to 140cm, the FHD decreases on average by 6mm. Minimal variation in FHD (0.2mm) was found between AP pelvis acquired on the x-ray tabletop and the trolley when using the standard mattress and an elevated platform at a 110cm SID. It must however be noted that the mattress used on the x-ray tabletop for Paper 2 was 5cm in thickness and may be thicker and of different density to a typical mattresses used on radiology tabletops, with some departments not using mattresses on x-ray tabletops (Alresheedi, 2020; Angmorterh et al., 2019; Everton et al., 2014a). Paper 2 did however find that when using a 110cm SID in combination with the Bi-Flex mattress and platform not elevated (which often occurs according to the survey by Tugwell, 2014), FHD increases by 10.8mm from standard tabletop AP pelvic imaging. This imaging scenario on the trolley also resulted in the greater trochanters of a simulated 70kg male phantom, not being included within the boundaries of

the image receptor as discussed above; Figure 2. It can be assumed that this problem would be exacerbated within clinical practice for patients of varying sizes, especially female patient with larger buttocks (Williams, 2012). This work therefore advocates an increase in SID for trolley imaging to not only reduce patient radiation dose but to compensate for the increased OID, ensuring anatomy coverage resulting from the increased magnification.

The above variation in FHD when increasing SID (reduces magnification) or when a large OID is present (increases magnification) is important when interpreting AP pelvis images, as orthopaedic surgeons often use them to plan surgical intervention. They rely on measurements made on radiographic images to aid in selecting the appropriate implant (Charity, Day, Vasukutty, Ramesh & Kumar, 2008; Pachter, Garfinkel, Romness, & Gladnick, 2019). Selecting the correct size implant is essential for a successful surgery as under or over estimation can cause significant clinical issues including, risk of dislocations, loading and acetabular erosion. This is why local clinical practice uses a calibration ball for pre-surgical AP pelvic imaging, however, following the findings from Paper 2, the importance of the calibration ball and its correct use has been further emphasised, with its increase utilisation for other AP pelvis clinical indications (see Appendix 3). To evaluate this further, an undergraduate project was conducted on the use of the calibration ball for AP pelvis and how its incorrect use can impact magnification and measurement estimations (Jones, 2018).

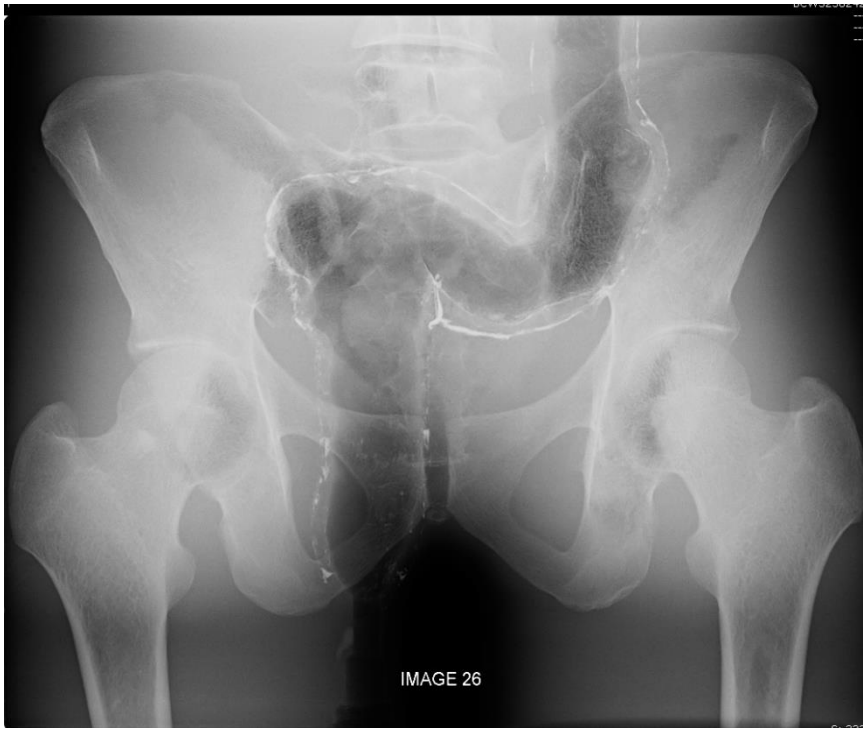


FIGURE 2 - IMAGE ACQUIRED USING BI-FLEX MATTRESS, 110CM SID, 16MAS AND PLATFORM NOT ELEVATED (MAXIMUM MAGNIFICATION)

The above demonstrates that measuring FHD was an important addition to Paper 1 and 2, as the results were more clinically relevant and highlighted areas for consideration beyond radiation dose and image quality. Nevertheless, magnification was not measured for neonatal incubator imaging for various reasons. During the pilot study, heart to lung size/ratio was explored as a method to determine magnification, however, it became apparent that this ratio remained consistent, regardless of magnification. In addition, for trolley imaging, the recommendations associated with image annotations to ensuring transparency for the potential variation in image magnification was deemed transferable to neonatal imaging without requiring specific calculations (see Appendix 2). However, for the purpose of this thesis, magnification factor was later calculated for the different imaging conditions seen in Paper 6, to demonstrate the potential variation (Table 6.).

In summary, the work presented within this thesis shows that OID and magnification requires consideration when imaging patients, especially if there is additional OID such as that seen for trolley and incubator imaging. These consideration include the possible variability between image magnification, and the need to increase SID not only to reduce radiation dose but to compensate for the OID to ensure coverage of anatomy. When there is an increase in OID or a modification to SID, image magnification is affected which may also influence visual interpretation, especially when comparing images of the same patient. From the work, it is recommended that the SID used to acquire the image, and whether the tray/platform is used, is annotated onto the image, or use a calibration device; these may aid with interpretation Further work is however required to explore how differences in image magnification could impact image interpretation especially since larger OID for trolley imaging resulted in increased VGA scores. In addition, the acquisition parameter used for standard AP pelvis on an x-ray tabletop is not transferable to trolley imaging due numerous reasons including additional geometry. The same is evident for the work on neonatal chest imaging, with acquisition parameters used for a direct exposure requiring modification when using the tray. The large OID found for both trolley and incubator imaging (from using the tray/platform) results in a reduced SOD (if a standard SID is used), resulting in greater patient radiation dose. Lastly, the works within this thesis demonstrates how geometry can influence, both image quality and radiation dose, with as little as a few millimetre change in SID and OID.

5. THE IMPACT OF ATTENUATION ON IMAGE QUALITY AND RADIATION DOSE

Attenuation is the reduction in beam intensity from absorption and scatter. This affects the number of photons reaching the detector which impacts on image quality. An absorbing material between the patient and the detector reduces the image forming radiation and therefore reduces CNR; and to compensate for this, the tube output may need to be increased (Everton et al., 2014b; Hess & Neitzel, 2012; Jiang et al., 2015; Mutch & Wentworth, 2007). As discussed in section 3.1, this assumption for the required increase in radiation dose may not be as relevant for digital imaging systems due to it high dynamic range, different energy response and post processing capabilities (Seibert, 2009; Jones et al., 2015). The patient also acts as an attenuator, and so does the x-ray tube (inherent filtration), with additional filters to remove low energy x-ray photons. These low energy photons would otherwise not contribute to image quality but would add to patient dose, as they would be absorbed or scattered prior to reaching the image receptor (Martin, 2007).

For the studies presented within this thesis, attenuation was a secondary consideration to geometry. The experimental studies (Paper 1, 2, 6) were conducted to simulate clinical practice and therefore the effect of attenuation and geometric factors were collectively explored, in combination with other acquisition parameters, by evaluating their overall impact on radiation dose and image quality. To the author's knowledge, no previous optimisation studies had been conducted for trolley imaging and therefore to help inform Paper 2, a small pilot study exploring mattress attenuation was attempted. It was deemed unnecessary to replicate this pilot study for Paper 6 as attempts to establish attenuation properties for incubator components was already evident (Mucht & Wentworth 2007; Rizzi et al., 2014).

The following section considers the impact of attenuation on the six studies presented within this thesis, critically evaluates the methods and approaches used, whilst providing recommendations for further evaluation.

5.1 - ATTENUATION AND TROLLEY IMAGING

Attenuation became a consideration when designing and planning for Papers 2 and 3, as it was evident that the trolley components, such as the mattresses, were not designed with imaging as the primary consideration. Two different mattresses of varying thicknesses were evaluated in Paper 2 on a commercially available trolley. Limited information was found within manufacturer specification brochures and from the initial correspondences with manufacturers when asked about the density of

the foam used within their mattresses. This may reflect on the limited consideration to radiology when designing such equipment or the corporate intellectual property considerations from disclosing such information. A pilot study was therefore conducted to explore the attenuation of these mattresses to be used. This was achieved by placing the image receptor with an ionising chamber at its surface under the trolley with an elevated platform. Three repeated exposures were made (and averaged) for four different scenarios: no mattress, standard trolley mattress (65mm), Bi-Flex mattress (130mm) and the x-ray tabletop mattress (50mm) used to acquire the reference image (See Figure 3). It is acknowledged that the standard x-ray tabletop mattress would not normally be placed on the trolley, but for consistency of comparison, this was deemed reliable for determining the difference in attenuation properties of the three mattresses used in Paper 2. Similar image receptor dose was found between the standard trolley mattress and the x-ray tabletop mattress, however, it must be noted that various different mattresses are used within x-ray rooms with varying thickness and construction (Alresheedi, 2020) but also some imaging department do not use mattresses on tabletops (Angmorterh et al., 2019; Everton et al., 2014a). This means that the lack of difference found between these two mattresses may not reflect the consensus within clinical departments especially when considering the image receptor dose from having no mattress (see Figure 3). The Bi-flex mattress further reduced image receptor dose by 13%.

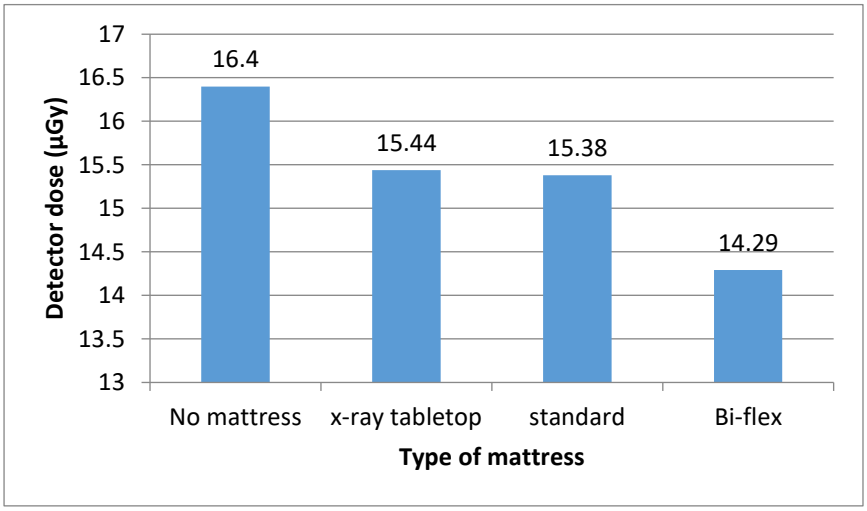


FIGURE 3 – FIGURE DEMONSTRATING THE DETECTOR DOSE FOR NO MATTRESS AND THREE DIFFERENT MATTRESSES.

The reduction in detector dose found between the trolley mattresses in the pilot study was not evident within the main experimental study (Paper 2). No significant difference was found in VGA or CNR between the trolley mattresses using a fixed mAs (no AEC available on the trolley to compensate for reduction of photons at image receptor). From Figure 3, the 13% reduction in detector dose seen with the Bi-Flex mattress (13%), in reality, accounts for 2.1microGy and may explain the limited

significance. However, there was a significant difference between the reference image (with the 50mm mattress) and the overall trolley images using the same acquisition parameters for visual image quality and CNR. It could therefore be assumed that the main cause for attenuation for trolley imaging comes from the tabletop material/thickness combined with the increased OID present as opposed to the mattresses. Knowing the thickness and density of the trolley tabletop (if manufacturers had been able to disclose this information) may have therefore been a useful addition to the study with the author recognising this as a limitation. Similar findings were seen within Mutch and Wentworth's (2007) study on neonatal incubators whereby the greatest reduction in image receptor dose came from the support tray and canopy as opposed to the mattresses. This will be further considered below. One limitation to the trolley pilot study was that the ionising chamber was not placed on the surface of the trolley top as an additional measure. This would have consolidated the assumption that the trolley top and additional OID was the main source of reduction in photons reaching the image receptor.

Further communication with the trolley manufacturer following publication led to the sharing of mattress specification, specifically density. From these specification, it was evident that the 65mm difference seen between the thickness of the Bi-Flex mattress and standard mattress was constructed from foam with lower density. This means the 65mm standard mattress is made of 65kg/m^3 foam whereas the Bi-Flex mattress is made of two different density foam of 65kg/m^3 and 30-35kg/m^3. Although the proportion of the low to high density foam was not disclosed by the manufactures, this additional information regarding mattress material reinforces why there may not have been a significant difference found between both trolley mattresses within Paper 6. ArjoHuntleigh Healthcare UK state within their brochures that their mattresses have been tested for x-ray translucency, however, this statement is not supported by empirical evidence, with no additional or similar information regarding the trolley tabletop (Lifeguard trolley range, ArjoHuntleigh, UK). On reflection, it was evident from the results of the pilot study that the Bi-Flex mattress was constructed differently. If it was made entirely of 65kg/m^3 (the same as the standard mattress), this would have resulted in half the image receptor dose. This work therefore reinforces anecdotal evidence and findings from Mutch and Wentworth (2007), that the thickness of an additional attenuating component is not correlated to the amount of attenuation present; it is the density of the material that is the main influencer.

Although such findings may be considered obvious, it is still important to validate such outcomes with empirical evidence in order to provide radiographers with information to inform decision making. This is reinforced when considering findings from Tugwell (2014) and Paper 4 where some

radiographers/hospitals increase exposure factors for scenarios with additional attenuating components without prior knowledge to their density and potential impact on image quality and radiation dose. Such information may however not mean much to radiographers, but if they knew the density and material(s) of a standard radiographic mattress and an x-ray tabletop – this could be used as baseline information to help put this type of information into context (this is further discussed below).

From this work on trolley imaging, the finding of no difference between the standard and Bi-Flex mattress for image quality and radiation dose also raises the question whether the Bi-Flex mattress should become the customary mattress with the Lifeguard 50 trolley. The Bi-Flex mattress reduces the likelihood of pressure ulcer development, but with no significant impact on visual image quality and radiation dose. Pressure ulcers are more problematic in elderly patients who have suspected neck of femur fractures because they are more susceptible to these sores (Haleem, Heinert & Parker, 2008). Due to this complication, patients are usually transferred onto a thick pressure relieving mattress, such as the Bi-Flex mattress, on admission, and remain on them for potentially long periods of time including for their imaging (Vickery, 2001).

5.2 - ATTENUATION AND NEONATAL INCUBATOR IMAGING

Attenuation continued to be a focus for the neonatal work conducted, for the same rationale as trolley imaging; they are equipment designed with imaging not the primary consideration. Attenuation was not individually evaluated for each incubator component, as this had already been done within the literature (Jiang et al., 2015; Mutch & Wentworth, 2007; Rattan & Cohen, 2013; Rizzi et al., 2014), but also, the work aimed to simulate clinical practice by exploring numerous interlinked variables collectively.

From Paper 6, when comparing direct verses tray exposure for both incubators, there was a statistically significant difference in visual image quality, CNR and radiation dose; with image quality decreasing and radiation dose increasing for tray exposures. This demonstrates that the additional mattress, tray support and OID, all adversely impact image quality and radiation dose. Unfortunately, as each component was not individually evaluated, to what extend and the ratio to which each component influenced image quality and radiation dose could not be established. However, this information had already been established by Mutch and Wentworth (2007) who used the same incubators than those used in Paper 6. The aim of Paper 6 was to ensure a method that was more clinically applicable especially when considering the limitations associated with Mutch and Wentworth's (2007) study. For example, the use of a Leeds Test Object to evaluate image quality can be beneficial in situations such as for routine quality control to quantify the degree of threshold

contrast in each image, it behaves differently to the contrast of clinically relevant details with changing acquisition parameters (Kupinski, 2012). Mutch and Wentworth (2007) also used one of themselves as authors to observer and assess image quality which could introduce bias. Image receptor dose was also the only radiation dose measurement within the study, which gives limited information regarding the risk associated with each exposure condition explored. Lastly, attenuation was the main focus of Mutch and Wentworth's (2007) study and therefore the required modification in acquisition parameters to overcome the additional attenuation was not considered.

As identified from Paper 4, none of the previous studies on incubator imaging (Jiang et al., 2015; Rattan & Cohen, 2013; Rizzi et al., 2014) quantified or disclosed the density of each incubator components to account for such wide variation in the reported percentage reduction in detector dose (12-72%). Manufacturers may not release the exact details of their components owing to intellectual property. Although mattress thickness was identical for both incubators within Paper 6, the material and density of the foam used was not established. When searching for this information, it was found that mattresses used for neonates are specifically designed to reduce the pressure on their skin (Drager, UK), which again indicates that their radiolucency may be a secondary consideration, if considered at all. In retrospect, the authors should have made additional efforts to contact manufacturers directly to enquire about the mattress and the other component's density and materials to correlate with study findings.

One finding in terms of attenuation from Paper 6 was that images acquired using the Drager incubator had an overall lower image quality (both VGA and CNR) compared to GE but with also a reduction in effective dose too. There are numerous factors that would explain this finding including the material and construction of the additional attenuating materials from each manufacturer and the fact that a greater maximum achievable distance could be achieved for Drager incubators. In addition, it was noticed that for a direct exposure at 100 cm SID, DAP for both incubators were identical and yet ESD at the surface of phantom was not. For direct exposure using 100cm SID, 60kV and 0.5mAs; DAP was 0.21cGycm^2 for both incubators but ESD was 14µGy for Drager and 18.1µGy for GE. This means that the incubator canopy for Drager attenuates more of the x-ray beam than GE. The only specification found for the Drager canopy was not related to density but only to its material in terms of being scratch resistant and designed with angles rounded to remove visual distortions. Such finding could be predicted if prior knowledge to the density and thickness of the components were available (which they were not). This is important as manufacturers should ensure that such specification is transparent to radiology in order to help inform decision making.

5.3 - ADDITIONAL INFORMATION SOUGHT ON ATTENUATION

To enhance understanding of the findings relating to attenuation from the trolley and neonatal work, further information was recently sought from manufacturers. Both Drager and GE provided limited and non-specific information to the material density of the different components of their incubators. GE did however provide some density quantities for the incubator mattress using pound per cubic meters and pounds per cubic foot, which are different metrics to those provided to ArjoHuntleigh (kg/m3). Having recently compiled the various materials used within both the trolley and incubator components, such as, carbon fiber, polycarbonate and polyurethane foam; it is evident that the highest density materials are used for the tabletop support, then the canopy, and lastly the mattresses. This type of information could be very valuable for radiology to allow enhanced understanding of where the greatest attenuation may originate from, and to inform decision making if options such as opening the incubator canopy and using a direct exposure instead of the tray does is available and does not comprise the neonate's safety.

Currently there remains a gap between manufacturing companies and radiology evaluation, especially in terms of ensuring the equipment is evaluated using methods that are transferable to clinical practice. It must however be remembered that the aim of the experimental studies within this thesis was not to explore the attenuation properties of individual trolley and incubator components, but to evaluate their effect on image quality and radiation dose when combined with other factors such as acquisition parameters, to provide recommendation for clinical practice. However, what this work does demonstrate is the lack of transparent information denoting the density and attenuation properties of equipment components such as for trolleys and incubators. This highlights the need for further work and collaboration between radiology and manufacturers when developing and evaluation such equipment. Development of a standardised density rating scale for radiology in terms of optimal density (kg/m^3) for various materials used within imaging equipment and non-imaging equipment such as trolleys and incubators would be beneficial. A table of the amount of transmission per thickness for various material would help staff understand attenuation better as currently, these quantity and metrics (kg/m^3) may mean nothing to clinical staff. This is reinforced by the fact that no published methods for testing x-ray mattress radiation attenuation properties exists, with Alresheedi, Walton, Tootell, Webb and Hogg (2021) aiming to develop such method within a recent study.

To summarise, this work shows the potential impact of additional attenuating components in radiology, especially for examinations that use equipment that are not designed with imaging as their primary focus. It is however important to consider attenuation in conjunction with other factors, as their impact on image quality and radiation dose, as seen within the six papers presented, will be dependent on multiple other factors such as geometry and exposure factors. In addition, the work

demonstrates that a reduction in image receptor dose may be evident when additional or different attenuating components are present, however these may not result in a significant decrease in visual image quality as found for trolley imaging. Radiology must be critical when manufacturers promote their products as “radiolucent” or “suitable for imaging” as little independent evaluation seems to exist to support these statements. Radiology should also be involved in the development and evaluation of equipment, such as trolleys and incubators, to assess their impact on image quality and radiation dose prior to procurement. The density of the materials used within equipment components is also an important consideration for radiology and manufactures should ensure that this information is easily accessible.

During recent manufacturer correspondences, it also became evident that further studies are necessary to evaluate the attenuation properties of more recently developed mattresses for neonatal incubators such as those that have gel or are electrically heated. Gel is of higher density to foam and anecdotal evidence suggests that copper wiring within newer heated mattresses may also be visible on images, especially when using DDR image receptor with high detective quantum efficiency (DQE). With spatial resolution and DQE increasing with new DR technology, it would also be advocated that further evaluation is conducted on trolley imaging using DR technology as oppose to CR technology used within Paper 2.

Lastly, this work (papers 1-6) has led to further local evaluation of the attenuation properties of other ancillary equipment. Blizzard manufacturer approached radiology to evaluate two newly developed warming blankets. They wanted to explore their potential impact on image quality and radiation dose as patients may present to x-ray or CT with these blankets. This demonstrates the in-direct impact of the presented studies in terms of highlighting the importance for manufacturers to collaborate with radiology and ensure their products are fit for purpose from and imaging perspective.

6. INTELLECTUAL OWNERSHIP AND CONTRIBUTION

The intellectual ownership, type, and percentage contribution of all co-authors for each paper (1-6) within this thesis are displayed in Table 7. The method used is based on a subset of categories for authorship, as recommended by the International Committee of Medical Journal Editors (ICMJE, n.d.). Correspondence emails confirming the agreed contribution to each study are demonstrated in Appendix 5.

The type of contribution is summarised as:

a. Concept and Design

b. Searching/Reviewing Literature

c. Data Collection

d. Data Analysis

e. Drafting and Revision

f. Final Approval

TABLE 7 – AUTHOR AND CO-AUTHOR'S CONTRIBUTION

Authors	Papers / Contribution (%) and Type					
	1	2	3	4	5	6
Jenna Tugwell-Allsup	50; a,b,d,e,f	80; a,b,c,d,e,f	80; a,b,c,d,e,f	85; a,b,c,d,e,f	80; a,b,c,d,e,f	75; a,b,c,d,e,f
Andrew England		5; e	5; e	15; e	20; e	5; e
Rhys Wyn Morris						10; c
Richard Hibbs						10; d
Peter Hogg	50* ; a,e	15; a,e	10; e			
Jeffrey Lang			5; e			

* PH taking overall responsibility of contribution of other co-authors from OPTIMAX 2013

7. PATHWAY TO IMPACT

When conducting research, the ultimate goal is for the study to have impact. Impact consideration is important as it helps to focus on the overall purpose of the work rather than the research process alone. Impact can be described as the '*effect that something has'*, whether this be contribution and improvements to education, society, the economy, the environment and/or technology (University of Salford, 2019). In health care research, this effect can be wide ranging, and should be considered in the context of the short, medium, and long-term influence of the research (Cruz Rivera, Kyte, Aiyegbusi, Keeley, & Calvert, 2017). There are various ways to measure research impact: citations, policy changes, number of reads, and presence on social media. These are measurable, however, research can be used in many ways, for example, to change aspects of practice or behaviour, or to indirectly influence attitudes that may later affect decision making. It is therefore often very difficult to demonstrate a causal link between research and subsequent decision-making in the policy or service arenas, even where that link exists. The anticipated pathway to impact of this work will be considered within this next section under four sub-heading, in accordance with a framework set out by Buykx et al. (2012):

1. Research-related Impact: *'Advancing knowledge'*
2. Policy impact: *'Informing decision making'*
3. Service impact: *'Improving health and health systems'*
4. Societal impact: *'Creating broad social and economic benefit'*

7.1 - RESEARCH-RELATED IMPACT: *'ADVANCING KNOWLEDGE'*

Capacity building, training and leadership are important areas that can demonstrate impact of the work. Although difficult to measure, educational impact is one indictor (Bornmann, 2016). The University of Salford's PhD thesis repository was manually searched using relevant key words such as 'optimisation' to help capture any citations that would demonstrate educational influence (See Table 8). A number of PhD theses were found, for example, Alzyoud's (2019) thesis aimed to establish a protocol to optimise erect AP pelvis, which cited papers 1 and 2 on numerous occasions to justify methodological decisions e.g. the use of Image J to establish SNR, the use of VGA for AP pelvis and PCXMC for deriving effective dose. In addition, the findings from papers 1 and 2 with regards to dose reduction with increasing SID for AP pelvis was also cited to consolidate findings. Mraity (2015) also

cited Paper 1 on numerous occasions to demonstrate idea development surrounding AP pelvis optimisation with Alresheedi (2020) citing Paper 2 several times to justify idea development surrounding mattresses and pressure ulcers, to highlight the potential radiation dose variability from different mattress attenuation and for justifying the modification of acquisition parameters.

7.1.1 CITATION ANALYSIS

Within academia, citation analysis is used as a performance indictor to reflect the impact of the research and/or its quality (Aksnes, Langfeldt, & Wouters, 2019). Citation analysis can identify studies that have been conducted following publication to recognise the influence and progression of the work within the same or similar research areas. The number of citations (searched 18/02/2020) for the six papers presented within this thesis can be found in Table 8. From this table, Enevoldsen and Kusk (2020) cited Papers 2, 3 and 4, in a single article conducted in Denmark. This demonstrates the scope of the impact, not just locally and nationally, but internationally too. They explored additional geometry and attenuation using an image receptor holder on the intensive care unit; this demonstrates the themes within this thesis transposed into a different radiographic situation. Papers 2 and 3 were used to strengthen the background and rationale for conducting this study whereas Paper 4 was used to reinforce some of the study's findings in relation to the impact from attenuation on image quality and radiation dose.

The neonatal studies (Papers 4, 5, and 6) are yet to gain many citations, perhaps owing to their limited time within the academic domain. Nevertheless, Omojola, Akpochafor, Adeneye, Akala, and Agboje (2021) recently cited Paper 5 to demonstrate the international variation in acquisition parameters present within neonatal protocols and subsequently uses this to reinforce the requirement for optimisation and standardisation of neonatal chest imaging in Nigeria.

The limitations associated with citation analysis also needs consideration when reflecting upon the impact of the six papers (Nightingale & Marshall, 2012). Research output and citation activity from the radiography profession has previously been low and remains so in comparison to other health disciplines; this may influence the number of citations (Nightingale, 2016). This can be further compromised if articles are published within niche areas (such as optimising radiation dose and image quality) or are not published by recognised expert individuals within the field (Seglen, 1997). This is why other metrics are becoming increasingly utilised to reflect academic impact such as those from social networking platforms e.g. Twitter and ResearchGate (Table 8).

TABLE 8 – TABLE WITH ACADEMIC IMPACT METRICS

Paper	**1**	**2**	**3**	**4**	**5**	**6**
Year of publication	2014	2017	2017	2020	2020	2020
Journal Impact Factor (present)	0.96	0.96	0.39	0.96	0.96	0.96
(at time of publication)	1.11	1.12	0.15	0.96	0.96	0.96
Total citations	30	2	2	4	3	1
Journal Published citations	18	3	2	4	2	1
Self-citations	4	1	1	1	2	1
Scopus - Field-Weighted Citation Impact[1]	1.25	0.38	1.33	1.61	1.31	0.65
Mendeley Reads	65	36	7	12	18	8
Research Gate Reads	1,057	216	259	51	44	55
Twitter mentions	62	3	0	14	3	4
PhD Thesis Citations (UoS)*	3	2	0	0	0	0

*University of Salford's PhD thesis repository were searched manually

(Note that citation analysis was conducted 25/02/2021)

7.2 - PATHWAY TO POLICY IMPACT: 'INFORMING DECISION MAKING'

This section *'informing decision making* 'is often linked to service impact (next section 6.3). Policy impact however reflects more closely on areas where there is Stakeholder involvement, where the work has contributed to decision making, or where it has resulted in active participation in policy networks. Such impact was evident when considering the works' involvement and influence on equipment procurement. In 2019, the author was invited by the local emergency department to evaluate five new and different trolleys to ensure fit for purpose from an imaging perspective. This led to a robust and rigorous evaluation of trolleys in terms of image quality, radiation dose and physical qualities such as manoeuvrability (informed by some methods within the papers) (see Appendix 6). This allowed collaboration with not only the imaging department but trolley manufacturers too.

On the pathway to impact, it is anticipated that the same input will be provided from radiology when the neonatal unit is purchasing new incubators. Meetings have already commenced with members of the GE and Drager technical team, with both manufacturers keen for clinical radiology staff to be involved in future evaluation of newly designed incubators. GE have requested input to help update their imaging manual for recommended acquisition parameters when using the GE Giraffe incubator and Drager have published new training material for their incubators, citing and using the neonatal work (Paper 6) as evidence (See appendix 7). This successful initial collaboration with incubator manufacturers has also led to further engagement with NHS England Supply Chain. The author has commenced work to develop a radiology specification criteria for incubators to ensure competing manufacturers consider imaging requirements as part of the upcoming tendering process in 2021. The early stages of development will see the criteria having two aspects: compulsory (minimum specifications) and desirable imaging features. Previously, imaging was not mentioned within incubator's specification framework for tendering. This newly developed criteria will help prompt radiology involvement when evaluating incubators before they are purchased into clinical practice.

7.3 – PATHWAY TO SERVICE IMPACT: 'IMPROVING HEALTH AND HEALTH SYSTEMS'

Influence and change occurring directly from the studies in terms of service impact is ongoing and is the long-term goal. Following each study publication, local dissemination by the author occurred through CPD presentations with some incorporated in-house training. Numerous recommendations from the six studies were made during these sessions, leading to further collaboration and multidisciplinary audit and studies, especially with orthopaedics, surrounding the use of the calibration ball to denote the magnification factor for AP pelvis. Service evaluation is planned to assess the changes recommended from this work within clinical practice to establish whether there is improvement and service impact. However, problems have been encountered with attitude and adherence to change when striving to implement these findings. This is not uncommon with Buykx et al. (2012) suggesting that the process of translating new knowledge into action is complex, variable, and often slow. A gap between theory and practice still exists in healthcare based research too (Munn, McArthur, Mander, Steffensen, & Jordan, 2020; Murphy, Gibson, Moseley, & Rio, 2021). The author aims to develop an implementation strategy for clinical departments to allow recommendations from optimisation studies to be adopted into practice. This may be achieved using audit tools, PDSA cycles or longitudinal prospective studies, where change is monitored over a certain period and consequently reviewed. Jones et al. (2015) acknowledge that following an optimisation experiments, verification using clinical images of real patients may be necessary to ease transition and changes in practice. This approach would allow recommendations to be evaluated on a variety of

different patients (shape and size) to ensure they translate and correlate with the phantom based studies.

7.4 - SOCIETAL IMPACT: 'CREATING BROAD SOCIAL AND ECONOMIC BENEFIT'

For health care related research, it is important to consider the social impact of the work in terms of attitudes, behaviours and overall contribution to health knowledge. This again can be difficult to measure and not be apparent in the short-term period following publication. The initial sharing and attention on social media does however demonstrates distribution of information, allowing for potential collaboration and wider social dissemination (See table 6.1). As Paper 1 has been within the public domain for 7 years, it has consequently resulted in the highest number of social media shares and likes including 62 Twitter mentions. The societal impact from this study is also broad owing to its conduction within a European Summer School in 2013. This has allowed greater international collaboration, with numerous experts associated with the study and thus attracting greater attention. The pathway and potential influence and change from the work is also evident when considering that the research proposals for Papers 4, 5, and 6, resulted in the first author being awarded a Bevan Fellow with the Bevan Commission to ensure a national platform to disseminate the work further.

8. SUMMARY OF OVERALL CONTRIBUTION TO KNOWLEDGE

This thesis provides a critical review and a coherent narrative of the contribution made from six interconnected papers to fulfil the requirement of a PhD by Published Works. The papers along with the accompanying narrative has demonstrated developments in optimising image quality and radiation dose for examinations focussing on geometry and attenuation. From Paper 1 that explored increasing SID for AP pelvic imaging, to transposing this idea to AP pelvis on a trolley, an area with no previously published optimisation attempts. Papers 2 and 3 were the first studies to consider the impact of trolley design and OID on image quality and radiation dose. They provide the first recommendations and considerations for clinical practice whilst establishing a basis for further work. Papers 4, 5 and 6 subsequent continued with geometry and attenuation as themes but for neonatal chest imaging to both standardise and optimise this imaging examination. The overall impact of the six studies is evident from the number of citations and reads of each published paper (Table 8), to their clinical impact in terms of training opportunities, implementation, influence on procurement, and manufacturer collaboration. A summary of the main findings and recommendations from the six papers are as follows:

- Modifying SID and OID can impact image quality, radiation dose and magnification when imaging AP pelvis on the x-ray tabletop or trolley, and for neonatal chest imaging. This impact may not always require modification in technique or acquisition parameters, but only that it is understood and recognised within clinical practice.
- Increasing SID for AP pelvic imaging (whether on an x-ray table-top or on a trolley), will reduce patient radiation dose whilst maintaining images of diagnostic quality. A subsequent increase in mAs may be required (16mAs to 20mAs) when using the image receptor holder, to ensure diagnostic image quality.
- Increasing SID for neonatal chest imaging when using the image receptor holder is also advocated. A subsequent increase in mAs may however be required from 0.5mAs (when using a direct exposure) to 1mAs, to ensure diagnostic image quality. This recommended increase from 0.5mAs to 1mAs for neonatal chest imaging may still reduce neonatal radiation dose for numerous imaging departments when considering the exposure parameters already in use (Paper 5).

- Magnification within radiographic images varies when additional geometry are present such as an increase in SID or/and an increase in OID. It is therefore recommended that either a

standard SID is used to ensure consistent magnification factor but at greater radiation dose or, if using maximum achievable SID at lower radiation dose is used, that steps are taken to ensure magnification variation is transparent to the interpreter. This can be achieved by using post processing annotations to denote the SID used, and whether the trolley or incubator tray/platform was used. The use of calibration devices can also be used to ensure accurate scaling of images as seen within local clinical practice. This is especially important if patients required multiple follow up imaging where minimising radiation dose is necessary and for comparing subsequent images.

- Attenuation from the various components of x-ray and non-ray equipment needs to be understood hence evaluated during the procurement process to determine their effect on image quality and radiation dose. This can consequently eliminate misconceptions, such as those seen within the surveys (Paper 5 and Tugwell, 2014) and ensure practices are based on empirical evidence rather than assumptions alone. This is important as the thickness of the mattresses for trolley imaging did not correlate with their attenuation properties nor significantly impact image quality and radiation dose.
- Standard AP pelvis acquisition parameters used for x-ray tabletop are not directly transferable to AP pelvis acquired on a trolley, modifications are necessary and therefore developing specific exposure charts and DRLs for this type of imaging is a future consideration.

As seen above, the contribution from the published work has been successful in providing numerous recommendations for clinical practice, with modifications already evident within local practice. Manufacturer collaboration to ensure radiology's input in the designing and evaluation of such equipment has also been an essential aspect of the work. This has consequently strengthened radiology's position as a stakeholder during equipment procurement processes for both imaging and non-imaging equipment (such as trolleys and incubators). Another important contribution from these studies has been their impact and influence on other studies within the field. This impact was evident for studies who progressed the work and themes seen within this thesis e.g. Tugwell-Allsup et al. (2020), Enevoldsen and Kusk, (2020) and Alzyoud (2019) to those who have cited or read the work following publication (Table 8).

The impact of the six published studies on patient safety and comfort is also an important contribution from optimising these examinations. Modifying a technique to improve image quality and reduce dose would be deemed counterproductive if it compromised patient safety or comfort. For example, no significant difference was found between both mattresses used on the trolley in terms of image quality and radiation dose. Such finding is important when purchasing new trolleys, as

the Bi-Flex mattress offers more patient benefits since it is designed to reduce the likelihood of developing pressure ulcers (ArjoHuntleighs, 2010). Another safety implication associated with the work was that radiographers within one imaging department were transferring trolley patients onto the x-ray table-top for AP pelvic imaging. Following dissemination of findings from Paper 2, this practice has since changed, with most patients remaining on trolleys for imaging. This means less manual handling of patients and the reduced likelihood of exacerbating injury whilst transferring (RCR, 2011). These benefits are similar when considering neonatal imaging within incubators. Papers 4, 5 and 6 provide recommendations for clinical practice when using the incubator tray. Using the incubator tray also results in less patient handling thus reducing the risks associated with cross infection (which is even more pertinent in the current pandemic) and other potential adverse effects such as hypoexemia and bradycardia (Danford, Miske, Headley, & Nelson, 1983; Long, Philip & Lucey, 1980).

The advancement in knowledge and experience from utilising optimisation methodologies, especially surrounding the evaluation of image quality and radiation dose, has also been an important aspect in learning, developing, and improving this niche research area. Numerous methodological inconsistencies and limitations were observed and appraised which led to several recommendations for improvements and further study. These include, the incorporation of a qualitative feature to VGA to gain in depth understanding of decision making when evaluating image quality, validating a new criteria for VGA to denote diagnostic image quality, and a study to explore how variation in calculating SNR and CNR in terms of factors such as equation used, size, location and number of ROIs, affects their outcomes within optimisation studies and their subsequently correlation to visual image quality (see section 2.1.2).

9. FUTURE DIRECTION AND FURTHER STUDIES

The work presented within this thesis has made several important contributions to the radiography profession, however, the continuation of projects within this area is important to ensure unanswered questions are explored and to consolidate and validate findings. The next section considers the future direction and projects planned following completion of the PhD.

9.1 - CONTINUATION OF THE NEONATAL OPTIMISATION WORK

Following the Prima Facie for this PhD process in June 2020, another study was conducted and published on neonatal chest imaging exploring the differences in radiation dose and image quality for images acquired with both CR and DDR portable imaging systems (Tugwell-Allsup et al., 2021). This was the first study to compare DDR and CR imaging systems for neonatal imaging using an anthropomorphic phantom under controlled conditions. They key findings from this study were DDR produced images of highest CNR, with incubator tray reducing CNR for both CR and DDR. However, DDR tray still had better image quality compared to CR direct and therefore where possible, DDR should be the imaging system of choice for portable examinations on neonates owing to its superior image quality at lower radiation dose.

Another study is also in progress for neonatal chest imaging, exploring the use of additional copper filtration using DDR, as recently advocated by Samsung manufacturers. Following a rigorous literature review, no studies were found on additional copper filtration for neonatal imaging using DR. In addition, when searching Samsung's manufacturer website, there is a small print statement where they advocate the addition of the copper filters, declaring the recommendations are based on limited phantom and clinical studies, with no experiments conducted on AP chest for neonates (Samsung healthcare, 2016). However, theoretically, adding copper filtration (e.g. 0.1Cu) can remove low energy x-ray photons which does not contribute to image quality but would otherwise add to patient dose, as they would be absorbed or scattered prior to reaching the image receptor (Butler & Brennan, 2009). It was therefore decided that another experimental study was necessary to explore this further.

To conclude, the six papers presented within this thesis have provided a platform for these other studies to occur using similar methods, whilst also highlighting further studies that would be beneficial to build upon the current evidence provided within these six studies.

REFERENCES

Aichinger, H., Dierker, J., Joite-Barfuß, S., & Säbel, M. (2004*).* Optimisation of Image Quality and Dose. In: *Radiation Exposure and Image Quality in X-Ray Diagnostic Radiology* (pp. 109-116). Springer: Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-09654-3_11

Aksnes, D. W., Langfeldt, L., & Wouters, P. (2019). Citations, Citation Indicators, and Research Quality: An Overview of Basic Concepts and Theories*. SAGE Open,* 9(1), 215824401982957. doi.org/10.1177/2158244019829575

Allen, E., Hogg, P., Ma, W.K., & Szczepura, K. (2013). Fact or fiction: An analysis of the 10 kVp 'rule' in computed radiography. *Radiography*, 19, 223-227

Al-Murshedi, S., Hogg, H., & England, A. (2020). Neonatal chest radiography: Influence of standard clinical protocols and radiographic equipment on pathology visibility and radiation dose using a neonatal chest phantom. *Radiography*, 26(4), 282–287. doi.org/10.1016/j.radi.2020.02.005

Alpen, E.L. (1998). *Radiation Biophysics* (2nd ed.). Massachusetts: Academic Press

Alresheedi, N.M. (2020). A new standard in testing mattresses for use in x-ray imaging: Developing, validating and using a novel method to test x-ray mattresses for pressure ulcer development, radiation dosimetry and image quality (Unpublished doctoral dissertation). University of Salford, Manchester, UK.

Alresheedi, N., Walton, L. A., Tootell, A., Webb, J.-A., & Hogg, P. (2021). Pressure distribution analysis of X-Ray table mattresses. J*ournal of Medical Imaging and Radiation Sciences*, 52(1), 97–103. doi.org/10.1016/j.jmir.2020.11.001

Alzyoud, K.S. (2019). Establishing an Evidence-Base for Erect Pelvis Radiography: Positioning, Radiation Dose and Image Quality. (Doctoral dissertation, University of Salford, Manchester, UK). Retrieved from http://usir.salford.ac.uk/id/eprint/52289/

Alzyoud, K.S., Hogg, P., Snaith, B., Flintham, K., & England, A. (2019). Impact of body part thickness on AP pelvis radiographic image quality and effective dose. *Radiography*, 25(1), e11–e17. doi.org/10.1016/j.radi.2018.09.001

American College of Radiology. (2014). ACR-SPR practice parameter for the performance of chest radiography. Retrieved from https://www.acr.org/-/media/ACR/Files/Practice-Parameters/chestrad.pdf?la=en

Angmorterh, S. K., England, A., Webb, J., Szczepura, K., Stephens, M., Anaman-Torgbor, J., … Hogg, P. (2019). An Investigation of Pressure Ulcer Risk, Comfort, and Pain in Medical Imaging. *Journal of Medical Imaging and Radiation Sciences*, 50(1), 43–52. doi.org/10.1016/j.jmir.2018.07.003

ArjoHuntleighs. (2010). Bi-flex trolley mattress replacement system. Bedfordshire: ArjoHuntleigh Getinge Group. Retrieved from http://www.arjolibrary.com

Bloomfield, C., Boavida, F., Chabloz, D.,Crausaz, E., Huizinga, E., Hustveit, H. …Visser, R. (2014). Experimental article – Reducing effective dose to a paediatric phantom by using different combinations of kVp, mAs and additional filtration whilst maintaining image quality. In P. Hogg, L. Lança (Eds.), *Radiation dose and image quality optimisation in medical imaging,* Erasmus Intensive Programme OPTIMAX#2014: Lisbon, Portugal.

Bornmann, L. (2016). Measuring impact in research evaluations: a thorough discussion of methods for, effects of and problems with impact measurements. *Higher Education*, 73(5), 775–787. doi.org/10.1007/s10734-016-9995-x

Brennan, P.C., McDonnell, S., & O'Leary, D. (2004). Increasing film-focus distance (FFD) reduces radiation dose for x-ray examinations. *Radiation Protection Dosimetry,*108, 263-268.

Buissink, C., Alrowily, M., Dougoud, C., Linneman, J., Lirot, M., Mzobe, N. … van der Heij-Meijer., A. (2020). Impact of gonad shielding for AP pelvis on dose and image quality on different female sizes: A phantom study. *Radiography*, Suppl 2: S71-S78. doi: 10.1016/j.radi.2020.06.013.

Burgess, A. (2011). Visual Perception Studies and Observer models in Medical Imaging. *Seminars of Nuclear Medicine*, 41, 419-436. doi:10.1053/j.semnuclmed.2011.06.005

Butler, M.L., & Brennan, P. C. (2009). Nonselective Filters Offer Important Dose-Reducing Potential in Radiological Examination of the Paediatric Pelvis. *Journal of Medical Imaging and Radiation Sciences*, 40(1), 15–23. doi.org/10.1016/j.jmir.2008.11.002

Buykx, P., Humphreys, J., Wakerman, J., Perkins, D., Lyle, D., McGrail, M. & Kinsman, L. (2012). "Making evidence count": A framework to monitor the impact of health services research. *Australian Journal of Rural Health*, 20(2), 51–58.

Cannon, J., Silvestri, S., & Munro, M. (2009). Imaging Choices in Occult Hip Fracture. *The Journal of Emergency Medicine*, 37(2), 144–152. doi.org/10.1016/j.jemermed.2007.12.039

Carlton, R. R. & Arlene Mckenna Adler (2013) *Principles of radiographic imaging: an art and a science*. Clifton Park, Ny: Delmar/Cengage Learning.

Carroll, Q. (2018). *Radiography in the digital age: physics, exposure, radiation biology.* Springfield, Illinois Thomas, Publisher, Ltd

Carroll, Q.B., & Bowman, D. (2013). *Adaptive Radiography with Trauma, Image Critique and Critical Thinking*, (International ed.). New York: Cengage Learning

Carter, P.H., Paterson, A.M., Thornton, L.M., Hyatt, A.P., Milne, A., & Pirrie, J.R. (1994). *Chesneys' Equipment for Student Radiographers* (4th ed.). London: Blackwell Scientific

Carver, E, & Carver, B. (2012). *Medical imaging: techniques, reflection & evaluation.* (2nd ed.). Philadelphia: Churchill Livingstone

Chan, C. T. P., & Fung, K. K. L. (2015). Dose optimization in pelvic radiography by air gap method on CR and DR systems – A phantom study. *Radiography*, 21(3), 214–223. doi.org/10.1016/j.radi.2014.11.005

Charity, R., Day, N., Vasukutty, N., Ramesh, M.R., & Kumar, P. (2008). Is it possible to pre-operatively plan implant size in hip hemiarthroplasty? *Orthopaedic Proceedings*, 90-b:supp_iii, 472-472. Retrieved from: https://online.boneandjoint.org.uk/toc/procs/90-B/SUPP_III

Charnley, C., England, A., Martin, A., Taylor, S., Benson, N., & Jones, L. (2016). An option for optimising the radiographic technique for horizontal beam lateral (HBL) hip radiography when using digital X-ray equipment. *Radiography*, 22(2), e137–e142. doi.org/10.1016/j.radi.2016.01.004

Commission of the European Communities (CEC). (1996a). European guidelines on quality criteria for diagnostic radiographic images in paediatrics (EUR 16261 EN). Luxebourg: CEC Retrieved from: https://www.sprmn.pt/pdf/EuropeanGuidelinesEur16261.pdf

Commission of the European Communities (CEC). (1996b).European guidelines on quality criteria for diagnostic radiographic images:(EUR 16260 EN). Luxembourg: CEC. Retrieved from: https://www.sprmn.pt/pdf/EuropeanGuidelineseur16260.pdf

Cook, V.J., Shaw, K., & Witwit, A. (2015*).* Paediatic Radiography. In: S. Whitley, G. Jefferson, K. Holmes, C. Slone, C. Anderson, G. Hoadly (Eds.), *Clark's positioning in radiography* (pp 423-436). 13th ed. London: CRC Press

Cruz Rivera, S., Kyte, D. G., Aiyegbusi, O. L., Keeley, T. J., & Calvert, M. J. (2017). Assessing the impact of healthcare research: A systematic review of methodological frameworks. *PLOS Medicine*, *14*(8), e1002370. doi.org/10.1371/journal.pmed.1002370

Danford, D. A., Miske, S., Headley, J., & Nelson, R. M. (1983). Effects of routine care procedures on transcutaneous oxygen in neonates: a quantitative approach. Archives of Disease in Childhood, 58(1), 20–23. doi.org/10.1136/adc.58.1.20

Davey, E., & England, A. (2015). AP versus PA positioning in lumbar spine computed radiography: Image quality and individual organ doses, *Radiography*, 21(2), 188-196

Davies, B.H., Manning-Stanley, A.S., Hughes, V.J., & Ward, A.J. (2020). The impact of gonad shielding in anteroposterior (AP) pelvis projections in an adult: A phantom study utilising digital radiography (DR), *Radiography*, 26(3), 240-247. doi.org/10.1016/j.radi.2020.01.007.

Dawkins, S. (2012). Impact Assessment on a Newly Implemented Service Utilising Recovery Nurses as Transfer Nurses, Incorporating a Literature Review of Pressure Ulcer Reduction Strategies, i.e. Mattress and Overlay Types, for Patients on Hospital Trolleys. *British Journal of Anaesthetic and Recovery Nursing*, 13(3-4), 58-64

Del Rio, V., Satta, L., & Fanti, V. (2016). Radiologic imaging of the newborn inside the incubator. Radiation dose and image quality. In: abstracts of the 9th National Congress of the Associazione Italiana di Fisica Medica. *Phys Med*, 3: e71e96. http://dx.doi.org/10.1016/j.ejmp.2016.01.260

Dobbins, J.T. (2000). Image quality metrics for digital systems. In R. L. van Metter, J. Beutel, and H. Kundel (Eds.), *Handbook of Medical Imaging* (pp. 161-222) Society of Photo-Optical Instrument Engineers, Bellingham, WA

Enevoldsen, S., & Kusk, M. W. (2020). Image quality of bedside chest radiographs in intensive care beds with integrated detector tray: A phantom study. *Radiography* 27(2), 453-458. doi.org/10.1016/j.radi.2020.10.012

England, A., Evans, P., Harding, L., Taylor, E., Charnock, P., & Williams, G. (2014). Increasing source-to-image distance to reduce radiation dose from digital radiography pelvic examinations. *Radiol Technol,*86(3), 246-56.

European Council Directive. (2013/59/EU). Directive 2013/59/EU of 5th of December 2014 Euratom on basic safety standards for the protection against the dangers arising from exposure to ionising radiation and repealing directives 89/618/Euratom, 90/641/Euratom, 96/29/ Euratom, 97/43/Euratom and 2003/122 Euratom. Official Journal of the European Union.

Everton, C., Bird, S., Brito, W., Collé, P., Franco, AP., Lutjeber, S., …Angmorterh, S. (2014a). Experimental article – An experimental study to compare the interface pressure and experience of healthy participants when lying still for 20 minutes in a supine position on two different imaging surfaces. In P. Hogg, L. Lança (Eds.), *Radiation dose and image quality optimisation in medical imaging,* Erasmus Intensive Programme OPTIMAX#2014: Lisbon, Portugal.

Everton, C., Bird, S., Brito, W., Collé, P., Franco, A.P., Lutjeber, S., … Angmorterh, S. (2014b). Review article – The effects of clinical support surfaces on pressure as a risk factor in the development of pressure ulcers, from a radiographical perspective: a narrative literature review. In P. Hogg, L. Lança (Eds.), *Radiation dose and image quality optimisation in medical imaging,* Erasmus Intensive Programme OPTIMAX#2014: Lisbon, Portugal.

Farrell, K.R.C., Abbott, C., Round, K., Willis, S.J., Yalden, R., & Knapp, K.M. (2008). Pelvic projection radiography: increasing the source to image distance provides diagnostic images at reduced dose. Proceedings of the UK radiological congress, page 16. Manchester: *British Institute of Radiology*. Retrieved from http://www.birpublications.org/doi/book/10.1259/conf-pukrc.2008

Fauber, T.L. (2016). *Radiographic imaging and exposure* (5th ed.). Missouri: Mosby, Inc

Fisher, D. R., & Fahey, F. H. (2017). Appropriate Use of Effective Dose in Radiation Protection and Risk Assessment. *Health Physics*, 113(2), 102–109. doi.org/10.1097/hp.0000000000000674

Freitas, M. B., Pimentel, R. B., Braga, L. F., Salido, F. S. A., Neves, R. F. C. A., & Medeiros, R. B. (2020). Patient dose optimization for computed radiography using physical and observer-based measurements as image quality metrics. *Radiation Physics and Chemistry*, 172, 108768. doi.org/10.1016/j.radphyschem.2020.108768

Gleeson, C.E., Spedding, R.L., Harding, L.A., & Caplan, M. (2001) The mediastinum--is it wide? *Emerg Med J*, 18(3):183-5. doi: 10.1136/emj.18.3.183.

Gorham, S., & Brennan, P.C. (2010). Impact of focal spot size on radiologic image quality: A visual grading analysis. *Radiography,* 16(4), 304-313.

Grondin, Y., Matthews, K., McEntee, M., Rainford, L., Casey, M., Tonra, M., … Brennan, P.C. (2004). Dose-reducing strategies in combination offers substantial potential benefits to females requiring X-ray examination. *Radiation Protection Dosimetry,* 108(2), 123-132.

Gunn, C., O'Brien, K., Fosså, K., Tonkopi, E., Lanca, L., Martins, C. T., … Johansen, S. (2019). A multi institutional comparison of imaging dose and technique protocols for neonatal chest radiography. *Radiography*, 26(2), e66-e72. doi.org/10.1016/j.radi.2019.10.013

Hakansson, M., Svensson, S., Zachrisson, S., Svalkvist, A., Bath, M., & Mansson, L. G. (2010). VIEWDEX: an efficient and easy-to-use software for observer performance studies. Radiation Protection Dosimetry, 139(1-3), 42–51. doi.org/10.1093/rpd/ncq057

Haleem, S., Heinert, G., & Parker, M.J. (2008). Pressure sores and hip fractures. *Injury,* 39(2), 219-223. doi: 10.1016/j.injury.2007.08.030.

Harding, L., Manning-Stanley, A., Evans, P., Taylor, M., Charnock, P., & England, A. (2014). Optimum patient orientation for pelvic and hip radiography: a randomised trial. *Radiography*, 20, 22-32.

Harrison, J., & Lopez, P. O. (2015). Use of effective dose in medicine. *Annals of the ICRP,* 44(1), 221–228. doi.org/10.1177/0146645315576096

Heath, R., England, A., Ward, A., Charnock, P., Ward, M., Evans, P,. & Harding, L. (2011). Digital pelvic radiography: increasing distance to reduce dose. *Radiol Technol*, 83(1), 20-28.

Helmrot, E., Pettersson, H., Sandborg, M., & Altén, J.N. (2007). Estimation of dose to the unborn child at diagnostic x-ray examinations based on data registered in RIS/PACS. *European Radiology*, 17, 205-209. doi:10.1007/s00330-006-0286-2

Hess, R., & Neitzel, U. (2012). Optimizing Image Quality and Dose for Digital Radiography of Distal Pediatric Extremities Using the Contrast-to-Noise Ratio. *RöFo - Fortschritte Auf Dem Gebiet Der Röntgenstrahlen Und Der Bildgebenden Verfahren,* 184(07), 643–649. doi.org/10.1055/s-0032-1312727

Hinojos-Armendáriz, V. I., Mejía-Rosales, S. J., & Franco-Cabrera, M. C. (2018). Optimisation of radiation dose and image quality in mobile neonatal chest radiography. *Radiography*, 24(2), 104–109. doi.org/10.1016/j.radi.2017.09.004

Hogg, P., & Blindell, P. (2012). *Software for image quality evaluation using a forced choice method*. Paper presented at the UKRC, Manchester, UK. p. 139

ICMJE. (n.d.). ICMJE | Recommendations | Defining the Role of Authors and Contributors. Retrieved December 9, 2019, from http://www.icmje.org/recommendations/browse/roles-and-responsibilities/defining- the-role-of-authors-and-contributors.html

ICRP (1993). Quantities and units in Radiation Protection Dosimetry. Report 51. Bethesda, USA: ICRU

ICRP. (2006). The optimisation of radiological protection: Broadening the process, ICRP 101. *Annals of ICRP, 36*(3), 69-87

ICRP. (2007). The 2007 recommendations of the ICRP on radiological protection, publication 103. *Annals of ICRP 37 (2-4)*. doi.org/10.1007/s13398-014-0173-7.2

Jiang, X., Baad, M., Reiser, I., Feinstein, K. A., & Lu, Z. (2015). Effect of comfort pads and incubator design on neonatal radiography. *Pediatric Radiology*, 46(1), 112–118. doi.org/10.1007/s00247-015-3450-5

Jones, A., Ansell, B., Jerrom, C., & Honey, I. (2015). Optimization of image quality and patient dose in radiographs of paediatric extremities using direct digital radiography. *Br J Radiol*, 88(1050), 20140660. doi: 10.1259/bjr.20140660

Keating, M., & Grange, S. (2011). Image quality in the anteroposterior cervical spine radiograph: Comparison between moving, stationary and non-grid techniques in a lamb neck. *Radiography,* 17(2), 139-144.

Khong, P-L., Ringertz, H., Donoghue, V., Frush, D., Rehani, M., Appelgate, K., & Sanchez, R. (2013). ICRP Publication 121: Radiological Protection in Paediatric Diagnostic and Interventional Radiology. *Annals of the ICRP*, 42(2), 1–63. doi.org/10.1016/j.icrp.2012.10.001

Kim, J. H. (2018). Three principles for radiation safety: time, distance, and shielding. *The Korean Journal of Pain,* 31(3), 145. doi.org/10.3344/kjp.2018.31.3.145

Krupinski, E.A. (2010). Current perspectives in medical image perception. *Attention Perception and Psychophysics,* 72(5). doi:10.3758/APP.72.5.1205.

Kumar, R. (2014). *Research Methodology A Step-by-Step Guide for Beginners* (4th ed.). London: SAGE Publications Ltd

Kupinski, M.A. (2012). *Evaluation and Image Quality in Radiation-Based Medical Imaging*. In C. Grupen, I. Buvat (Eds.), Handbook of Particle Detection and Imaging (pp. 1083-1093). Berlin: Springer-Verlag. DOI. 10.1007/978-3-642-13271-1_43

Ladia, A.P., Skiadopoulos, S.G., Kalogeropoulou, C.P., Zampakis, P.E., Dimitriou, G.G., & Panayiotakis, G.S. (2016). Radiation dose and image quality evaluation in paediatric radiography. *International Journal of New Technology and Research (IJNTR)*, 2(3), 9-14.

Lança, L., Franco, L., Ahmed, A., Harderwijk, M., Marti, C., Nasir, S., … Hogg, P. (2014). 10 kVp rule – An anthropomorphic pelvis phantom imaging study using a CR system: Impact on image quality and effective dose using AEC and manual mode. *Radiography*, 20(4), 333–338. doi.org/10.1016/j.radi.2014.04.007

Linsenmaier, U., Krötz, M., Kanz, K.G., Russ, W., Papst, C., Rieger, J., ... Pfeifer, K.J. (2001). Evaluation of spine boards for X-Ray diagnostics. *Rofo*, 173(11), 1041-7. doi: 10.1055/s-2001-18311.

Long, J.G., Philip, A.G., Lucey, J.F. (1980). Excessive handling as a cause of hypoxemia. *Pediatrics*, 65, 203-207.

Ludewig, E., Richter, A., & Frame, M. (2010). Diagnostic imaging--evaluating image quality using visual grading characteristic (VGC) analysis. *Vetinary Research Communications,* 34(5), 473-479

Lyra, M. E., Kordolaimi, S. D., & Salvara, A.-L. N. (2010). Presentation of Digital Radiographic Systems and the Quality Control Procedures that Currently Followed by Various Organizations Worldwide. *Recent Patents on Medical Imaging*, 2(1), 5–21. doi.org/10.2174/1877613201002010005

Ma, W. K., Hogg, P., Tootell, A., Manning, D., Thomas, N., Kane, T., … Kitching, J. (2013). Variation of visual image quality using CR technology, relationship with E. *Radiography*, 19(1), 85–86. doi.org/10.1016/j.radi.2012.11.007

Ma, W.K., Hogg, P., & Norton, S. (2014). Effects of kilovoltage, milliampere seconds, and focal spot size on image quality. *Radiol Technol*, 85(5):479-85.

Malone, J., Guleria, R., Craven, C., Horton, P., Järvinen, H., Mayo, J., … Czarwinski, R. (2012). Justification of diagnostic medical exposures: some practical issues. Report of an International Atomic Energy Agency Consultation. *British Journal of Radiology*, 85(1013), 523–538. doi: 10.1259/bjr/42893576

Manning, D., Ethell, S., & Donovan, T. (2004). Detection or decision error? Missed lung cancer from posteroanterior chest radiographs. *Br J Radiol*, 77(915), 231-5

Manning-Stanley, A., Ward, A., & England, A. (2012). Options for radiation dose optimisation in pelvic digital radiography: a phantom study. *Radiography,* 18, 256-63.

Månsson, L.G. (2000). Methods for the Evaluation of Image Quality: A Review. *Radiation Protection Dosimetry*, 90(1-2), 89-99.

Mantiuk, R.K., Tomaszewska, A., & Mantiuk, R. (2012). Comparison of Four Subjective Methods for Image Quality Assessment. *Computer Graphics Forum*, 31(8), 2478-2491. Retrieved from http://mmi.tudelft.nl/pub/hantao/SPIE10REDI.pdf

Martin, C.J. (2007). Optimisation in general radiography. Biomedical Imaging and Interventional Journal, 3(2), e18. doi:10.2349/biij.3.2.e18

Martin, C. J., Harrison, J. D., & Rehani, M. M. (2020). Effective dose from radiation exposure in medicine: Past, present, and future. *Physica Medica*, 79, 87–92. doi.org/10.1016/j.ejmp.2020.10.020

Martin, L., Ruddlesden, R., Makepeace, R., Robinson, L., Mistry, T., & Starritt, H. (2013). Paediatric x-ray radiation dose reduction and image quality analysis. *J Radiol Prot*, 33(3). doi.org/10.1088/0952-4746/33/3/621.

Mc Fadden, S., Roding, T., de Vries, G., Benwell, M., Bijwaard, H., & Scheurleer, J. (2018). Digital imaging and radiographic practise in diagnostic radiography: An overview of current knowledge and practice in Europe. *Radiography*, 24(2), 137–141. doi.org/10.1016/j.radi.2017.11.004

Mekiš, N., Mc Entee, M.F., & Stegnar, P. (2010). PA positioning significantly reduces testicular dose during sacroiliac joint radiography. *Radiography* 16(4), 333-338

Mohammed Ali, A., Hogg, P., Abuzaid, M., & England, A. (2019). Impact of acquisition parameters on dose and image quality optimisation in paediatric pelvis radiography—A phantom study. *European Journal of Radiology*, 118, 130–137. doi.org/10.1016/j.ejrad.2019.07.014

Moore, C. S., Wood, T. J., Beavis, A. W., & Saunderson, J. R. (2013). Correlation of the clinical and physical image quality in chest radiography for average adults with a computed radiography imaging system. *The British Journal of Radiology*, 86(1027), 20130077. doi.org/10.1259/bjr.20130077

Mori, M., Imai, K., Ikeda, M., Iida, Y., Ito, F., Yoneda, K., & Enchi, Y. (2013). Method of measuring contrast-to-noise ratio (CNR) in nonuniform image area in digital radiography. *Electronics and Communications in Japan*, 96(7), 32–41. doi.org/10.1002/ecj.11416

Morrell, R.E. (2006). Dosimetry and Optimisation in High Dose Fluoroscopic and Fluorographic Procedures. (Doctoral dissertation, University of Nottingham, Nottingham, UK) Retrieved from http://eprints.nottingham.ac.uk/10181/

Mraity, H. (2015). Optimisation of radiation dose and image quality for AP pelvis radiographic examination. (Doctoral dissertation, Salford University, Manchester, UK) Retrieved from http://usir.salford.ac.uk/36914/

Mraity, H., England, A., & Hogg, P. (2014a). Developing and validating a psychometric scale for image quality assessment. *Radiography*, 20(4), 306-311.

Mraity, H., England, A., & Hogg, P. (2018). AP pelvis radiography: The impact of focal spot size on radiation dose and image quality. Conference: European Congress of Radiology. Retrieved from: https://www.researchgate.net/publication/329277473_AP_pelvis_radiography_The_impact_of_focal_spot_size_on_radiation_dose_and_image_quality

Munn, Z., McArthur, A., Mander, G. T. W., Steffensen, C. J., & Jordan, Z. (2020). The only constant in radiography is change: A discussion and primer on change in medical imaging to achieve evidence-based practice. *Radiography*, 26, S3–S7. doi.org/10.1016/j.radi.2020.07.001

Murphy, M. C., Gibson, W., Moseley, G. L., & Rio, E. K. (2021). Are you translating research into clinical practice? What to think about when it does not seem to be working. *British Journal of Sports Medicine*, bjsports-2020-102369. doi.org/10.1136/bjsports-2020-102369

Mutch, S.J., Wentworth, S.D. (2007). Imaging the neonate in the incubator: an investigation of the technical, radiological and nursing issues. *Br J Radiol*, 80, 902-10.

Nightingale, J. (2016). Establishing a radiography research culture – Are we making progress? *Radiography* [Editorial], 22(4), 265-266. doi.org/10.1016/j.radi.2016.09.002

Nightingale, J. M., & Marshall, G. (2012). Citation analysis as a measure of article quality, journal influence and individual researcher performance. *Radiography*, 18(2), 60–67. doi.org/10.1016/J.RADI.2011.10.044

Omojola, A. D., Akpochafor, M. O., Adeneye, S. O., Akala, I. O., & Agboje, A. A. (2021). Estimation of dose and cancer risk to newborn from chest X-ray in South-South Nigeria: a call for protocol optimization. *Egyptian Journal of Radiology and Nuclear Medicine*, 52(1). doi.org/10.1186/s43055-021-00445-w

Pachter, C. S., Garfinkel, J. H., Romness, D. W., & Gladnick, B. P. (2019). Radiographic Calibration With a Prosthetic Femoral Head Allows Accurate Preoperative Templating for Total Hip Arthroplasty. *Orthopedics*, 42(3), e346–e349. doi.org/10.3928/01477447-20190321-06

Poletti, J. L., & McLean, D. (2005). The effect of source to image-receptor distance on effective dose for some common X-ray projections. *The British Journal of Radiology*, 78(933), 810–815. doi.org/10.1259/bjr/74823655

Precht, H., Hansson, J., Outzen, C., Hogg, P., & Tingberg, A. (2019). Radiographers' perspectives' on Visual Grading Analysis as a scientific method to evaluate image quality. *Radiography*, 25, S14–S18. doi.org/10.1016/j.radi.2019.06.00

QAA. (2020). Characteristic Statement: Doctoral Degree. Third Edition. Gloucester: QAA. Retrieved from https://www.qaa.ac.uk/docs/qaa/quality-code/doctoral-degree-characteristics-statement-2020.pdf?sfvrsn=a3c5ca81_14

Rattan, A. S., & Cohen, M. D. (2013). Removal of Comfort Pads underneath Babies. *Academic Radiology*, 20(10), 1297–1300. doi.org/10.1016/j.acra.2013.07.007

Reis, C., Gonçalves, J., Klompmaker, C., Bárbara, A. R., Bloor, C., Hegarty, R., … Hogg, P. (2014). Image quality and dose analysis for a PA chest X-ray: Comparison between AEC mode acquisition and manual mode using the 10 kVp "rule." *Radiography*, 20(4), 339–345. doi.org/10.1016/j.radi.2014.06.001

Rizzi, E., Emanuelli, S., Amerio, S., Fagan, D., Mastrogiacomo, F., Gianino, P., & Cesarani, F. (2014). Optimization of Exposure Conditions for Computed Radiology Exams in Neonatal *Intensive Care. Open Journal of Radiology*, 04(01), 69–78. doi.org/10.4236/ojrad.2014.41009

Rosner, B. (2017). *Fundamentals of biostatistics*. Boston: Cengage Learning.

Samei, E. (2009). Effective DQE (eDQE) and speed of digital radiographic systems: An experimental methodology. *Medical Physics*. 36(8): 3806–3817 . doi: 10.1118/1.3171690

Samsung healthcare. (2016). *Digital Radiography GM85*. Retrieved from: https://www.samsunghealthcare.com/en/products/DigitalRadiography/AccE%20GM85/Radiology/benefit

Sandborg, M., Båth, M., Järvinen, H., & Faulkner, K. (2015). Slide set of 138 slides based on the chapter authored by Chapter 23: Justification and Optimisation in Clinical Practice. Retrieved from https://humanhealth.iaea.org/HHW/MedicalPhysics/TheMedicalPhysicist/Studentscorner/HandbookforTeachersandStudents/Chapter_23.pdf

Sandborg, M., & Önnerth, M. (2004). Comparison of human observer efficiency in pelvis radiographs in two different anatomical regions. Report from the Department of Radiation Physics, Linkoping University, Sweden. Retrieved from http://liu.diva-portal.org/smash/get/diva2:328215/FULLTEXT01.pdf

Seeram, E., Davidson, R., Bushong, S., & Swan, H. (2013). Radiation dose optimization research: Exposure technique approaches in CR imaging – A literature review. *Radiography*, 19(4), 331-338.

Seglen, P. O. (1997). Why the impact factor of journals should not be used for evaluating research. *BMJ*, *314*(7079), 497–497. doi.org/10.1136/bmj.314.7079.497

Seibert, J.A. (2009). Digital radiography: the bottom line comparison of CR and DR technology. *Appl Radiol*, 21, e8.

Slade, D., Harrison, S., Morris, S., Alfaham, M., Davis, P., Guildea, Z., & Tuthill, D. (2005). Neonates do not need to be handled for radiographs. *Pediatric Radiology*, 35(6), 608–611. doi.org/10.1007/s00247-005-1414-x

Starc, T., & Makis, N. (2016). The impact of increasing SID on patient dose in pa abdomen imaging. Proceedings of the European Congress of Radiology, Vienna (C–1074). doi.10.1594/ecr2016/C-1074 Retrieved from https://epos.myesr.org/poster/esr/ecr2016/C-1074

Sun, Z., Lin, C., Tyan, Y., Ng, KH. (2012). Optimization of chest radiographic imaging parameters: a comparison of image quality and entrance skin dose for digital chest radiography systems. *Clin Imag*, 36(4), 279-86.

Tapiovaara, M. (2006). Relationships between physical measurements and user evaluation of image quality in medical radiology – a review. In: STUK Helsinki: Radiation and Nuclear Safety Authority. Retrieved from https://www.julkari.fi/bitstream/handle/10024/124751/stuk-a219.pdf?sequence=1

Tesselaar, E., Dahlström, N., & Sandborg, M. (2015). Clinical audit of image quality in radiology using visual grading characteristics analysis. *Radiation Protection Dosimetry*, 169(1-4), 340–346. doi.org/10.1093/rpd/ncv411

The Ionising Radiation (Medical Exposure) Regulations (2017). Queen's Printer of Acts of Parliament. Retrieved from http://www.legislation.gov.uk/uksi/2017/1322/contents/made

The Royal College of Radiologists. (2011). *Standards of practice and guidance for trauma radiology in severely injured patients*. London: RCR

The Royal College of Radiologists, Society and College of Radiographers, and British Institute of Radiology. (2015). *A guide to understanding the implications of the Ionising Radiation (Medical Exposure) Regulations in diagnostic and interventional radiology.* London: RCR

The Royal College of Radiologists. Clinical radiology UK workforce census report 2018 report. London: RCR, 2019

Thornbury, J. R., Fryback, D. G., Patterson, F. E., & Chiavarini, R. L. (1977). Effect of screen/film combinations on diagnostic certainty: Hi-Plus/RPL versus Lanex/Ortho G in excretory urography. *American Journal of Roentgenology,* 130(1), 83-87

Tingberg, A., Herrmann, C., Lanhede, B., Almén, A., Sandborg, M., McVey, G., … Zankl, M. (2004). Influence of the characteristic curve on the clinical image quality of lumbar spine and chest radiographs. *The British Journal of Radiology*, 77(915), 204–215. doi.org/10.1259/bjr/22642890

Tootell, A., Szczepura, K. & Hogg, P. (2014). An overview of measuring and modelling dose and risk from ionising radiation for medical exposures. *Radiography*, 20(4), 323–332. doi: 10.1016/j.radi.2014.05.002.

Tugwell, J. (2014). Here comes a trolley: imaging the trolley bound patient - current working practices and experience. *Imaging Ther Pract*, September. Retrieved from https:// www.sor.org/learning/library-publications/imaging-therapy-practice/ september-2014/here-comes-trolley.

Tugwell-Allsup, J., Kenworthy, D., & England, A. (2021). Mobile chest imaging of neonates in incubators: Optimising DR and CR acquisitions. *Radiography, 27(1*), 75-80. doi.org/10.1016/j.radi.2020.06.005

Vickery, D. (2001). The use of the spinal board after the pre-hospital phase of trauma management. *Emergency Medicine Journal*, 18, 51-54

Vladimirov, A. (2010). Comparison of image quality test methods in computed radiography. (Masters dissertation, University of Tratu, Estonia). Retrieved from http://dspace.utlib.ee/dspace/bitstream/handle/10062/15191/Vladimirov_Anatoli.pdf;jsessionid=80A1A82F275CF25DA0B99383FFB3DACB?sequence=1

Vucich, J.J (1979) The role of anatomic criteria in evaluation of radiographic images. In: A.G. Haus (Ed). *The Physics of Medical Imaging*. (pp. 573–87), New York: American Association of Physics in Medicine

Uffmann M, & Schaefer-Prokop, C. (2009). Digital radiography: the balance between image quality and required radiation dose. *Eur J Radiol*, 72(2):202-8.

University of Salford, Manchester. (2019). *Research Impact*. University of Salford, Manchester. Retrieved December 20, 2019, from https://www.salford.ac.uk/research

Wall, B.F., Kendall, G.M., Edwards, A., Bouffler, S., Muirhead, C.R., & Meara, J.R. (2006). What are the risks from medical X-rays and other low dose radiation? *The British Journal of Radiology*, 79, 285–294

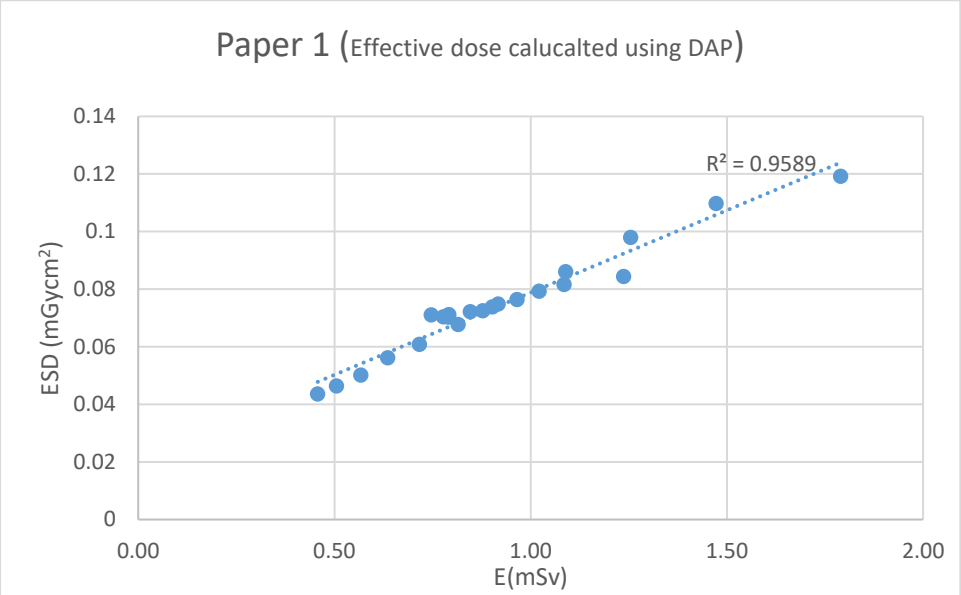
Woods, J., & Messer, S. (2009). Focusing on dose. *Imaging Ther Pract*, September:16-20.

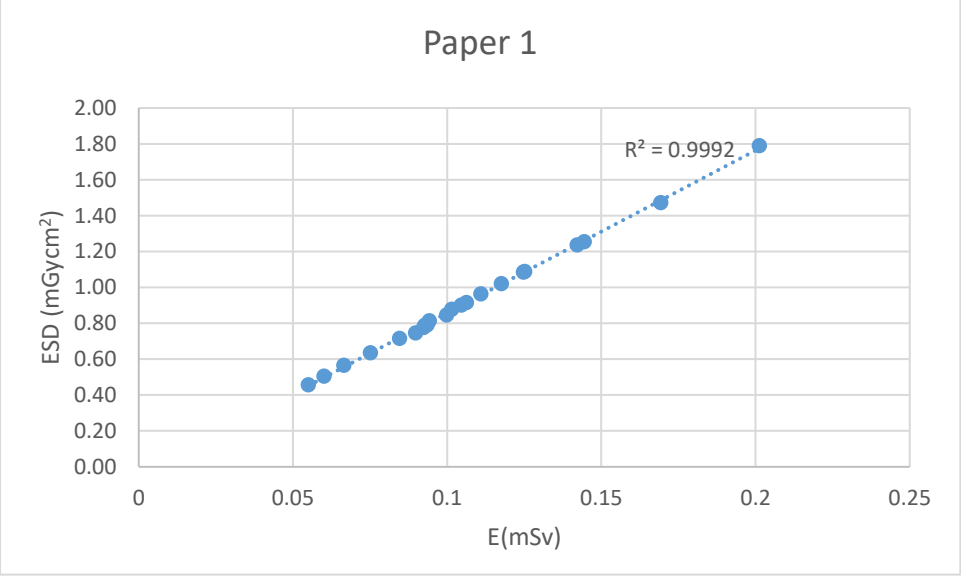
Whitley, S.A., Jefferson, G., Holmes, K., Sloane, C., Anderson, C., & Hoadley, G. (2015). *Clark's positioning in radiography*. 13th ed. London: CRC Press

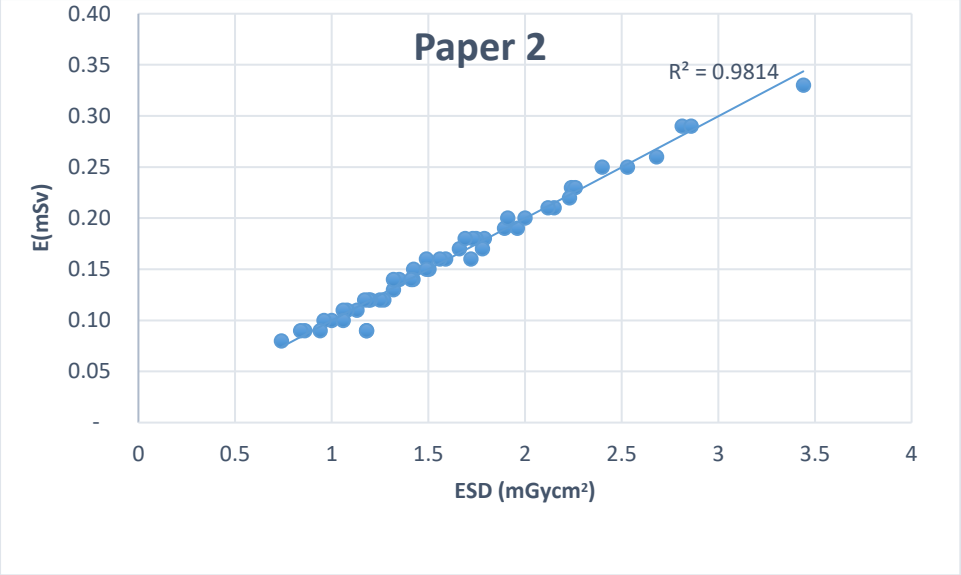
Williams, L. (2012). Pelvis and hips. In: B. Carver, E. Carver (Eds.), *Medical imaging: technique, reflection and evaluation,* (pp. 121-133). Philadelphia: Churchill Livingstone Elsevier

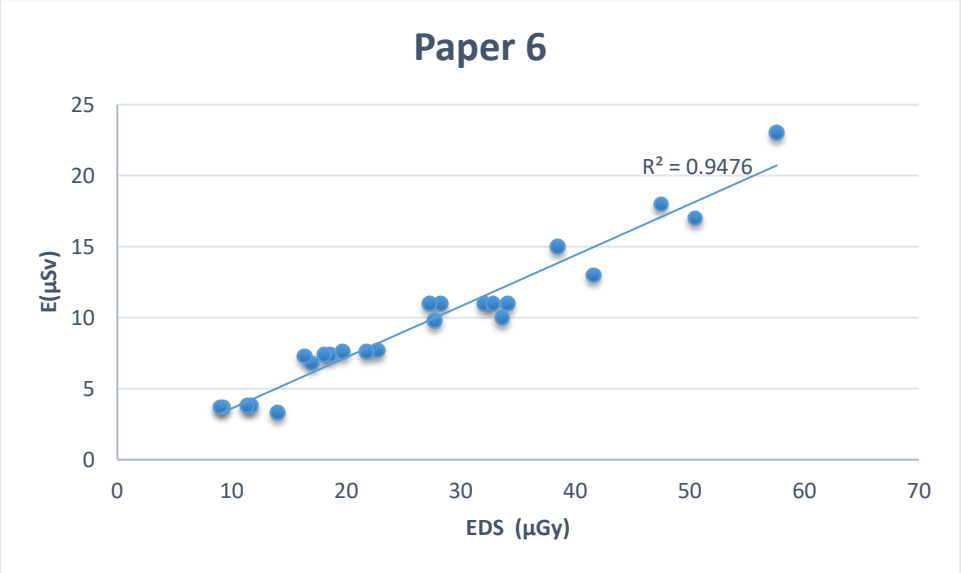
APPENDICES

Appendix 1

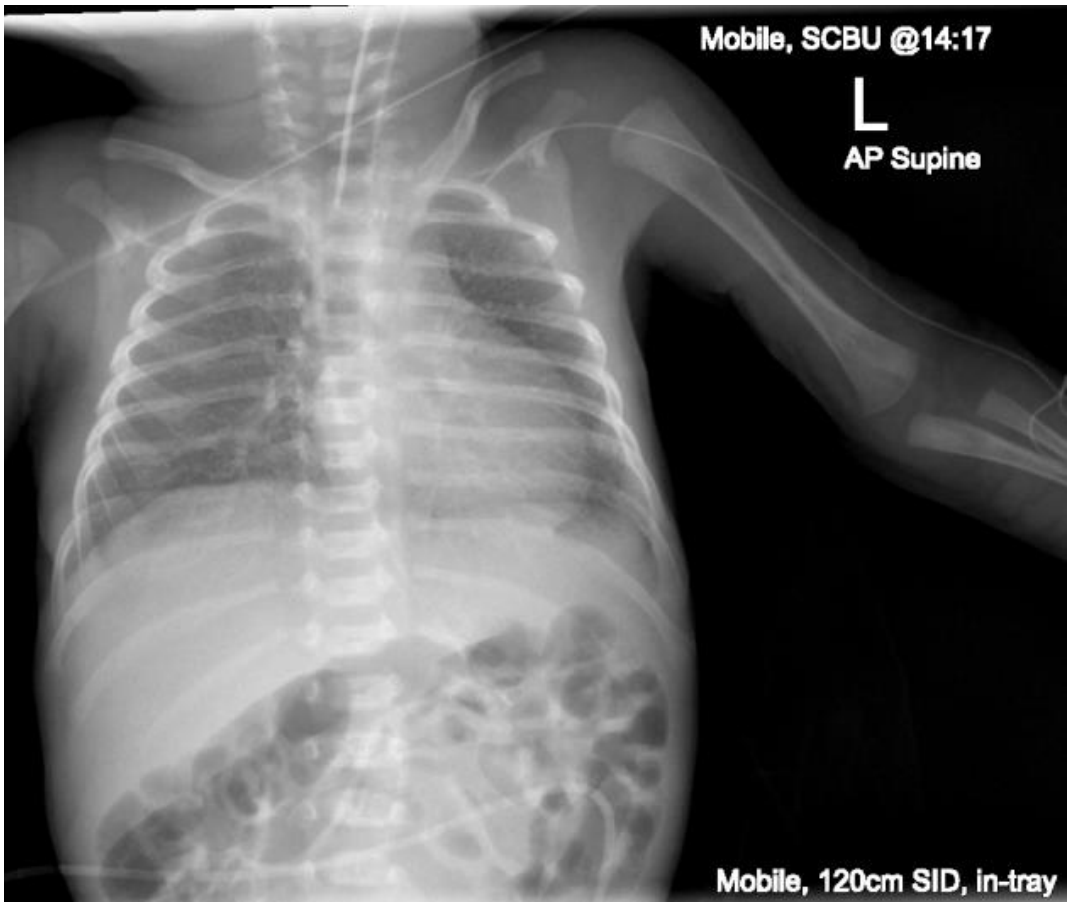




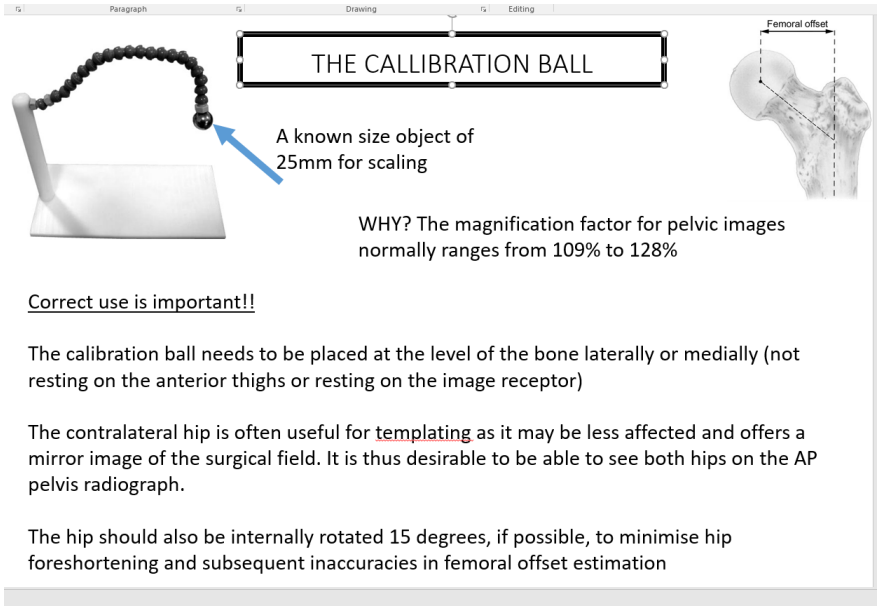

Paper 2
R² = 0.9814
E(mSv)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
-
0
0.5
1
1.5
2
2.5
3
3.5
4
ESD (mGycm²)


Paper 6
R² = 0.9476
E(µSv)
25
20
15
10
5
0
0
10
20
30
40
50
60
70
EDS (µGy)

Appendix 2



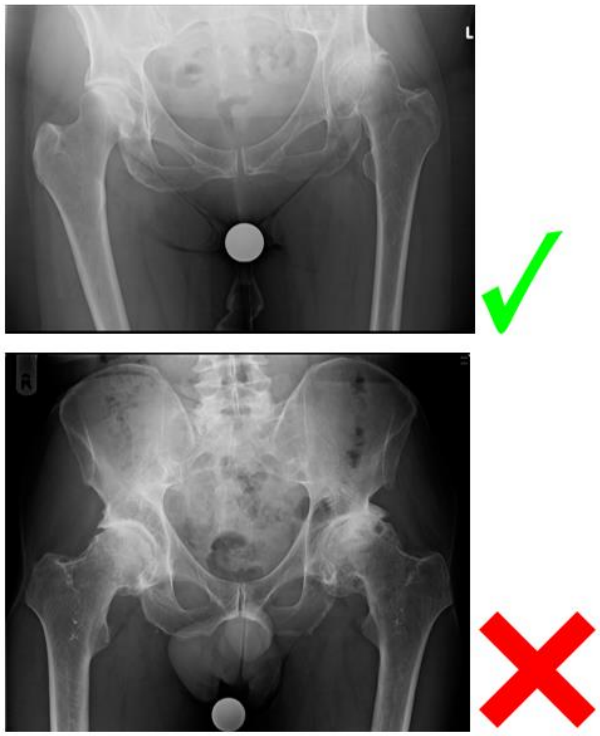
Appendix 3



Orthopaedic Pelvis/Hips with calibration (pre op)

All pelvis/hips with calibration for orthopaedics should include ASIS downward. Illiac Crest **NOT** required.

The surgeons are more interested in the diaphysis of the femur so ensure the upper border of the image receptor is level with ASIS. As long as the entire acetabulum is visible, you have covered enough upwards.



Appendix 4

Lay Summary of Blizzard experiment

The effect of warming blankets on image quality and radiation dose in CT and DR x-ray equipment.

To conduct the experiments, various different phantoms were used to simulate a patients head chest and trunk which included an anthropomorphic chest phantom (Lungman N1 Multipurpose Chest Phantom, Kyoto Kagaku Company, Japan) representing a 70Kg male and an RDS transparent sectional phantoms head, cervical spine and lower torso (see Figure 1 for set up). Due to the harmful effects of radiation and therefore from an ethical perceptive, patients cannot be used for such experiments. Phantoms however allow for multiple exposures under consistent conditions to occur for all image acquisitions allowing radiation dose and image quality to be compared under equal conditions.

The phantom will be imaged with standard acquisition parameters in both CT and general x-ray under the three different conditions below:

The three conditions tested are:

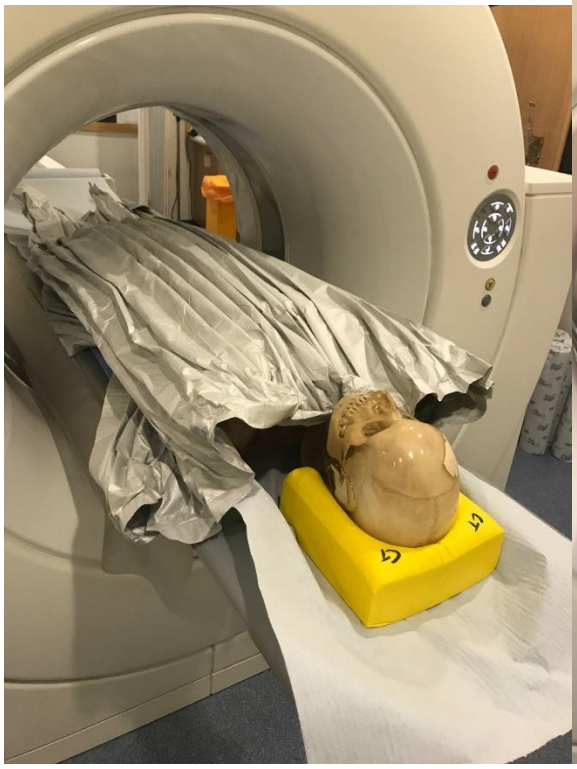
Blizzard Blanket (standard orange)

New Silver Blanket

Control (no Blanket)

Computed Tomography technique

The phantom(s) were imaged using a 128 slice Somatom Definition AS scanner (Siemens Healthcare, Erlangen, Germany). Our local standard trauma protocol/parameters for CT Head, Neck, Chest, Abdomen and Pelvis were used to acquire the images. Images were reconstructed as per local protocol and sent to the picture archiving communication system (PACS) for review.



Digital Radiography (DR)

The LUNGMAN phantom was also imaged as a supine AP chest x-ray in our digital trauma room. This room is a General Electric (GE) DR system. 95kV was used in conjunction with the AEC which gave 1.1mAs without grid.

Radiation Dose

DLP and DAP will be recorded for all image acquisitions to review whether the blankets have an effect on the radiation dose to the patient.

Image quality assessment

The acquired images will also be sent to two Consultant Radiologists for review in which they will be blinded to the image acquisition and conditions. The Consultant Radiologists will make two binary decision and further comments using a pro forma as follows:

Are there any artefacts on the images? YES/NO

If YES, do they impact on the radiology report hence diagnosis? YES/NO

Please comment further:

Results

Image quality

CT images

Both observers agreed that no artefacts could be seen on the CT images acquired using the blankets. One observer added a further comment of:

"On the lung windowing the sliver blanket is slightly visible (like any other blankets, clothes and hair etc) but this does not cause artefacts and does not influence image quality"

Digital chest x-ray

One observer found no artefact on none of the images. The second observer commented that the silver blanket caused a slight dense vertical line at the inferior end of the right scapula but this did not impact in diagnosis. However this dense line was not seen on the second exposure using the same blanket doubled up and therefore questioning whether this line was the result of the blanket.

Radiation Dose

No statistically significant difference was found between radiation dose and the three conditions tested.

Appendix 5

Rhys Morris <rhys.morris@bangor.ac.uk> | Jenna Allsup (BCUHB - Radiology)

RE:

You replied to this message on 24/08/2020 09:06.

Click here to download pictures. To help protect your privacy, Outlook prevented automatic download of some pictures in this message.

Dear Jenna,

I agree with the percentage contribution you've declared for the following paper:

Paper 6: Optimisation of image quality and radiation dose for incubator imaging.

(75% contribution from Jenna) – concept, searching / reviewing literature, conceived and planning of experiments, writing the manuscript, manuscript submission.

Good luck with the PhD!

Best wishes,

Rhys

Right-click or tap and hold here to download pictures. To help protect your privacy, Outlook prevented automatic download of this picture from the Internet.

Rhys Morris
Darlithydd mewn Gwyddorau Iechyd (Radiograffeg)
Ysgol Gwyddorau Iechyd

E-bost: rhys.morris@bangor.ac.uk

Rhys Morris
Lecturer in Health Sciences (Radiography)
School of Health Sciences

Email: rhys.morris@bangor.ac.uk
Phone:

Updating inbox. This folder is up to date. Connected to: Microsoft Exchange

Delete | Respond | Quick Steps | Move | Tags | Editing | Zoom

Richard Hibbs <richard.hibbs@extra-ibs.com> | Jenna Allsup (BCUHB - Radiology) | 21/08/202

Re: Contribution confirmation

Dear Jenna
I am more than satisfied that your contribution to Paper 6 represents 75% of the academic input.

Kind regards
Richard Hibbs

Delete | Respond | Quick Steps | Move | Tags | Editing | Zoom

Jeffrey Legg <jlegg@vcu.edu> | Jenna Allsup (BCUHB - Radiology) | 21/08/2020

Re: Contribution

You replied to this message on 21/08/2020 16:27.

Thank you for your email. Yes, I agree with the percentage suggested.

Jeff Legg, PhD, RT(R)
Associate Professor & Chair
Department of Radiation Sciences
Virginia Commonwealth University

Peter Hogg <P.Hogg@salford.ac.uk> | Jenna Allsup (BCUHB - Radiology) | 21/08/2020

RE: contribution confirmation

Dear Jenna

I am happy with papers 2 and 3, though for *Paper 1 (Increasing source to image distance for AP pelvis imaging – Impact on radiation dose and image quality) maybe 50% is about right.*

Good luck with your PhD

Peter

Re: Contribution confirmation

From Andrew England **Date** 8/21/2020, 1:22:06 PM
To Jenna Allsup (BCUHB - Radiology)
Cc
Subject Re: Contribution confirmation

Dear Jenna,

Thank you for your email, I would certainly support your contributions.

Do you need anything further from me?

Andrew

On Fri, 21 Aug 2020 at 09:54, Jenna Allsup (BCUHB - Radiology) <Jenna.R.Allsup@wales.nhs.uk> wrote:

> Dear Andrew
>
> I'm currently in the process of applying for PhD by Publication and as part of this process, I have to inform the University regarding my contribution to the published work presented within the portfolio. For this to be valid, as co-author, you need to agree (or disagree) with the percentage contribution that I declare for the below papers. Please can you send an e-mail to confirm my contribution - this would be much appreciated. See below:
>
> *Paper 2: Antero-posterior (AP) pelvis x-ray imaging on a trolley: impact of trolley design, mattress design and radiographer practice on image quality and radiation dose*
>
> (80% contribution from Jenna) – concept, searching / reviewing literature, conceived, planned and conducted the experiments, performed the statistical analyses, the writing the manuscript, manuscript submission.
>
> *Paper 3: Challenges Associated With X-ray Imaging of Stretcher-Bound Patients*
>
> (80% contribution from Jenna) – concept, searching / reviewing literature, writing the manuscript, manuscript submission.
>
> *Paper 4: Imaging neonates within an incubator – a survey to determine existing working practice.*
>
> (80% contribution from Jenna) – concept, searching / reviewing literature, conceived and planned survey, performed data analysis, writing the manuscript, manuscript submission.
>
> *Paper 5: A systematic review of incubator-based neonatal radiography – what does the evidence say?*
>
> (85% contribution from Jenna) – concept, searching / reviewing literature, writing the manuscript, manuscript submission
>
> *Paper 6: Optimisation of image quality and radiation dose for incubator imaging.*
>
> (75% contribution from Jenna) – concept, searching / reviewing literature, conceived and planning of experiments, writing the manuscript, manuscript submission.
>
> Thank you so much
>
> KR
>
> Jenna

Appendix 6

ED YG Evaluation of Patient Trolleys Feb- March 2019

Criteria assessed / trolley tested	Arjo Huntleigh Lifeguard 50 	Stryker Prime X 'Big Wheel' 	Linet Sprint 100 	Anetic Aid QA3 
Overall suitability for intended area of use fit for purpose (ED Minors, Majors, Resus, Cas X-ray, CT) (Score 1- 5)				
Height variation (Score 1- 5)				
Tilt operation (Score 1- 5)				
Does it go low enough for ambulant patients (Score 1- 5)				
Leg positioning (Score 1- 5)				
Steering system ease of use (Score 1- 5)				
Manoeuvrability (Score 1- 5)				
Braking system (Score 1- 5)				
Assisted backrest ease of use (Score 1- 5)				
X-ray facility, able to do Ap Chest , Ap Pelvis, Lateral views, Hip. (Score 1- 5)				
X-ray image clarity (Score 1- 5)				

Safety sides operation (Score 1- 5)				
Push/pull handles (Score 1- 5)				
Footboard/monitor tray (if fitted) (Score 1- 5)				
Oxygen cylinder storage tray (Score 1- 5)				
Pinch points encountered (Score 1- 5)				
Comfort as reported by patient (Score 1- 5)				
	Score	Score	Score	Score

Staff role:_____

Appendix 7

Clinical Scenario
Taking x-ray with Babyleo TN500 and Isolette

Wibke Göring
Senior Product Manager Thermoregulation

Recommendations for taking x-rays in incubators

- Recommended exposure parameters for digital image receptors (DR): 60kV and 0,5mAs, small focus and pediatric filtration
- Max SID: Babyleo in lowest and x-ray tube in highest position
- Remove positioning aids
- Use x-ray tray when possible
- Some more hints:
  - When baby needs to be repositioned from prone to supine position, the image receptor can be placed directly under the baby
  - If the baby already lies on the back, use x-ray tray to avoid disturbance.
  - If imaging department is in doubt about artifacts from matresses or x-ray tray, take x-ray images with x-ray phantom (PMMA plates) instead of patient in Babyleo. Evaluate image quality on a diagnostic viewing monitor (not on mobile phones).

Tugwell-Allsup J et al., Optimising image quality and radiation dose for neonatal incubator imaging, Radiography,