Optimisation of radiographic technique factors for direct digital radiography: a systematic review

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Thesis Declaration

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Caitlin Jane Steffensen
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Summary

As the uptake of direct digital radiography technology increases across radiology departments in Australia, it is an important time to review currently accepted best practice. It has been widely reported across the literature that in the move from analogue to digital, most of the previously accepted techniques were simply translated across without review. Optimisation of radiographic technique parameters is important to ensure that the optimal balance between image quality and dose is struck. The objective of this review was to uncover and synthesise all available literature regarding appropriate technique parameters for direct digital radiography.

A comprehensive search of published and unpublished literature was undertaken to find studies that compared different radiographic technique parameters on direct digital radiography systems. Outcomes measured were subjective image quality and patient dose. Eight hundred and fifty-eight studies were retrieved for title and abstract screening. Ninety-one studies were retrieved for full-text screening, and 23 were included for review and methodological quality screening.

Unfortunately, due to the high level of methodological heterogeneity, meta-analysis was unable to be performed for any of the included studies. Narrative synthesis of the 23 included studies revealed some promising results for increasing source-to-image distance to maintain image quality whilst reducing patient dose, but there is limited evidence for any other interventions. A key finding of this thesis was that the goals of optimisation research varied greatly across the included studies. The author proposes a new naming convention and two distinct methodologies for future research to increase the applicability and validity of future work.

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A professional editor, Jane M Smith, was used in the preparation of this thesis. Editing assistance was restricted to ASEP Standards for 'Language and Illustrations' and for 'Completeness and Consistency'. Where there was advice on matters of 'Substance and Structure' exemplars only were given. Ms Smith formerly practiced as a physiotherapist.

Chapter One – Introduction

1.1 Background

The acquisition technology employed in acquiring projectional radiographs has changed significantly in the move from traditional screen-film (SF) imaging to computed radiography (CR) and finally to direct digital radiography (DDR). During this transition the method of image acquisition has shifted from an analogue process to a digital one.[1] The way projectional radiographs are acquired, manipulated, stored and viewed has changed, leading to significant changes for all stakeholders.[2] Images are now able to be viewed simultaneously by multiple viewers across differing geographic locations, and stored for almost instantaneous retrieval.[1] What has remained constant since the inception of diagnostic x-ray imaging is the need for image quality that is appropriate for diagnosis.

The literature acknowledges that dose and image quality are directly related.[3,4] Image quality can be significantly improved by increasing the exposure factors (up to a point), but this is at the expense of increased radiation dose to the patient.[5] *Optimisation* rather than *maximisation* of image quality in diagnostic radiography should be the chief goal. An optimised technique means that the clinical question is able to be answered whilst not imposing a radiation dose to the patient that is higher than necessary.[6] By utilising an optimised technique radiographers are able to ensure that their commitment to keeping doses "as low as reasonably achievable" (ALARA) is met, whilst not compromising the diagnostic quality of the examination.

In the literature, digital radiography (DR) is used as an umbrella term for images that are acquired through any mechanism that transforms the incident photon into an electrical charge.[7] Under this definition, DR comprises both CR and DDR.[1] DDR systems acquire images by converting the incident x-ray energy into a digital signal almost instantaneously,[4] skipping the intermediary storage step that is associated with CR.[8] The detector used in DDR systems acts as both the acquisition and conversion device, whereas a CR system has a separate acquisition device (the photostimulable phosphor plate) and conversion device (the processor). In a DDR system, the mechanism by which the energy is transformed into a digital signal depends on the type of detector used, and this is the method by which DDR systems are classified.[1] This review will focus only on the optimisation of radiographic technique parameters for DDR.

Common across all imaging modalities, not just reserved for DDR, is the need for appropriate image quality for diagnosis. When considering the term "image quality", it is important to make the distinction between a visually appealing image and an image of adequate quality. An image of "adequate" quality can effectively answer the clinical question posed,[5] regardless of whether the image is visually appealing to the reader or not. Adequate image quality in analogue imaging revolved around obtaining images with optimal contrast and density.[2] Image contrast and density were almost solely dependent on exposure technique and film-screen combination factors chosen prior to acquisition.[9,10] As the radiographic film acted as both the acquisition and display medium, there were limited means of altering the image appearance after exposure.[8]

The transition from analogue to digital imaging saw the decoupling of the acquisition and display mediums.[2]

In terms of acquisition, DDR detectors have a wider dynamic range than that of SF. The dynamic range, also known as latitude, of an acquisition device refers to the range of exposure values over which it is able to produce an adequate image.[11] DDR detectors do not require tight control of exposure factors in order to produce an image of diagnostic quality, as was the case in film imaging, due to their wide dynamic range.[10] Another advantage of the wide dynamic range of DDR detectors is their ability to represent structures of varying attenuation in a single image.[1] In terms of image display, digital radiography images are able to be manipulated after the fact by way of post-processing. Optimal contrast and brightness are no longer solely reliant on the use of a specific film-screen combination or set of radiographic technique parameters.[8]

Digital radiography technology has given rise to many avenues for dose reduction; no longer bound by a certain exposure requirement for optimal image quality, the new limiting factor is image noise.[12,13] A number of sources are responsible for image noise,[14] but regardless of its origin all noise leads to degradation of image quality. Noise is the result of statistical fluctuations in signal intensity received by the detector, and is represented in the resultant image as fluctuations in brightness, leading to a mottled appearance.[3,15] Visual appreciation of image noise is very subjective,[16] and what constitutes an acceptable level of noise depends on both the preference of the observer and on the clinical question being asked.[10,17]

Image quality research in medical imaging is performed by a variety of methods, using one or a combination of test objects, phantoms, and clinically acquired images.[5] Test objects are designed to measure a specific quality of an imaging system under ideal conditions, but it is difficult to link these results to performance in clinical use.[5] Imaging phantoms are specially designed objects that are used in the place of human subjects for research purposes. They fall into one of two broad categories: geometric or anthropomorphic. Geometric phantoms consist primarily of geometric shapes and may or may not be representative of human tissue, whereas anthropomorphic phantoms are designed to be analogous to human tissue and accurately represent the anatomical structure of the body.[18] As images of test objects alone are unable to be directly linked to clinical performance,[5] only studies using anthropomorphic phantoms and/or clinically acquired images will be included for review.

Imaging phantoms play a vital role in work to optimise radiographic technique parameters. Optimisation work requires multiple parameters to be investigated in varying combinations, which results in multiple exposures to ionising radiation. It would be unethical to perform these kinds of trials on human subjects, as it would directly contravene the ALARA principle. Anthropomorphic phantoms are an ideal substitute in this situation, as they are able to be imaged repeatedly, and they stay constant over time. This eliminates variations due to patient characteristics, and any effect shown can be directly linked to the technique parameter investigated. Whilst phantom testing is a good option for initial parameter selection, clinical validation studies performed with patients of varying habitus and pathology must be performed to demonstrate that the experimental technique is clinically acceptable.

Subjective and objective measures of image quality exist, as summarised well in Martin et al.[5] Subjective measures of image quality, such as visual grading analysis, performed on clinical images by appropriately credentialed individuals, is useful as it allows more direct assessment of clinical utility of the resultant image.[19,20] The most common objective measure of image quality is the signal-to-noise ratio (SNR), which describes the strength of a signal in the presence of background noise.[21] For the purpose of this review, any method of subjective image quality evaluation will be considered, provided that it is applied in an appropriate context.

There are five radiographic technique parameters available to be manipulated at the time of image acquisition. These are exposure factors (tube current time product and tube voltage), source-to-image distance, a choice of additional beam filtration, and a method of scatter reduction. The applied tube voltage directly controls the peak energy of the x-ray beam which is described by kilovoltage (kV).[23] The current applied to the x-ray tube and the length of time the current is applied for is described by milliampere-seconds (mAs).[23] The mAs used can be determined manually, by the radiographer, or automatically using Automatic Exposure Control (AEC). AEC controls mAs by automatically terminating the exposure once a predetermined dose to the ionisation chamber has been reached.[23] Additional beam filtration is used to remove low energy photons, and it acts on top of the inherent filtration within the tube housing. It is used to reduce the number of photons that would have sufficient energy to reach the patient, but insufficient energy to add to the diagnostic image, therefore adding only to the overall patient dose.[23] Source-to-image distance (SID) is the distance between the x-ray source and the image receptor.[23] Scattered radiation, which degrades image quality, can be compensated for by use of either an air-gap technique or an anti-scatter grid.[9] Manipulation of each of these parameters has a direct impact on patient dose, and on resultant image quality. Traditional selection of technique parameters has been a combination of governing body recommendations, manufacturer recommendations, and of the personal experience of the performing radiographer.[24]

Optimisation of radiographic technique parameters for improved image quality is of key concern in the pursuit of providing high-level patient care. Whilst the image acquisition technology has evolved and advanced, it is evident that limited work has been done to optimise technique parameters to suit this new technology.[2] To date, a search of PubMed, the Joanna Briggs Institute Database of Systematic Reviews and Implementation Reports, and the Cochrane Database of Systematic Reviews has shown there have been no systematic reviews on optimising image quality for DDR. This systematic review will synthesise available evidence to highlight areas for improvement upon currently accepted best practice, as well as establishing gaps in the literature deserving of further investigation.

1.2 Definition of terms used

As Low As Reasonably Achievable (ALARA) – guiding principle of radiography to ensure that the diagnostic purpose of an examination is achieved whilst limiting as much as possible the exposure of the patient to ionising radiation[29]

Automatic Exposure Control (AEC) – a component of a radiographic system designed to terminate the exposure once a predetermined dose to the ionisation chamber is reached.[23]

Direct Digital Radiography (DDR) – a general radiography system that acquires images by converting the incident x-ray energy into a digital signal almost instantaneously, skipping the intermediary storage step associated with computed radiography

Dose area product (DAP) or Air Kerma-Area product (KAP) – "the integral of the air kerma over the area of the x-ray beam in a plane perpendicular to the beam axis".[22(p. 28)]

Effective dose (E) – "the sum of the weighted equivalent doses in all the tissues and organs of the body",[22(p. 32)] it is a calculation of the stochastic risk to the patient following exposure to ionising radiation. Expressed in millisieverts (mSv)

Entrance skin dose (ESD) or Entrance-Surface Air Kerma – "the air kerma on the central x-ray beam axis at the point where the x-ray beam enters the patient or phantom",[22(p. 29)] measured in milligray (mGy)

Filter – two types of beam filtration exist for radiography systems: inherent and additional. Both types of filtration are designed to reduce the number of low energy photons that reach the patient and contribute to patient dose but not to the formation of the image.[23] Inherent filtration is part of the tube housing and is unable to be altered. Additional beam filtration is able to be selectively applied per examination. Additional beam filters can be composed of differing amounts of Copper (Cu) and Aluminium (Al).

Grid – a physical part of the radiography system that absorbs scattered photons to improve image contrast.[23] Multiple types of grids exist, but for the purposes of this text all will be referred to under the blanket term "grid".

Kilovoltage (kV) – tube voltage, the energy of the x-ray beam[23]

Milliampere seconds (mAs) – tube current time product[23]

Object-to-image distance (OID) – the distance from the patient to the image receptor.[23] Also known as **object-to-film distance (OFD)** in the literature

Picture Archiving and Communication System (PACS) – a network of computers designed to store and manage radiographic images.[23]

Source-to-image distance (SID) – the distance from the anode to the image receptor.[23] Also known as **film-to-focus distance (FFD)** in the literature

Source-to-skin distance (SSD) – the distance from the anode to the patient's skin.

1.3 Context of the review

It is a well-established fact that exposure to excessive ionising radiation can lead to significant negative health effects. The Australian Radiation Protection and Nuclear Safety Agency have identified that medical diagnostic tests and treatments account for over half of the ionising radiation exposure Australians experience each year.[25] With such a large component of the radiation burden experienced by Australians being from medical radiation sources, a key focus for radiographers and one of the guiding principles of the profession is to keep doses ALARA. Optimisation rather than minimisation should be the focus of this principle, as the dose of ionising radiation delivered to a patient must be of an adequate level to ensure that the examination is of diagnostic quality. The International Commission on Radiological Protection (ICRP) highlighted in their 2017 report that there is an urgent need to investigate the image quality per dose required for diagnosis.[26] The optimisation of radiographic technique is of great importance, as exposures too high for the diagnostic purpose are unacceptable, just as exposures that are too low for the diagnostic purpose are.[26] To date, there has been no systematic review of available evidence to confirm whether the currently accepted exposure parameters represent the best available techniques, especially in the context of evolving technology. This review seeks to either confirm current practices as optimal, or to uncover practices that may produce more optimised results.

1.4 Evidence synthesis

Systematic reviews are transparent, reproducible syntheses of the available evidence, designed to inform practice and policy.[27] When clinicians are selecting evidence to inform clinical practice, systematic reviews and meta-analyses represent the highest level of evidence available, according to the evidence-based healthcare evidence hierarchy.[28] Traditional selection of radiographic technique parameters has been a combination of governing body recommendations, manufacturer recommendations, and of the personal experience of the performing radiographer.[24] Medical radiations professionals in Australia are bound by the code of conduct produced by the Medical Radiations Practice Board of Australia (MRPBA). In this document, there is specific mention of the need to optimise exposure to ionising radiation to ensure that the exposure is ALARA.[29] By using evidence of the highest quality, such as that which is produced by systematic reviews and meta-analyses, practitioners can be assured they are aligning with the requirements set out by the MRPBA and meeting their legal and ethical obligations to patients.

1.5 Justification of review approach

The selection of a systematic review and meta-analysis was made for this review as it provided an opportunity to collate all the available evidence and synthesise it to produce meaningful recommendations for clinical practice. The Joanna Briggs Institute's approach also advocates for the inclusion of grey literature,[30] of which the author suspects there is a large amount in the area of exposure technique selection in radiography.

To date, there has been no large-scale systematic review of optimisation techniques for DDR. Diagnostic radiology procedures account for approximately 20% of a person's annual exposure to radiation.[31] As the National Council on Radiation Protection and

Measurements still endorses the linear no-threshold model of risk, we must limit as much as possible the exposure of people to ionising radiation, as any exposure, no matter how small, can increase a patient's lifetime cancer risk.[32] The use of a systematic review to collate all available evidence for technique optimisation limits the number of primary studies that need to be undertaken and uses the combined power of all included studies to draw meaningful conclusions from the data.

Chapter Two – Methods

2.1 Review question and objectives

The topic for this systematic review was to identify the effectiveness of adjusting radiographic technique parameters on image quality in projectional radiographs acquired on a DDR system.[33] The objective was to uncover clinically applicable exposure parameters for each routine radiographic projection for an average-sized patient that would result in adequate image quality for the lowest possible patient dose.

2.2 Participants

The review considered studies that included projectional radiographs acquired on a DDR system of the axial and appendicular skeleton. Only projectional radiographs of anthropomorphic phantoms, or those of adult or paediatric patients (living or post-mortem) were considered. Studies using test objects, such as contrast-detail phantoms, were excluded from this review as they are not considered true indicators of clinical utility of specified exposure factors.[5]

2.3 Interventions

This review considered studies that evaluated the effect of changing any/all/or a combination of the following radiographic technique parameters:

1. tube voltage within a clinically applicable range ≈ 40–150 kV
2. tube current time product within a clinically applicable range ≈ 0.1–200 mAs
3. additional beam filtration of Cu or Al in differing thicknesses
4. source-to-image receptor distance within a clinically applicable range >100 cm
5. use of anti-scatter grid, with a clinically acceptable ratio of 8:1–12:1, or air-gap technique.

2.4 Comparators

Evaluations of different ranges or options for each radiographic technique parameter were compared. Studies needed to directly compare either an optimised technique to a currently accepted standardised technique, or at least two different options for optimisation of a particular technique parameter to be included.

2.5 Outcomes

This review considered studies that included the following outcomes: evaluation of image quality and patient dose. Image quality needed to be evaluated by subjective means; objective evaluation was included for reference, but only in studies that also included subjective evaluation. Subjective image quality evaluation needed to be performed by individuals appropriately credentialed (per Australian standards regardless of the region of origin of the study) to make comment or report on diagnostic images; comments were made if this requirement was violated. Patient dose was considered also, to ensure that the technique was optimised, but only in studies that also measured image quality.

2.6 Study types

This review considered all experimental and quasi-experimental study designs including (but not limited to) randomised controlled trials, non-randomised controlled trials, before and after studies and interrupted time series studies that met our inclusion

criteria. In addition, analytical observational studies including prospective and retrospective cohort studies, case-control studies and analytical cross-sectional studies were considered for inclusion. This review also considered descriptive observational study designs including case series, individual case reports and descriptive cross-sectional studies for inclusion. Only studies published in English were included. Only studies published since 1997 were included, as the first digital flat panel detector was released for use in this year.[13]

2.7 Search strategy

The search strategy aimed to find both published and unpublished studies. An initial limited search of PubMed and Embase was undertaken, followed by an analysis of the text words contained in the title and abstract, and of the index terms used to describe articles. This informed the development of a search strategy which was tailored for each information source. Full search strategies for PubMed, Embase, Scopus, and CINAHL are detailed in Appendix 1. The reference list of all studies selected for critical appraisal was screened for additional studies.

The databases searched include: PubMed, EMBASE, Scopus, and CINAHL.

The search for unpublished studies included: ProQuest Repository for Masters and PhD theses.

Authors of included studies were contacted to obtain details of other studies worthy of inclusion. A search in Google Scholar of selected key words was performed, and results from the first ten pages was reviewed.

2.8 Study selection

Following the search, all identified citations were collated and uploaded into EndNote X8 (Clarivate Analytics, PA, USA) and duplicates were removed. Titles and abstracts were screened by two independent reviewers (CS & GM) for assessment against the inclusion criteria for the review. Studies that may have met the inclusion criteria were retrieved in full and their details were imported into EndNote X8. The full texts of selected studies were retrieved and assessed in detail against the inclusion criteria. Full-text studies that did not meet the inclusion criteria were excluded; reasons for exclusion are provided in Chapter three. Included studies underwent a process of critical appraisal. Several disagreements arose in the initial screening process that were successfully resolved through discussion.

2.9 Assessment of methodological quality

Selected studies were critically appraised by two independent reviewers (CS & GM) at the study level for methodological quality in the review using a bespoke critical appraisal instrument developed by the author and the author's team available for review in Appendix 2. Several disagreements arose in the initial screening process that were successfully resolved through discussion.

All studies, regardless of their methodological quality, underwent data extraction and synthesis (where possible).

2.10 Data extraction

Data were extracted from papers included in the review using a tailored extraction tool (available in Appendix 3) by the author and checked by the author's team for accuracy. The data extracted included specific details about the radiographic technique parameters investigated, the method of image quality evaluation, the types of examinations investigated, the subject used for the investigation (geometric phantom, anthropomorphic phantom, post-mortem subject, or evaluation of clinically acquired images), the type of DDR detector used and the results for image quality. No disagreements arose between the reviewers that required resolution through discussion. Authors of papers were contacted to request missing or additional data where required.

2.11 Data synthesis

Papers were unable to be pooled in statistical meta-analysis due to significant methodological heterogeneity. Subgroup analyses were unable to be conducted as there was insufficient data to investigate specific ranges of radiographic technique parameters for adult and paediatric populations, or for specific examinations of discrete body regions. Sensitivity analyses were also unable to be conducted to test decisions made regarding our analytical approach and our assumptions regarding the grouping of similar data.

Chapter Three – Results

The results of the comprehensive search are reported in full and presented in a PRISMA flow diagram in Figure 1.

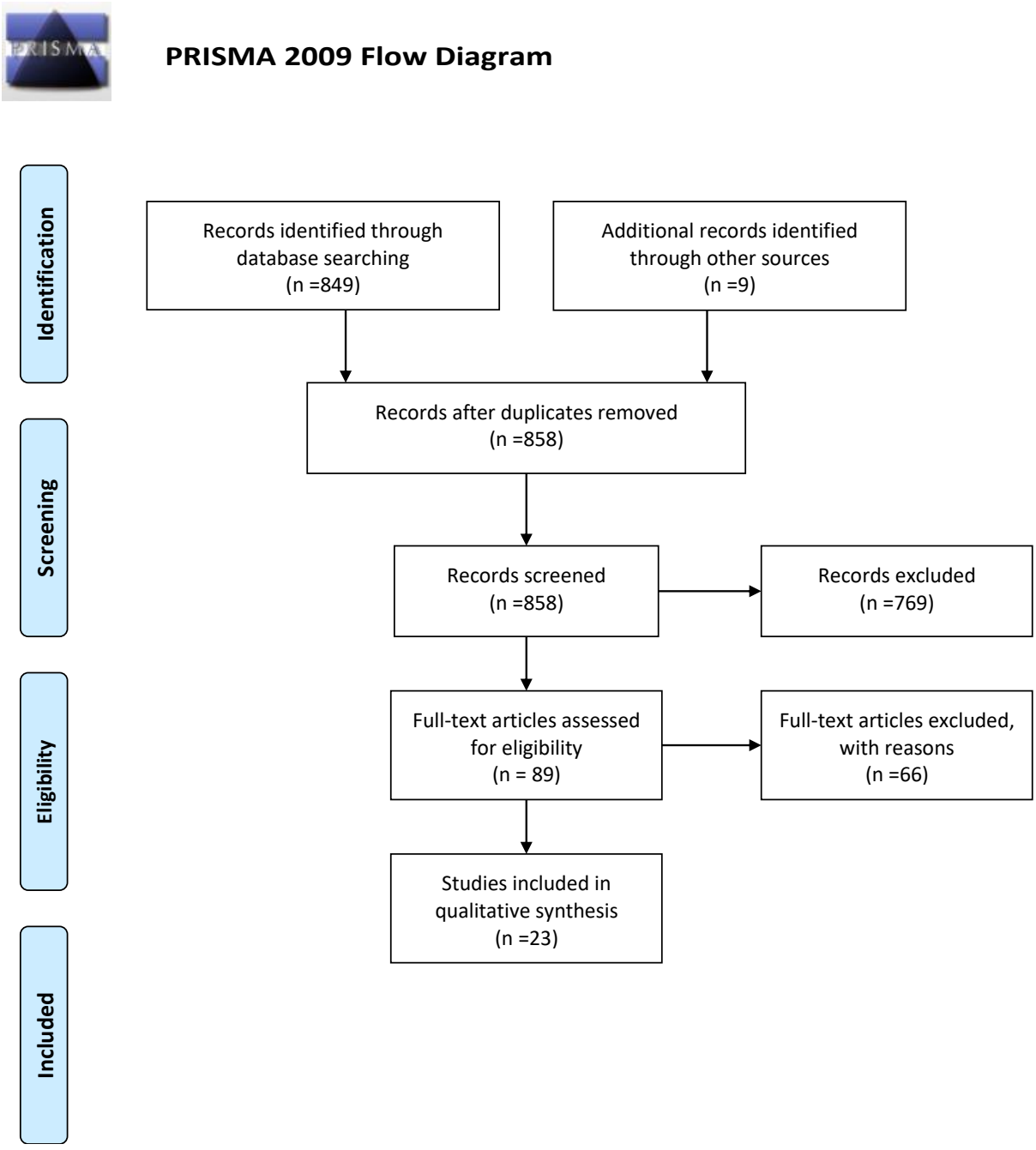

Figure 1 PRISMA flow diagram. From Moher et al.[34]

3.1 Description of included studies

Twenty-three studies were included in the narrative review. Included studies focussed on the full range of body regions and included both human and anthropomorphic phantoms as study participants. Included studies investigated all of the available technique parameters as outlined in the interventions section, but not all interventions

were evaluated for each individual body region. A complete summary of the included studies is shown in Appendix 4.

3.1.1 Excluded studies

Sixty-six studies were excluded at the full-text review stage. Fifteen studies[35-49] used a phantom that was not anthropomorphic, seven studies[50-56] did not report patient dose outcomes, eight studies[57-64] were not performed on DDR systems, seven studies[65-71] did not include subjective analysis of image quality, two included texts [72,73] were theses where the results had been published in other included studies, two included texts[74,75] were opinion pieces with no experimental data, one study[76] was in a language other than English, eight studies[77-84] did not compare the experimental techniques studied, eight included texts[24,85-91] were conference abstracts that did not include substantial enough information to warrant inclusion, three studies[2,92,93] used data that was duplicated in other studies, one study was excluded as the published study did not include substantial enough information to warrant inclusion and the author refused to provide further information. Four studies[94-97] were performed using DDR equipment that is outdated and no longer available for purchase. Whilst these studies met all of the inclusion criteria, as this type of detector is no longer available for purchase, a pragmatic decision was made to exclude them from the review.

3.1.2 Methodological quality

Methodological quality of the included studies was mixed. Full details of critical appraisal results are included in Appendix 5. To quantify the methodological quality of included studies, the author defined an arbitrary scoring system based on how many of the 11 criteria were met during critical appraisal to assist with reporting and interpretation of results. A study meeting eight or more criteria was considered “good”, a study meeting between five and eight criteria was considered “moderate”, and one meeting less than five criteria was considered “poor”.

Overall, nine studies were considered of “good” quality, 13 of “moderate” quality, and one of “poor” quality. In general, the criteria that most studies failed to meet were those of appropriate recruitment and representation of real-world patients. This is because the majority of studies were performed on anthropomorphic phantoms, but this also meant that most studies also met the criteria regarding standardised and similar samples. Important to note from this critical appraisal is that only approximately half of the studies met the criteria regarding appropriate equipment calibration. Of those that did not meet the criteria, the majority simply did not report whether the equipment was calibrated. In the absence of confirmation of correct calibration, the external validity of the results must be questioned. It is one of the recommendations of this review that confirmation that systems are performing to specification be a mandatory requirement in all studies investigating dose and image quality.

3.2 Findings of the review

The results for this review are sectioned into the various body parts. Under each section a short description of studies that met the inclusion criteria is provided along with the results.

3.2.1 Abdomen

3.2.1.1 Description of included studies

One study[98] met the inclusion criteria for radiographic evaluation of the abdomen. This study was a retrospective evaluation of clinical images acquired on identical imaging equipment with two different sets of radiographic technique parameters.

3.2.1.2 Methodological quality of included studies

The single included study was evaluated as having a good level of methodological quality.

3.2.1.3 Image quality evaluation

Visual grading analysis of each image was performed by three radiologists, independent of each other, according to a pre-established and agreed standard. Subjective image quality was rated on three criteria:

A. visualisation of the psoas outlines
B. visually sharp reproduction of the bones
C. reproduction of the kidney outlines.

The criteria used were adapted from a pre-established Commission of the European Communities (CEC) standard for radiographic evaluation of the urinary system, as there were no specific criteria for the abdomen.

Objective assessment was also undertaken by calculating the contrast-to-noise ratio (CNR) and signal-to-noise ratio (SNR) within the psoas muscle and sacroiliac joint.

For patients imaged in only one room, statistical significance was evaluated by the unpaired Student's t test for continuous data. For patients imaged in both rooms, statistical significance was evaluated by the paired Student's t test for continuous data. A p value of <0.05 was considered to indicate a statistically significant difference.

3.2.1.4 Patient dose evaluation

Patient dose for the included study was measured by effective dose. This was calculated by using DAP, SID, and field size as input data for the PCXMC software which calculated the resultant effective dose.

3.2.1.5 Technique comparison

One hundred and sixty-four patients were included for comparison of two different radiographic techniques. Of these 164 patients, 20 were imaged with both techniques, which allowed for direct comparison of exposure parameters and resultant image quality. The compared exposure parameters were as shown in Table 1:

Table 1 Technique parameters for AP abdomen projection

Protocol	**kVp**	**Detector Air Kerma**	**Filtration**	**SID**	**Grid Ratio**
Standard supine	80	4µGy	3.1mm Al (inherent)	120 cm	12:1
Experimental supine	92	5.8µGy	3.1mm Al (inherent)	120 cm	12:1

			+0.1mm Cu additional		
Standard erect	80	3µGy	3.1mm Al (inherent)	120 cm	10:1
Experimental erect	92	4.4µGy	3.1mm Al (inherent) +0.1mm Cu additional	120 cm	10:1

3.2.1.6 Image quality and dosimetry results

Objective measures of image quality appraisal revealed no significant differences between techniques in either the paired or unpaired groups (see Table 2).

Table 2 Objective image quality results for AP abdomen projection

Protocol	**Paired group p=**	**Unpaired group p=**
CNR Supine	0.52	0.34
CNR Erect	0.16	0.23
SNR Supine	0.29	0.18
SNR Erect	0.15	0.19

Mean image quality scores for the paired patients for each of the three criteria in each room were very similar, as shown in Table 3:

Table 3 Subjective image quality results for AP abdomen projection

Criteria	**Standard Technique**	**Experimental Technique**	**p value**
Visualisation of the psoas outline	Paired patients: 3.37 Unpaired patients: 3.18	Paired patients: 3.18 Unpaired patients: 3.18	0.01 0.82
Visually sharp reproduction of the bones	Paired patients: 3.73 Unpaired patients: 3.60	Paired patients: 3.73 Unpaired patients: 3.57	0.91 0.96
Reproduction of the kidney outlines	Paired patients: 4.63 Unpaired patients: 4.57	Paired patients: 4.31 Unpaired patients: 4.58	<0.001 0.78

Of all images performed, 99.9% were judged as having at least an “average” level of image quality.

In terms of dosimetry, the experimental technique yielded a 25.7% and 26.8% lower effective dose for supine and erect radiographs, respectively.

3.2.1.7 Optimised technique

The experimental technique was found to be the optimal technique in both instances. There was no statistically significant difference in image quality between the compared groups of patients who were imaged in only one room (p values >0.05 for all subjective and objective metrics). For patients who underwent imaging in both rooms, there were statistically significant differences in subjective image quality for visualisation of psoas outlines (p=0.01) and visualisation of kidney outlines (p <0.0001). There were no statistically significant differences in objective image quality for the paired groups (p values all >0.05).

3.2.2 Extremity

3.2.2.1 Description of included studies

One study[99] met the inclusion criteria for radiographic evaluation of the adult extremity (upper or lower limb). This study was an experimental evaluation of images of an anthropomorphic phantom on a single piece of imaging equipment with three different sets of radiographic technique parameters. The study investigated optimisation of the dorsi-palmar (DP) hand projection.

3.2.2.2 Methodological quality of included studies

The single included study was evaluated as having a moderate level of methodological quality.

3.2.2.3 Image quality evaluation

Image quality was evaluated by a large group of individuals, of varying qualification level and experience level, from radiologists through to student radiographers. Diagnostic quality of the images was evaluated according to criteria adapted from two radiographic positioning manuals on a five-point Likert scale. Criteria were as follows:

A. a visually sharp reproduction of the bony trabecular markings
B. adequate contrast and density to demonstrate soft tissue
C. a visually sharp reproduction of the cortical outlines of the anatomic structures

Results of these questions were evaluated by the two-way analysis of variance (ANOVA) with the Tukey post-hoc test (significance determined at $p < .05$).

Participants were also asked two questions to judge perceived image quality in terms of aesthetics and diagnostic quality as follows:

1. Do you find Image # _ aesthetically pleasing (i.e., “pretty”)?
2. How do you rate the overall diagnostic quality of Image #_?

Results of these questions were evaluated by the one-way ANOVA with the Tukey post-hoc test (significance determined at $p < .05$).

3.2.2.4 Patient dose evaluation

Patient dose for the included study was measured by dose area product (DAP).

3.2.2.5 Technique comparison

This study compared three different exposure techniques that adjusted kV and mAs. The compared exposure parameters were as shown in Table 4:

Table 4 Technique parameters for DP hand projection

Protocol	**kVp**	**mAs**	**Filtration**	**SID**	**Grid Ratio**	**DAP**
Standard	52	1.2	Not stated	127 cm	N/A	0.1
+20 kV	72	0.28	Not stated	127 cm	N/A	0.06
+30 kV	82	0.22	Not stated	127 cm	N/A	0.06

3.2.2.6 Image quality and dosimetry results

Image quality was evaluated according to the criteria outlined in the image quality section, and the results are as shown in Table 5:

Table 5 Image quality results for DP hand projection

Protocol	**Aesthetic Quality**		**Diagnostic Value**		**Criterion A**		**Criterion B**		**Criterion C**	
	Score	P=	Score	P=	Score	P=	Score	P=	Score	P=
Standard	4.2		4.33		4.47		3.93		4.44	
+20 kV	3.95		4.01	<0.0001	3.88	<0.00001	4.17	>0.05	3.83	<0.00001
+30 kV	3.58	<0.0001	3.67	<0.0001	3.46	<0.00001	4.01	>0.05	3.54	<0.00001

In terms of dosimetry, as shown in Table 4, DAP was reduced by 40% for both the +20 kV and +30 kV techniques.

3.2.2.7 Optimised technique

The standard technique was found to be the optimal in terms of perceived aesthetic and diagnostic quality, and in terms of the diagnostic criteria.

3.2.3 Shoulder

3.2.3.1 Description of included studies

One study[100] met the inclusion criteria for radiographic evaluation of the adult shoulder joint. This study was an experimental evaluation of clinical images performed with and without use of a radiographic grid.

3.2.3.2 Methodological quality of included studies

The single included study was evaluated as having a good level of methodological quality.

3.2.3.3 Image quality evaluation

Image quality was independently evaluated by two consultant radiologists. Diagnostic quality of the images was evaluated according to DIMOND III digital image criteria for AP shoulder examinations, which are based on the CEC criteria. Images were rated as either "fulfils" or "doesn't fulfil" the following criteria:

A. visualisation of typical structures of compacta and spongiosa
B. imaging of the joints in typical projections
C. visually sharp reproduction of the cortical joint surface.

A paired t test was used to assess the significance of quality differences, with significance level determined at $p<.05$). Inter-rater reliability was assessed using Cohen's kappa.

3.2.3.4 Patient dose evaluation

Patient dose for the included study was measured by thermoluminescent dosimeters attached to the patient which measured the entrance skin dose and backscatter. Effective dose (E) was calculated with these values and beam conditions by Xdose software that uses Monte Carlo modelling.

3.2.3.5 Technique comparison

This study compared the use of similar exposure conditions, with and without the use of a radiographic grid. At the time of investigation, both techniques were in routine use at the department. Choice of technique depended on radiographer preference. The compared exposure parameters were as shown in Table 6:

Table 6 Technique parameters for AP shoulder projection

Protocol	**kVp**	**Automatic Exposure Control (AEC)**	**Filtration**	**SID**	**Grid Ratio**
Grid	60	Yes	Not Stated	100 cm	13:1
Non-Grid	60	Yes	Not Stated	100 cm	Nil

3.2.3.6 Image quality and dosimetry results

The image quality results for the single included studies are shown below in Table 7:

Table 7 Image quality results for AP shoulder projection

Protocol	% fulfilment of criterion A	% fulfilment of criterion B	% fulfilment of criterion C
Grid	100	94	100
Non-Grid	100	100	78

Dosimetry results for the single included study are shown below in Table 8:

Table 8 Dose results for AP shoulder projection

Patient Population	Mean E with grid (µSv)	Mean E without grid (µSv)	% change
Female	7.05	1.75	303
Male	11.25	2.17	418

3.2.3.7 Optimised technique

All images included in the study were considered by the radiologists to be of diagnostic quality.

The authors did not report the p values for each of the image quality criteria, but narratively reported that no statistically significant differences were apparent. In consequence, they advocate for the removal of the grid for AP shoulder imaging.

3.2.4 Skull

3.2.4.1 Description of included studies

Two studies[99,101] met the inclusion criteria for radiographic evaluation of the adult skull. One study by Joyce et al.[101] was an investigation of the impact of adjusting SID on image quality and patient dose on the OF10° and lateral skull projectional radiographs. The other study by Lorusso et al.[99] was an investigation of the impact of adjusting kV on image quality and patient dose on lateral skull imaging.

3.2.4.2 Methodological quality of included studies

Methodological quality of included studies was mixed. Joyce et al.[101] was evaluated as having a high level of methodological quality. Lorusso et al.[99] was evaluated as having a moderate level of methodological quality.

3.2.4.3 Image quality evaluation

3.2.4.3.1 Joyce et al.[101]

Image quality was independently evaluated by four experienced radiographers. Diagnostic quality of the images was evaluated according to modified diagnostic requirements from the European Guidelines on Quality Criteria for Diagnostic Radiographic Images. Images were rated on a four-point scale on the following criteria:

OF10° skull projection

A. reproduction of the lambda
B. visually sharp reproduction of the frontal sinus, ethmoid cells, and apex of the petrous temporal bones and the internal auditory canals
C. reproduction of the cochlear canals
D. visually sharp reproduction of the outer and inner lamina of the cranial vault.

Lateral skull projection

A. visually sharp reproduction of the outer and inner lamina of the cranial vault, the floor of the sella, and the apex of the petrous temporal bone
B. visually sharp reproduction of the vascular channels, the vertex of the skull, and the trabecular structure of the cranium
C. reproduction of the posterior meningeal artery indentation
D. reproduction of the suture of the squamous temporal bone.

One-way ANOVA was performed on each dataset for dosimetric data, with significance level determined at $p<.05$. A Kruskal-Wallis test with a significance level of $p<0.05$ was used to analyse the image quality data. The inter- and intra-observer variability was expressed as the Fleiss kappa and Cohen kappa, respectively.

3.2.4.3.2 Lorusso et al.[99]

Image quality was evaluated by a large group of individuals, of varying qualification level and experience level, from radiologists through to student radiographers. Diagnostic quality of the images was evaluated according to criteria adapted from the European Guidelines on Quality Criteria for Diagnostic Radiographic Images on a five-point Likert scale. Criteria were as follows:

A. visually sharp reproduction of the outer and inner lamina of the cranial vault

B. visually sharp reproduction of the floor of the sella
C. visually sharp reproduction of the apex of the petrous temporal bone
D. visually sharp reproduction of the vertex of the skull
E. visually sharp reproduction of the trabecular structure of the cranium.

Results of these questions were evaluated by the two-way ANOVA with the Tukey post-hoc test (significance determined at $p < .05$).

Participants were also asked two questions to judge perceived image quality in terms of aesthetics and diagnostic quality as follows:

1. Do you find Image # _ aesthetically pleasing (ie, 'pretty')?
2. How do you rate the overall diagnostic quality of Image #_?

Results of these questions were evaluated by the one-way analysis of variance (ANOVA) with the Tukey post-hoc test (significance determined at $p < .05$).

3.2.4.4 Patient dose evaluation

The method of patient dose evaluation varied between the included studies. The study by Joyce et al.[101] estimated the effective dose to the patient by inputting entrance skin dose data as measured by thermoluminescent dosimeters placed at various points across the phantom into the PCXMC software that uses Monte Carlo modelling for its calculations. The study by Lorusso et al.[99] used DAP to compare patient doses for the evaluated techniques.

3.2.4.5 Technique comparison

Table 9 shows the experimental parameters for skull imaging used in each study. Techniques in bold are the reference technique (if used).

Table 9 Technique parameters for skull imaging

Study	Protocol	kVp	mAs	Filtration	SID	Grid	Grid F_0
Joyce et al.[101]	**OF10° 100**	**75**	**AEC**	**Not Stated**	**100 cm**	**Yes**	**100 cm**
Joyce et al.[101]	OF10° 130	75	AEC	Not Stated	130 cm	Yes	100 cm
Joyce et al.[101]	OF10° 150	75	AEC	Not Stated	150 cm	Yes	180 cm
Joyce et al.[101]	**Lateral 100**	**70**	**AEC**	**Not Stated**	**100 cm**	**Yes**	**100 cm**
Joyce et al.[101]	Lateral 130	70	AEC	Not Stated	130 cm	Yes	100 cm
Joyce et al.[101]	Lateral 150	70	AEC	Not Stated	150 cm	Yes	180 cm
Lorusso et al.[99]	**Standard**	**75**	**7.1**	**Not Stated**	**127 cm**	**6:1**	**Linear**
Lorusso et al.[99]	+20 kV	95	2.5	Not Stated	127 cm	6:1	Linear
Lorusso et al.[99]	+30 kV	105	1.7	Not Stated	127 cm	6:1	Linear

3.2.4.6 Image quality and dosimetry results

Dosimetry results for the two included studies are shown below in Table 10:

Table 10 Dose results for skull imaging

Protocol	E (mSv)	DAP ($dGycm^2$)	% reduction	P value
OF10° 100	0.0231			
OF10° 130	0.0183		20.1%	<0.05
OF10° 150	0.0178		21.9%	<0.05
Lateral 100	0.0114			
Lateral 130	0.0092		19.2%	<0.05
Lateral 150	0.0087		23.9%	<0.05
Standard		1.1		
+20 kV		0.6	45%	
+30 kV		0.4	64%	

3.2.4.6.1 Joyce et al.[101]

Visual Grading Analysis (VGA) data were narratively reported for each projection. For the OF10° projection overall, there were no statistically significant differences in image quality for radiographs acquired at each of the three SID values ($p > 0.05$). When each criterion was analysed individually, there was a statistically significant reduction in image quality for only criterion C, reproduction of the cochlear canals between the 100 and 150 cm images and the 130 and 150 cm images ($p \leq 0.05$). For all other criteria there were no statistically significant differences ($p > 0.05$).

For the lateral projection overall, there was a statistically significant decrease in image quality for images acquired at 150 cm and 130 cm. When each criterion was analysed individually, there was a statistically significant reduction in image quality for only criterion C, reproduction of the posterior meningeal artery indentation between the 100 and 150 cm images and the 130 and 150 cm images ($p \leq 0.05$). For all other criteria there were no statistically significant differences ($p > 0.05$).

3.2.4.6.2 Lorusso et al.[99]

Table 11 Image quality results for lateral skull projection

Parameter	Data	Protocol		
		Standard	**+20 kV**	**+30 kV**
Aesthetic Quality	Score	4.19	3.86	3.41
	P=			
Diagnostic Value	Score	4.35	3.86	3.57
	P=			
Criterion A	Score	4.26	3.06	3.53
	P=			≤.00001
Criterion B	Score	4.58	3.84	3.29
	P=			≤.00001
Criterion C	Score	4.09	3.56	3.08
	P=		≤.00001	≤.00001
Criterion D	Score	4.30	3.93	3.70
	P=		≤0.01	≤.00001
Criterion E	Score	4.31	3.78	3.32
	P=		≤.0001	≤.00001

Despite preference for the standard technique, all images were rated a 3 or higher, indicating that the images were of diagnostic quality.

3.2.4.7 Optimised technique

For the OF10° projection, the single included study showed that increasing SID from 100 cm to 150 cm did not have a statistically significant effect on overall image quality but has the potential to significantly reduce patient effective dose by 21.9%. For the lateral projection, both increasing SID and increasing kV lead to significant reductions in image quality; therefore in both circumstances the optimised technique is the standard technique.

3.2.5 Spine

3.2.5.1 Description of included studies

Five studies[100, 102-105] met the inclusion criteria for radiographic evaluation of the adult spinal column, two investigating the cervical spine region specifically,[100, 102] and three investigating the lumbar spine region.[103, 104, 105] Included studies investigated a number of different parameter manipulations, including SID, kV, and grid usage.

3.2.5.2 Methodological quality of included studies

Methodological quality of included studies was mixed and graded as in Table 12:

Table 12 Methodological quality grading of included studies for spine imaging

Study	**Quality level**
Roberts et al.[100]	Moderate
Joyce et al.[102]	Moderate
Brindhaban et al.[103]	Moderate
Geijer et al.[104] (2009)	Moderate
Geijer and Persliden [105] (2005)	Moderate

3.2.5.3 Image quality evaluation

3.2.5.3.1 Roberts et al.[100]

Image quality was measured and evaluated in an identical method to that outlined for the same study in the shoulder section. The specific DIMOND III criteria for the lateral cervical spine projection are as follows:

A. complete imaging of the cervical spine, including the upper cervical spine and the seventh vertebra
B. visually sharp imaging, as a single line, of the upper and lower-plate surface in the centred beam area
C. visualisation of the intervertebral spaces, intervertebral joints and spinous processes
D. visualisation of the soft tissues, particularly the retrotracheal space
E. visually sharp imaging of the cortical and trabecular structures
F. visualisation of the upper border of the first thoracic vertebra.

3.2.5.3.2 Joyce et al.[102]

Image quality was evaluated by a panel of four experienced clinicians; specialisation was not disclosed. As this study investigated specifically the arthritic cervical spine, the criteria evaluated both normal anatomic features and arthritic indicators. Each of the experimental images was compared to a reference image, and the raters were asked to choose whether the experimental image was better, equal, or worse than the reference image for the following criteria:

A. intervertebral disc space
B. intervertebral facet joint
C. spinous processes
D. trabecular bone pattern.

Results of this investigation were analysed by using the non-parametric Mann-Whitney U test and a significance of $p<0.05$ was utilised. Inter-observer and intra-observer variability was also evaluated.

3.2.5.3.3 Brindhaban et al.[103]

Image quality was evaluated by a panel of three experienced radiologists. Diagnostic quality of the images were evaluated according to the European Guidelines on Quality Criteria for Diagnostic Radiographic Images for lumbar spine imaging. Images were rated on a five-point scale on the following criteria:

A. reproduction of the spinous and transverse processes
B. reproduction of the intervertebral joints
C. visually sharp reproduction of the pedicles
D. visually sharp reproduction, as a single line, of the upper and lower-plate surfaces in the centred beam area.

The authors weighted criteria C and D as being twice as important as criteria A and B. The Kruskal-Wallis test was used for evaluation, with significance at $p<0.05$.

3.2.5.3.4 Geijer et al.[104] (2009)

Image quality was evaluated by a panel of eight radiologists. Diagnostic quality of each projection was evaluated according to the following criteria based on the European guidelines on quality criteria for diagnostic radiographic images.

AP Projection:

A. visually sharp reproduction of the upper and lower end-plate surfaces in the centred beam area
B. visually sharp reproduction of the pedicles
C. reproduction of the intervertebral joints
D. reproduction of the spinous and transverse processes
E. visually sharp reproduction of the cortex and trabecular structures
F. reproduction of the sacroiliac joints.

Lateral Projection:

A. visually sharp reproduction of the upper and lower end-plate surfaces
B. reproduction of the pedicles and the intervertebral foramina
C. visualisation of the spinous processes
D. visually sharp reproduction of the cortex and trabecular structures.

A rank-invariant non-parametric method of analysis was employed to evaluate the images. The value Relative Position (RP) describes the change in image quality between the reference image and the experimental image, and can have a value from –1 to 1. The value Relative Rank Variance (RV) was used as a measure of homogeneity; the closer RV is to 0 the more homogenous the change is for the experimental group.

3.2.5.3.5 Geijer and Persliden[105] (2005)

Image quality was evaluated by a panel of eight radiologists. Diagnostic quality of each projection was evaluated according to the following 13 criteria, the first seven which

are based on the European guidelines on quality criteria for diagnostic radiographic images.

A. visually sharp reproduction, as a single line, of the upper and lower-plate surfaces in the centred beam area
B. visually sharp reproduction of the pedicles
C. reproduction of the intervertebral joints
D. reproduction of the spinous and transverse processes
E. visually sharp reproduction of the cortex and trabecular structures
F. reproduction of the adjacent soft tissues, particularly the psoas shadow
G. reproduction of the sacroiliac joints
H. image quality in underexposed areas
I. image quality in overexposed areas
J. amount of noise in the image
K. contrast
L. sharpness
M. overall quality.

For all 13 criteria, a VGA score was calculated based on a formula apparently derived by the authors. For the seven CEC criteria alone, a VGA score was also calculated, and median VGA values for each observer and kV level were analysed with an analysis of variance (ANOVA) with a Bonferroni post-hoc correction.

3.2.5.4 Patient dose evaluation

The method of patient dose evaluation varied between the included studies, as shown in Table 13.

Table 13 Dose measurement methods for spine imaging

Study	**Dose measurement method**
Roberts et al.[100]	Effective dose calculated by Xdose software from measured ESD
Joyce et al.[102]	ESD measurements by thermoluminescent dosimeters (TLDs)
Brindhaban et al.[103]	Effective dose
Geijer et al.[104] (2009)	Effective dose calculated by PCXMC software from measured ESD
Geijer and Persliden [105] (2005)	Effective dose calculated by PCXMC software from measured ESD

3.2.5.5 Technique comparison

3.2.5.5.1 Lateral cervical spine

Techniques in bold in Table 14 are the reference technique (if used).

Table 14 Technique parameters for lateral cervical spine projection

Study	kVp	mAs	Filtration	SID	Grid	Grid Ratio
Joyce et al.[102]	65	3.81	Not Stated	150 cm	Not stated	
	65	5.51	Not Stated	180 cm	Not stated	
	65	7.44	Not Stated	210 cm	Not stated	
Roberts et al.[100]	80	AEC	Not Stated	180 cm	No	
	98	AEC	Not Stated	180 cm	Yes	13:1

3.2.5.5.2 Lumbar spine

Techniques in bold in Table 15 are the reference technique (if used).

Table 15 Technique parameters for lumbar spine imaging

Study	Projection	kVp	mAs	Filtration	SID	Grid	Grid F_0
Brindhaban et al.[103]	**AP**	**85**	**16**	**Not Stated**	**Not Stated**	**Not stated**	
	AP	**85**	**25**	**Not Stated**	**Not Stated**	**Not stated**	
	AP	**85**	**32**	**Not Stated**	**Not Stated**	**Not stated**	
	AP	98	8	Not Stated	Not Stated	Not stated	
	AP	98	12	Not Stated	Not Stated	Not stated	
	AP	95	16	Not Stated	Not Stated	Not stated	
	AP	112	4	Not Stated	Not Stated	Not stated	
	AP	113	6	Not Stated	Not Stated	Not stated	
	AP	109	8	Not Stated	Not Stated	Not stated	
Geijer et al.[104] (2009)	**AP**	**77**	**AEC (400)**	**2.5mm Al**	**110 cm**	**Yes**	**12:1**
	AP	66	AEC (800)	4.5mm Al	110 cm	Yes	12:1
	AP	60	AEC (800)	4.5mm Al	110 cm	Yes	12:1

	Lateral	**90**	**AEC (400)**	**4.5mm Al**	**110 cm**	**Yes**	**12:1**
	Lateral	77	AEC (800)	4.5mm Al	110 cm	Yes	12:1
	Lateral	70	AEC (800)	4.5mm Al	110 cm	Yes	12:1
	AP	48	125	5.2mm Al	Not Stated	Not stated	
	AP	52	80	5.2mm Al	Not Stated	Not stated	
	AP	57	50	5.2mm Al	Not Stated	Not stated	
	AP	63	40	5.2mm Al	Not Stated	Not stated	
	AP	70	25	5.2mm Al	Not Stated	Not stated	
Geijer and Persliden[105] (2005)	**AP**	**77**	**20**	**5.2mm Al**	**Not Stated**	**Not stated**	
	AP	85	12.5	5.2mm Al	Not Stated	Not stated	
	AP	96	10	5.2mm Al	Not Stated	Not stated	
	AP	109	6.3	5.2mm Al	Not Stated	Not stated	
	AP	125	5	5.2mm Al	Not Stated	Not stated	

3.2.5.6 Image quality and dosimetry results

3.2.5.6.1 Lateral cervical spine

Image quality results for the lateral cervical spine projection are reported in Table 16:

Table 16 Image quality and dosimetry results for lateral cervical spine projection

Study	kVp	mAs	Image quality (IQ) score	Dose
Joyce et al.[102]	**65**	**3.81**	**56.0**	**113.41** µGy (ESD)
	65	5.51	50.85	87.47 µGy (ESD)
	65	7.44	65.35	70.965µGy (ESD)
Roberts et al.[100]	80	AEC	A: 95% B: 100% C: 100% D: 100% E: 100% F:78%	Male: 2.44µSv (E) Female: 1.44 44µSv (E)
Roberts et al.[100]	98	AEC	A: 89% B: 100% C: 100% D: 100% E: 100% F: 58%	Male: 3.5144µSv (E) Female: 2.8644µSv (E)

3.2.5.6.2 Lumbar Spine

Image quality scores and dosimetry results for the three included studies are presented below in Table 17:

Table 17 Image quality and dosimetry results for lumbar spine imaging

Study	Projection	kVp	mAs	IQ Score	Dose
Brindhaban et al.[103]	**AP**	**85**	**16**	**4.2**	**0.34mSv (E)**
	AP	**85**	**25**	**4.2**	**0.52mSv (E)**
	AP	**85**	**32**	**4.8**	**0.7mSv (E)**
	AP	98	8	4.1	0.23mSv (E)
	AP	98	12	3.9	0.36mSv (E)
	AP	95	16	4.4	0.43mSv (E)
	AP	112	4	3.9	0.16mSv (E)
	AP	113	6	3.7	0.25mSv (E)

	AP	109	8	4.0	0.29mSv (E)
Geijer et al.[104] (2009)	**AP**	**77**	**AEC (400)**		**0.10mSv (E)**
	AP	66	AEC (800)	RP 0.151 RRV 0.011	0.05mSv (E – est)
	AP	60	AEC (800)	RP 0.689 RRV 0.000	<0.10mSv (E – est)
	Lateral	**90**	**AEC (400)**		**0.05mSv (E)**
	Lateral	77	AEC (800)	RP -0.213 RRV 0.203	0.03mSv (E – est)
	Lateral	70	AEC (800)	RP 0.290 RRV 0.290	<0.05mSv (E – est)
	AP	48	125	0.25	0.11mSv (E)
	AP	52	80	0.33	0.11mSv (E)
	AP	57	50	-0.04	0.11mSv (E)
	AP	63	40	0.21	0.11mSv (E)
	AP	70	25	-0.17	0.11mSv (E)
Geijer and Persliden[105] (2005)	**AP**	**77**	**20**		0.11mSv (E)
	AP	85	12.5	-0.21	0.11mSv (E)
	AP	96	10	-0.67	0.11mSv (E)
	AP	109	6.3	-0.58	0.11mSv (E)
	AP	125	5	-0.75	0.11mSv (E)

None of the included studies reported p values for each of the studied projections. Some studies included narrative reports of significance; in their 2005 study, Geijer and Persliden[105] reported that for the AP lumbar spine projection, VGA scores were significantly inferior for all values of 96 kV and above in comparison to all levels from 85 kV and below (p values between 0.000 and 0.005). Joyce et al.[102] reported in their 2008 study that there was a significant improvement in image quality and decrease in ESD for lateral cervical spine projections performed at 210 cm compared to those performed at 150 cm ($p<0.05$). Geijer et al.[104] (in 2009) reported a statistically significant change in improvement of image quality when the kV was lowered from 77

to 60 and the system speed was changed from 400 to 800 for the AP projection. No statistically significant results were reported for normal patient size for the lateral projection.

3.2.5.7 Optimised technique

For the lateral cervical spine projection, results indicate that increasing SID is an effective optimisation technique. Removing the anti-scatter grid is an effective dose reduction method but there is an associated loss of image quality.

For both the AP and lateral lumbar spine projections, reducing kV was an effective method to improve image quality. One study[103] also had an associated increase in patient dose, but two other studies[104,105] showed that it was possible to avoid this with adjustment of AEC technique parameters.

3.2.6 Paediatric imaging

3.2.6.1 Description of included studies

One study[106] met the inclusion criteria for paediatric imaging. This study was a triple-blind randomised controlled trial that investigated the effect of changing kV on image quality for paediatric chest radiographs.

3.2.6.2 Methodological quality of included studies

The single included study was evaluated as having a good level of methodological quality.

3.2.6.3 Image quality evaluation

Five radiologists of differing levels of experience evaluated clinical image quality of chest radiographs using a visual grading analysis score (VGAS) technique based on the revised CEC imaging criteria. Criteria were as follows:

A. Position and symmetry of the scapula and sternoclavicular joint:
    a. sternoclavicular joint symmetry (1 point)
    b. scapulas spin out (1 point).
B. Lung fields:
    a. within the zone. (1 point)
    b. in the zone (1 point)
    c. take-away (1 point).
C. Trachea shows:
    a. pipe (1 point)
    b. carina (1 point)
    c. left main bronchus (1 point)
    d. right main bronchus (1 point)
    e. segmental bronchus (1 point).
D. Mediastinum:
    a. between one and four thoracic vertebrae (1 point)
    b. most thoracic vertebrae (1 point)
    c. all thoracic vertebrae (1 point)
    d. sections of the aorta (1 point)
    e. right cardiac border (1 point)
    f. left cardiac border (1 point).
E. Ribs:
    a. bone cortex (1 point)
    b. trabecular bone (1 point).
F. Chest wall:
    a. soft tissue (1 point)
    b. fat line (1 point)
    c. breast tissue (1 point).
G. Noise:
    a. free of noise (3 points)
    b. scarce noise (2 points)
    c. significant noise, did not affect diagnosis (1 point)
    d. obvious noise, no diagnosis possible (0 points).

The scoring rubric used to assign a rating to the images is outlined below in Table 18:

Table 18 VGA scoring criteria for paediatric imaging

Scores	**Excellent**	**Good**	**Moderate**	**Poor**
Total Points:	18-24	14-17	10-13	<10

Mean values for VGAS were evaluated with one-way ANOVA with significance at $p<0.05$.

3.2.6.4 Patient dose evaluation

Patient dose for the included study was measured by dose area product (DAP).

3.2.6.5 Technique comparison

This study compared three different exposure techniques that adjusted kV and mAs. The compared exposure parameters were as in Table 19. Techniques in bold are the reference technique (if used):

Table 19 Technique parameters for paediatric chest imaging

Age	**Protocol**	**kVp**	**AEC (Speed 400)**	**Filtration**	**SID**	**Grid**	**Grid Ratio**
0-1	A	50	Yes	Not stated	Not stated	Yes	8:1 12:1
0-1	B	60	Yes	Not stated	Not stated	Yes	8:1 12:1
0-1	C	70	Yes	Not stated	Not stated	Yes	8:1 12:1
0-1	**Control**	**102**	**Yes**	**Not stated**	**Not stated**	**Yes**	**8:1 12:1**
1-3	A	55	Yes	Not stated	Not stated	Yes	8:1 12:1
1-3	B	66	Yes	Not stated	Not stated	Yes	8:1 12:1
1-3	C	73	Yes	Not stated	Not stated	Yes	8:1 12:1
1-3	**Control**	**102**	**Yes**	**Not stated**	**Not stated**	**Yes**	**8:1 12:1**
3-7	A	60	Yes	Not stated	Not stated	Yes	8:1 12:1
3-7	B	70	Yes	Not stated	Not stated	Yes	8:1 12:1
3-7	C	81	Yes	Not stated	Not stated	Yes	8:1 12:1
3-7	**Control**	**102**	**Yes**	**Not stated**	**Not stated**	**Yes**	**8:1 12:1**
7-11	A	70	Yes	Not stated	Not stated	Yes	8:1 12:1

7-11	B	81	Yes	Not stated	Not stated	Yes	8:1 12:1
7-11	C	90	Yes	Not stated	Not stated	Yes	8:1 12:1
7-11	**Control**	**102**	**Yes**	**Not stated**	**Not stated**	**Yes**	**8:1 12:1**
11-14	A	80	Yes	Not stated	Not stated	Yes	8:1 12:1
11-14	B	90	Yes	Not stated	Not stated	Yes	8:1 12:1
11-14	C	102	Yes	Not stated	Not stated	Yes	8:1 12:1
11-14	**Control**	**102**	**Yes**	**Not stated**	**Not stated**	**Yes**	**8:1 12:1**

3.2.6.6 Image quality and dosimetry results

The results for image quality and patient dose for the single included study are presented below in Table 20.

Table 20:Image quality and dosimetry results for paediatric imaging

Age	Protocol	kVp	VGAS	DAP
0-1	A	50	18.02	0.42
0-1	B	60	17.89	0.31
0-1	C	70	17.78	0.29
0-1	**Control**	**102**	**16.67**	**0.34**
1-3	A	55	18.06	0.56
1-3	B	66	17.95	0.39
1-3	C	73	17.88	0.34
1-3	**Control**	**102**	**16.60**	**0.40**
3-7	A	60	18.11	0.43
3-7	B	70	17.93	0.31
3-7	C	81	17.72	0.22
3-7	**Control**	**102**	**16.68**	**0.32**
7-11	A	70	17.98	0.47
7-11	B	81	17.82	0.29
7-11	C	90	17.69	0.21
7-11	**Control**	**102**	**16.69**	**0.25**
11-14	A	80	17.96	0.44
11-14	B	90	17.77	0.25
11-14	C	102	16.61	0.26
11-14	**Control**	**102**	**16.57**	**0.27**

DAP for protocol A was significantly higher than control ($p<0.001$), not statistically significant for protocol B ($p=0.75$). Protocol C gave the lowest dose (p value not stated).

Mean VGAS was significantly lower for control protocol than all experimental protocols ($p<0.001$) No difference between protocol A and B ($p=0.334$). Protocol C gave significantly lower image quality than protocol A ($p=0.008$) and protocol B ($p=0.049$).

3.2.6.7 Optimised technique

In every age group, as kV increased, VGAS score decreased. The protocols with the highest patient dose were associated with the highest image quality. For ages 0–1, 1–3, 3–7, and 11–14 years both protocol B and C gave better or equivalent image quality scores for lower dose than the control protocol. For ages 7–11 years only protocol C gave better or equivalent image quality for lower patient dose.

3.2.7 Pelvic girdle

3.2.7.1 Description of included studies

Eight studies[99, 107-113] met the inclusion criteria for radiographic investigation of the adult pelvis and hip. For clarity these studies will be grouped by projection.

3.2.7.1.1 Horizontal beam lateral hip

A single study[107] met the inclusion criteria for the horizontal beam lateral hip projection. This phantom study investigated the use of anti-scatter grid, additional tube filtration, SID, ODD, and kV.

3.2.7.1.2 AP Pelvis

Seven studies[99, 108-113] met the inclusion criteria for the AP pelvis projection. Two studies[108,109] investigated the effect of changing SID on image quality, two studies[110,111] investigated the effect of changing patient orientation on image quality, and three studies[99,112,113] investigated the effect of changing kV on image quality.

3.2.7.2 Methodological quality of included studies

The included studies' methodological quality was assessed as shown below in Table 21:

Table 21 Methodological quality grading of included studies for pelvis imaging

Study	**Quality Grading**
Charnley et al.[107]	Good
England et al.[108]	Good
Heath et al.[109]	Good
Persliden et al.[112]	Moderate
Lorusso et al.[99]	Moderate
Fauber et al.[113]	Moderate
Harding et al.[110]	Good
Manning-Stanley et al.[111]	Moderate

3.2.7.3 Image quality evaluation

3.2.7.3.1 Horizontal beam lateral hip

A total of five observers (four reporting radiographers and one clinical radiographer) evaluated images of an anthropomorphic phantom against that of a reference standard according to the following criteria based on the CEC criteria. Wording of the criteria is faithfully reproduced as it appears in the original study, with adjustment to Australian spelling.

A. Is the sharpness of the cortex and trabeculae pattern in relation to the acetabulum and the associated joint space?
B. Is the sharpness of the femoral head articular cortex
C. Is the sharpness the trabeculae pattern of the femoral head?
D. Is the sharpness of the cortex and trabeculae pattern of the femoral neck
E. Is the sharpness of the cortex and trabeculae pattern of the proximal femoral shaft that is visible
F. Overall, the radiographic image quality of the full image is:
G. For suspected fracture, is the image on the left diagnostically acceptable?

Visual grading analysis was performed using a two alternative forced choice technique, comparing the experimental image to a reference standard. Image quality results were summarised using the mode.

3.2.7.3.2 AP Pelvis

A summary of the image quality criteria and statistical methods for each of the included studies is presented below in Table 22. Appendix 6 details in full the actual image quality criteria used for each of the studies.

Table 22 Image quality methods for pelvis imaging

Study	**Observers**	**IQ Criteria**	**Statistical Analysis**
England et al.[108]	One radiologist, two reporting radiographers	VGA using adapted European Commission Guidelines on Quality Criteria – 3-point scale, from perfect to inadequate	Mann-Whitney U test for non-parametric and t test for parametric data
Fauber et al.[113]	Two senior radiologists	Graded the amount of noise present, and ranked images from best to worst	1-way ANOVA for dose, Tukey post-hoc test for significance (significance value at $p<0.05$)
Lorusso et al.[99]	Student radiographers, radiographers, radiologists	5-point scale – 1 being the worst, 5 being the best, 3 being acceptable for diagnosis	1-way ANOVA for dose, Tukey post-hoc test for significance (significance determined at $p<0.05$).
Persliden et al.[112]	Two radiologists	5-point scale – 1 being the best, 5 being the worst, 3 being acceptable for diagnosis. Standard deviation of noise calculated for a circular ROI	Nil
Heath et al.[109]	Two reporting radiographers, Two senior radiographers	VGA using adapted European Commission Guidelines on Quality Criteria – 5-point scale, 1 being severe decrease in visibility, 3 being the same as reference standard, 5 being severe increase	Paired t test for differences due in IQ and dose

Harding et al.[110]	One radiologist, two reporting radiographers	VGA using adapted European Commission Guidelines on Quality Criteria – 3-point scale, 3 being perfect, 1 being inadequate, 2 being adequate	Image quality – Mann-Whitney U test Dose – t test
Manning-Stanley et al.[111]	Two radiographers	VGA using adapted European Commission Guidelines on Quality Criteria on a 3-point scale, 3 being perfect, 1 being inadequate, and 2 being adequate	Dose – t test IQ – Wilcoxon signed ranks test

3.2.7.4 Patient dose evaluation

3.2.7.4.1 Horizontal beam lateral hip

Patient dose for the included study[107] was measured by dose area product (DAP).

3.2.7.4.2 AP Pelvis

Dose evaluation for the included studies is presented below in Table 23:

Table 23 Dosimetry methods for AP pelvis projection

Study	**Dose statistic**	**Dose measurement method**
England et al.[108]	ESD and E	Quality Assurance Dose Data System using SSD, mAs, kV
Heath et al.[109]	ESD and E	Quality Assurance Dose Data System using SSD, mAs, kV
Persliden et al.[112]	ESD and E	E calculated by PCXMC using ESD, kV and filtration
Lorusso et al.[99]	DAP	DAP meter on tube
Fauber et al.[113]	ESD	TLDs
Harding et al.[110]	ESD and E	Quality Assurance Dose Data System using SSD, mAs, kV
Manning-Stanley et al.[111]	ESD and E	Quality Assurance Dose Data System using SSD, mAs, kV

3.2.7.5 Technique comparison

3.2.7.5.1 Horizontal beam lateral hip

Only the five lowest DAP techniques that had greater or equivalent image quality to that of the reference standard were reported in full. Image quality statistics were not reported in full, but it was narratively reported that all of the five lowest DAP techniques listed below in Table 24 had equivalent or better image quality to that of the reference standard. Technique in bold is the reference technique.

Table 24 Technique parameters and dosimetry results for horizontal beam lateral hip projection

kVp	AEC	Filtration	SID	Grid	ODD	DAP (μGym^2)
90	Yes	0.1mm Cu	135 cm	Yes	45 cm	20.3
110	Yes	0.1mm Cu	180 cm	No	45 cm	40
100	Yes	0.1mm Cu	180 cm	No	45 cm	48
110	Yes	Nil	180 cm	No	45 cm	50
90	Yes	0.1mm Cu	180 cm	No	45 cm	58
90	**Yes**	**Nil**	**180 cm**	**Yes**	**45 cm**	**166.5**

3.2.7.5.2 AP Pelvis

Exposure techniques for the AP pelvis projection are outlined in Table 25; those in bold are reference techniques (where used).

Table 25 Technique parameters for AP pelvis projection

Study	Protocol	kVp	AEC	Filtration	SID	Grid	Patient Orientation
Fauber et al.[113]	**A**	**70**	**50 mAs**	Not stated	Not stated	Not stated	
	B	81	25	Not stated	Not stated	Not stated	
	C	93	12.5	Not stated	Not stated	Not stated	
	D	105	6.3	Not stated	Not stated	Not stated	
	E	121	3.2	Not stated	Not stated	Not stated	
Lorusso et al.[99]	**A**	**85**	**10 mAs**	**Not Stated**	**127 cm**	**Yes**	
	B	105	4 mAs	Not Stated	127 cm	Yes	
	C	115	3.7 mAs	Not Stated	127 cm	Yes	
Persliden et al.[112]	A	77	Not stated	4.85mm Al (total)	Not Stated	Not stated	
	B	77	Not stated	4.85mm Al (total)	Not Stated	Not stated	
	C	77	Not stated	4.85mm Al (total)	Not Stated	Not stated	

	D	77	Not stated	4.85mm Al (total)	Not Stated	Not stated	
	E	77	Not stated	4.85mm Al (total)	Not Stated	Not stated	
	F	77	Not stated	4.85mm Al (total)	Not Stated	Not stated	
	G	77	Not stated	4.85mm Al (total)	Not Stated	Not stated	
	H	77	Not stated	4.85mm Al (total)	Not Stated	Not stated	
	I	77	Not stated	4.85mm Al (total)	Not Stated	Not stated	
	J	77	Not stated	4.85mm Al (total)	Not Stated	Not stated	
	K	77	Not stated	4.85mm Al (total)	Not Stated	Not stated	
	L	77	Not stated	4.85mm Al (total)	Not Stated	Not stated	
	M	77	Not stated	4.85mm Al (total)	Not Stated	Not stated	
	N	77	Not stated	4.85mm Al (total)	Not Stated	Not stated	
	O	77	Not stated	4.85mm Al (total)	Not Stated	Not stated	
	P	77	Not stated	4.85mm Al (total)	Not Stated	Not stated	
	Q	77	Not stated	4.85mm Al (total)	Not Stated	Not stated	
Heath et al.[109]	**A**	**80**	**AEC**	**Not Stated**	**100 cm**	**Yes**	
	B	80	AEC	Not Stated	80 cm	Yes	
	C	80	AEC	Not Stated	90 cm	Yes	
	D	80	AEC	Not Stated	110 cm	Yes	
	E	80	AEC	Not Stated	120 cm	Yes	
	F	80	AEC	Not Stated	130 cm	Yes	
	G	80	AEC	Not Stated	140 cm	Yes	
	H	80	AEC	Not Stated	147 cm	Yes	
	I	80	AEC	Not Stated	80 cm	No	
	J	80	AEC	Not Stated	90 cm	No	

	K	80	AEC	Not Stated	100 cm	No	
	L	80	AEC	Not Stated	110 cm	No	
	M	80	AEC	Not Stated	120 cm	No	
	N	80	AEC	Not Stated	130 cm	No	
	O	80	AEC	Not Stated	140 cm	No	
	P	80	AEC	Not Stated	147 cm	No	
Harding et al.[110]	A (Pelvis)	75	AEC	3.5mm Al (total)	115 cm	Yes	
	B (Pelvis)	75	AEC	3.5mm Al (total)	115 cm	Yes	**Patient orientation reversed**
	C (Hips)	75	AEC	3.5mm Al (total)	115 cm	Yes	
	D (Hips)	75	AEC	3.5mm Al (total)	115 cm	Yes	**Patient orientation reversed**
Manning-Stanley et al.[111]	A	80	AEC – top 2	Not Stated	100 cm	Yes	
	B	80	AEC – top left	Not Stated	100 cm	Yes	
	C	80	AEC – top right	Not Stated	100 cm	Yes	
	D	80	AEC – mid	Not Stated	100 cm	Yes	
	E	80	AEC – top left & mid	Not Stated	100 cm	Yes	
	F	80	AEC – top right & mid	Not Stated	100 cm	Yes	
	G	80	AEC – All	Not Stated	100 cm	Yes	
	H	80	AEC – top 2	Not Stated	100 cm	Yes	**Patient orientation reversed**
	I	80	AEC – top left	Not Stated	100 cm	Yes	**Patient orientation reversed**
	J	80	AEC – top right	Not Stated	100 cm	Yes	**Patient orientation reversed**

	K	80	AEC – mid	Not Stated	100 cm	Yes	**Patient orientation reversed**
	L	80	AEC – top left & mid	Not Stated	100 cm	Yes	**Patient orientation reversed**
	M	80	AEC – top right & mid	Not Stated	100 cm	Yes	**Patient orientation reversed**
	N	80	AEC – All	Not Stated	100 cm	Yes	**Patient orientation reversed**

3.2.7.6 Image quality and dosimetry results

Dosimetry and image quality results for the AP pelvis projection are reported in Table 26 and Table 27, respectively.

Table 26 Dosimetry results for AP pelvis projection

Study	**Protocol**	**Dose**	**P Value**
Fauber et al.[113]	**A**	**187.4mR (ESD)**	**<0.05**
	B	129.3mR (ESD)	<0.05
	C	80.53mR (ESD)	<0.05
	D	49.48mR (ESD)	<0.05
	E	39.04mR (ESD)	>0.05
Lorusso et al.[99]	**A**	**3.7dGycm^2 (DAP)**	
	B	2.1dGycm^2 (DAP)	
	C	2.0dGycm^2 (DAP)	
Persliden et al.[112]	A	0.026mGy (ESD)	
	B	0.032mGy (ESD)	
	C	0.038 mGy (ESD)	
	D	0.048 mGy (ESD)	
	E	0.06 mGy (ESD)	
	F	0.078 mGy (ESD)	
	G	0.095 mGy (ESD)	
	H	0.119 mGy (ESD)	
	I	0.156 mGy (ESD)	
	J	0.19 mGy (ESD)	
	K	0.237 mGy (ESD) 0.06mSv (E)	
	L	0.299 mGy (ESD)	
	M	0.38 mGy (ESD)	
	N	0.477 mGy (ESD)	
	O	0.595 mGy (ESD)	
	P	0.76 mGy (ESD)	

	Q	0.951 mGy (ESD)	
Heath et al.[109]	**A**	**0.51mSv (E)**	
	B	0.65mSv (E)	
	C	0.56 mSv (E)	
	D	0.47 mSv (E)	
	E	0.45 mSv (E)	
	F	0.44 mSv (E)	
	G	0.44 mSv (E)	
	H	0.44 mSv (E)	
	I	0.19 mSv (E)	
	J	0.16 mSv (E)	
	K	0.15 mSv (E)	
	L	0.13 mSv (E)	
	M	0.13 mSv (E)	
	N	0.12 mSv (E)	
	O	0.12 mSv (E)	
	P	0.12 mSv (E)	
Harding et al.[110]	**A**	**0.16mSv (E)**	
	B	0.11mSv (E)	0.03
	C	**0.16mSv (E)**	
	D	0.07mSv (E)	<0.001
Manning-Stanley et al.[111]	A	0.52 mSv (E)	
	B	0.50 mSv (E)	
	C	0.61 mSv (E)	
	D	0.47 mSv (E)	
	E	0.47 mSv (E)	
	F	0.50 mSv (E)	
	G	0.49 mSv (E)	
	H	0.27 mSv (E)	
	I	0.31 mSv (E)	
	J	0.30 mSv (E)	
	K	0.44 mSv (E)	
	L	0.36 mSv (E)	
	M	0.35 mSv (E)	
	N	0.33 mSv (E)	

Table 27 Image quality results for AP pelvis projection

Study	**Protocol**	**IQ Rating**	**P Value**
Fauber et al.[113]	**A**	**Noise: #1**	**0.000**
		Quality: =#1	
	B	Noise: #2	
		Quality: =#1	
	C	Noise: #3	
		Quality: =#3	
	D	Noise: =#4	
		Quality: =#3	
	E	Noise: =#4	

		Quality: #5	
Lorusso et al.[99]	**A**	**Aesthetic Quality: 3.76**	**<0.001**
		Diagnostic Quality: 3.86	**<0.001**
	B	Aesthetic Quality: 3.15	
		Diagnostic Quality: 3.28	
	C	Aesthetic Quality: 3.11	
		Diagnostic Quality: 3.21	
Persliden et al.[112]	A	Radiologist 1: 5 Radiologist 2: 5 Noise: 4331	
	B	Radiologist 1: 5 Radiologist 2: 5 Noise: 2007	
	C	Radiologist 1: 5 Radiologist 2: 5 Noise: 1337	
	D	Radiologist 1: 5 Radiologist 2: 5 Noise: 1267	
	E	Radiologist 1: 5 Radiologist 2: 5 Noise: 931	
	F	Radiologist 1: 4 Radiologist 2: 5 Noise: 824	
	G	Radiologist 1: 3 Radiologist 2: 5 Noise: 694	
	H	Radiologist 1: 3 Radiologist 2: 4 Noise: 567	
	I	Radiologist 1: 3 Radiologist 2: 4 Noise: 539	
	J	Radiologist 1: 2 Radiologist 2: 4 Noise: 469	
	K	Radiologist 1: 2 Radiologist 2: 2 Noise: 372	
	L	Radiologist 1: 1 Radiologist 2: 3 Noise: 341	
	M	Radiologist 1: 1 Radiologist 2: 2 Noise: 306	
	N	Radiologist 1: 1 Radiologist 2: 2 Noise: 272	

	O	Radiologist 1: 1 Radiologist 2: 1 Noise: 270	
	P	Radiologist 1: 1 Radiologist 2: 1 Noise: 241	
	Q	Radiologist 1: 1 Radiologist 2: 1 Noise: 226	
Heath et al.[109]	**A**		
	B	30.0	
	C	31.1	
	D	31.9	
	E	32.5	
	F	33.4	
	G	33.3	
	H	32.1	
	I	21.0	
	J	22.0	
	K	21.1	
	L	22.5	
	M	22.5	
	N	21.6	
	O	22.0	
	P	22.8	
Harding et al.[110]	**A**	**95.2**	
	B	87.7	0.03
	C	**83.4**	
	D	70.2	0.04
Manning-Stanley et al.[111]	A	15	>0.10
	B	15.5	>0.10
	C	16.5	>0.10
	D	15.5	
	E	15.5	
	F	16	
	G	15	
	H	14.5	>0.10
	I	14.5	>0.10
	J	14.5	>0.10
	K	15.5	
	L	14.5	
	M	14.5	
	N	15	

3.2.7.7 Optimised technique

As can be seen in Table 276 and 27, for the AP pelvis projection, lowering mAs or increasing kV consistently leads to lower image quality scores and lower patient doses, but increasing SID has no effect on image quality and lowers patient dose.

For the horizontal beam lateral hip projection, it was shown that the use of additional beam filtration is an effective method of dose reduction that has limited effect on image quality.

3.2.8 Chest

3.2.8.1 Description of included studies

Eight studies[99, 114-120] met the inclusion criteria for radiographic investigation of the adult thorax. For clarity these studies will be grouped by projection.

3.2.8.1.1 PA chest

Eight studies met the inclusion criteria for the PA chest projection.[99,114-120] These studies investigated a number of different technique parameters, including kV, filtration, SID, mAs, and scatter correction.

3.2.8.1.2 Lateral chest

Two studies met the inclusion criteria for the lateral chest projection.[115,116] One retrospective study evaluated the effect of changing kV, SID, density, and filtration on image quality,[115] and one retrospective study[116] evaluated only the effect of changing filtration on image quality.

3.2.8.2 Methodological quality of included studies

The included studies' methodological quality was assessed as shown in Table *28*:

Table 28: Methodological quality of included studies for adult chest imaging

Study	**Quality Grading**
Bernhardt et al.[114]	Moderate
Lorusso et al.[99]	Moderate
Metz et al.[117]	Moderate
Moey and Shazli[118]	Good
Grewal et al.[115]	Moderate
Shaw et al.[119]	Good
Uffman et al.[120]	Good
Hamer et al.[116]	Good

3.2.8.3 Image quality evaluation

3.2.8.3.1 Lateral chest

Image quality was judged for each of the included studies as shown in Table 29:

Table 29 Image quality evaluation for lateral chest projection

Study	**Observers**	**IQ Criteria**	**Statistical Analysis**
Grewal et al.[115]	Three radiologists	European Guidelines and Modified criteria (16 in total) 3-point scale: 1=poor, 2=satisfactory, 3=good	Two-tail test or Fisher's exact test, significance $p<0.05$
Hamer et al.[116]	Three radiologists	7-point ordinal scale, criteria based on modified European Guidelines on Quality Criteria for Diagnostic Radiographic Images. 1= excellent, 7=non-diagnostic	Logistic regression analysis and Mann-Whitney U test for unpaired subjects, Wilcoxon and McNemar test for paired patients

Appendix 7 details in full the actual image quality criteria used for each of the studies.

3.2.8.3.2 PA chest

Image quality was judged for each of the included studies as shown in Table 30:

Table 30 Image quality evaluation for PA chest projection

Study	Observers	IQ Criteria	Statistical Analysis
Grewal et al.[115]	Three radiologists	European Guidelines and Modified criteria (16 in total) 3-point scale: 1=poor, 2=satisfactory, 3=good	Two-tail test or Fisher's exact test, significance $p<0.05$
Bernhardt et al.[114]	Five radiologists	Assessment of visibility of patterns. 5-point scale: 1= definitely present, 5= definitely not present	ROC analysis, 95% CI, with Bonferroni adjustment
Hamer et al.[116]	Three radiologists	7-point ordinal scale, criteria based on modified European Guidelines on Quality Criteria for Diagnostic Radiographic Images. 1= excellent, 7=non-diagnostic	Logistic regression analysis and Mann-Whitney U test for unpaired subjects, Wilcoxon and McNemar test for paired patients
Lorusso et al.[99]	91 observers: six radiologists, four radiology residents, 48 radiographers, 31 student radiographers, two PACS administrators	5-point scale, criteria based on modified European Guidelines on Quality Criteria for Diagnostic Radiographic Images, plus one question regarding aesthetic quality and one regarding diagnostic quality of images. 1= very	One-way ANOVA with Tukey post-hoc test, significance at $p=0.05$

		dissatisfied, 3=acceptable, 5=very satisfied	
Metz et al.[117]	Four radiologists	Assessment of visibility of patterns. 5-point scale: 5= definitely present, 1= definitely not present	ROC analysis, 95% CI
Moey and Shazli[118]	Two radiologists	4-point scale. criteria based on modified European Guidelines on Quality Criteria for Diagnostic Radiographic Images, 1 being the worst and 4 being the best	Wilcoxon test
Shaw et al.[119]	Two radiologists, one reporting radiographer	5-point scale, criteria based on modified European Guidelines on Quality Criteria for Diagnostic Radiographic Images. 1=poor, 3=just acceptable, 5=excellent	Visual grading regression, $p<0.05$ significant
Uffman et al.[120]	Five radiologists	5-point scale, 10 anatomical structures graded according to visibility. 5= excellent visibility, 1=unacceptable image. Ranked image triplets from each patient for each kV level from best to worst	One-way ANOVA, critical differences calculated post-hoc

Appendix 8 details in full the actual image quality criteria used for each of the studies.

3.2.8.4 Patient dose evaluation

3.2.8.4.1 Lateral chest

Patient dose was evaluated using the methods outlined in Table 31:

Table 31 Dose measurement for lateral chest projection

Study	**Dose Parameter**	**Calculation/Measurement Method**
Grewal et al.[115]	ESD and E	Entrance surface air kerma (ESAK) and incident air kerma (INAK) measured for each clinical kV level, E calculated by PCXMC software
Hamer et al.[116]	DAP, ESD, and Absorbed Dose	DAP measured by ionisation chamber, ESD and A measured in phantom study

3.2.8.4.2 PA Chest

Patient dose was evaluated using the methods outlined in Table 32:

Table 32 Dose measurement for PA chest projection

Study	Dose Parameter	Calculation/Measurement Method
Grewal et al.[115]	ESD and E	ESAK and INAK measured for each clinical kV level, E calculated by PCXMC software
Bernhardt et al.[114]	ESD and E	ESD including backscatter using dosimeter, E calculated by Huda method
Hamer et al.[116]	DAP, ESD, and Absorbed Dose	DAP measured by ionisation chamber, ESD and A measured in phantom study
Lorusso et al.[99]	DAP	DAP measured by ionisation chamber
Metz et al.[117]	ESD and E	ESD measured by detector, E calculated using Monte Carlo techniques
Moey and Shazli[118]	DAP, ESD, and E	DAP measured by tube output, ESD and E calculated from this value using CALDose_X 5.0 Monte Carlo software
Shaw et al.[119]	DAP and E	DAP measured by ionisation chamber in tube, E calculated by PCXMC program using Monte Carlo simulation
Uffman et al.[120]	Kerma area product (KAP) and E	KAP calculated by system output, E calculated using PCXMC Monte Carlo simulation software

3.2.8.5 Technique comparison

3.2.8.5.1 Lateral chest

Exposure techniques for the lateral chest projection are outlined in Table 33; those in bold are reference techniques (where used).

Table 33 Technique parameters for lateral chest projection

Study	Protocol	kVp	Density	Filtration	SID	Grid
Grewal et al.[115]	A	125	+4	Nil	180 cm	Yes
Grewal et al.[115]	B	109	0	0.1mm Cu + 1mm Al	199 cm	Yes
Hamer et al.[116]	**A**	**125**	**0**	**0**	**180 cm**	**Yes**
Hamer et al.[116]	B	125	0	0.3mm Cu	180 cm	Yes

3.2.8.5.2 PA chest

Exposure techniques for the PA chest projection are outlined in Table 34; those in bold are reference techniques (where used).

Table 34 Technique parameters for PA chest projection

Study	Protocol	kVp	AEC	Filtration	SID	Grid
Grewal et al.[115]	A	102	Yes (+4 Density)	Nil	180 cm	Yes
	B	102	Yes (0 Density)	0.1mm Cu + 1mm Al	199 cm	Yes
Bernhardt et al.[114]	**A**	**125**	**Yes**	**Nil**	**115 cm**	**Yes**
	B	90	No (mAs matched ESD to technique A)	Nil	115 cm	Yes
	C	70	No (mAs matched ESD to technique A)	Nil	115 cm	Yes
Hamer et al.[116]	**A**	**125**	**Yes**	**Nil**	**180 cm**	**Yes**
	B	125	Yes	0.3mm Cu	180 cm	Yes
Lorusso et al.[99]	**A**	**120**	**0.7 mAs**	**Not stated**	**127 cm**	**Yes**
	B	140	0.9 mAs	Not stated	127 cm	Yes
	C	150	0.7 mAs	Not stated	127 cm	Yes
Metz et al.[117]	A	100	AEC 2.5µGy dose 4.48 mAs	Nil	180 cm	Yes
	B	120	AEC 2.5µGy dose 2.78 mAs	Nil	180 cm	Yes
	C	140	AEC 2.5µGy dose 2.01 mAs	Nil	180 cm	Yes
	D	100	AEC 1.56µGy dose 2.95 mAs	Nil	180 cm	Yes
	E	120	AEC 1.56µGy dose 1.86 mAs	Nil	180 cm	Yes
	F	140	AEC 1.56µGy dose 1.32 mAs	Nil	180 cm	Yes
	G	100	AEC 1.25µGy dose 2.42 mAs	Nil	180 cm	Yes
	H	120	AEC 1.25µGy dose 1.51 mAs	Nil	180 cm	Yes
	I	140	AEC 1.25µGy dose 1.08 mAs	Nil	180 cm	Yes
Moey and Shazli[118]	**A**	**121.5**	**AEC mean mAS=1.57**	**0.2mmCu**	**180 cm**	**Yes**
	B	112.7	AEC mean mAs=2.32	0.2mmCu	180 cm	Yes
Shaw et al.[119]	A	125	1.4 mAs	Nil	180 cm	No
	B	125	3.2 mAs	Nil	180 cm	Yes
	C	125	2.6 mAs	Nil	180 cm	Air Gap
	D	109	2.0 mAs	Nil	180 cm	No
	E	109	4.7 mAs	Nil	180 cm	Yes

	F	109	2.6 mAs	Nil	180 cm	Air Gap
	G	90	3.6 mAs	Nil	180 cm	No
	H	90	8.9 mAs	Nil	180 cm	Yes
	I	90	4.6 mAs	Nil	180 cm	Air Gap
	J	81	5.4 mAs	Nil	180 cm	No
	K	81	13.4 mAs	Nil	180 cm	Yes
	L	81	7.0 mAs	Nil	180 cm	Air Gap
Uffman et al.[120]	A	121	AEC, average 1.8 mAs	Nil	180 cm	Yes
	B	90	AEC, average 4.2 mAs	Nil	180 cm	Yes
	C	150	AEC, average 1.11 mAs	Nil	180 cm	Yes

3.2.8.6 Image quality and dosimetry results

3.2.8.6.1 Dosimetry results

3.2.8.6.1.1 Lateral chest

Patient dose results for the lateral chest projection are summarised in Table 35:

Table 35 Dosimetry results for lateral chest projection

Study	**Protocol**	**Dose**
Grewal et al.[115]	A	0.063mSv (E)
	B	0.045mSv (E)
Hamer et al.[116]	**A**	**Unpaired: 25.6µGym2 (DAP)** **Paired: 32.2µGym2 (DAP)**
	B	Unpaired: 11.3µGym2 (DAP) Paired: 14.4µGym2 (DAP)

No data on statistical significance was reported in the included studies.

3.2.8.6.1.2 PA Chest

Patient dose results for the PA chest projection are summarised in Table 36:

Table 36 Dosimetry results for PA chest projection

Study	Protocol	Dose	P Value
Grewal et al.[115]	A	0.021mSv (E)	
	B	0.010mSv (E)	
Bernhardt et al.[114]	**A**	**ESD: 0.50mGy** **E: 0.07mSv**	
	B	ESD: 0.49mGy E: 0.054mSv	
	C	ESD: 0.47mGy E: 0.04mSv	
Hamer et al.[116]	**A**	**Unpaired: 6.4µGym^2 (DAP)** **Paired: 6.8 µGym^2 (DAP)**	
	B	Unpaired: 2.9µGym2 (DAP) Paired: 3.5µGym2 (DAP)	
Lorusso et al.[99]	A	1.1dGycm^2	
	B	0.8dGycm^2	
	C	0.8dGycm^2	
Metz et al.[117]	A	ESD:0.113mGy E: 14.5µSv	
	B	ESD: 0.104mGy E: 15.2µSv	
	C	ESD: 0.098mGy E: 16.4µSv	
	D	ESD: 0.078mGy E: 9.2µSv	
	E	ESD: 0.064mGy E: 9.5µSv	
	F	ESD: 0.060mGy E: 10.2µSv	
	G	ESD: 0.058mGy E: 7.4µSv	
	H	ESD: 0.051mGy E: 7.6µSv	
	I	ESD: 0.048mGy E: 8.2µSv	
Moey and Shazli[118]	**A**	**0.089mGy**	
	B	0.0195mGy	<0.05
Shaw et al.[119]	A	DAP: 8.6cGycm^2 E:17.3	
	B	DAP: 18.5 E: 37.4	

	C	DAP: 10.8 E: 22.6	
	D	DAP: 9.6 E: 17.4	
	E	DAP: 21.0 E: 37.9	
	F	DAP: 11.8 E: 22.2	
	G	DAP:11.9 E:17.8	
	H	DAP: 27.5 E: 41.2	
	I	DAP: 15.0 E: 23.2	
	J	DAP: 14.2 E: 18.8	
	K	DAP: 33.7 E: 44.4	
	L	DAP: 18.3 E: 25.1	
Uffman et al.[120]	**A**	**KAP: 1.05dGycm^2 E: 20.6µSv**	
	B	KAP: 1.43dGycm^2 E: 21.3µSv	>0.05
	C	KAP: 0.86dGycm^2 E: 19.5µSv	>0.05

For studies that were controlled by AEC, as kV increases, effective dose decreased in two out of three studies and increased in one out of three studies, as demonstrated in the graph below. The study by Metz et al.[117] that demonstrated that as kV increased, so did effective dose, which contradicts the results by Shaw et al.[119] and Uffman et al.[120]

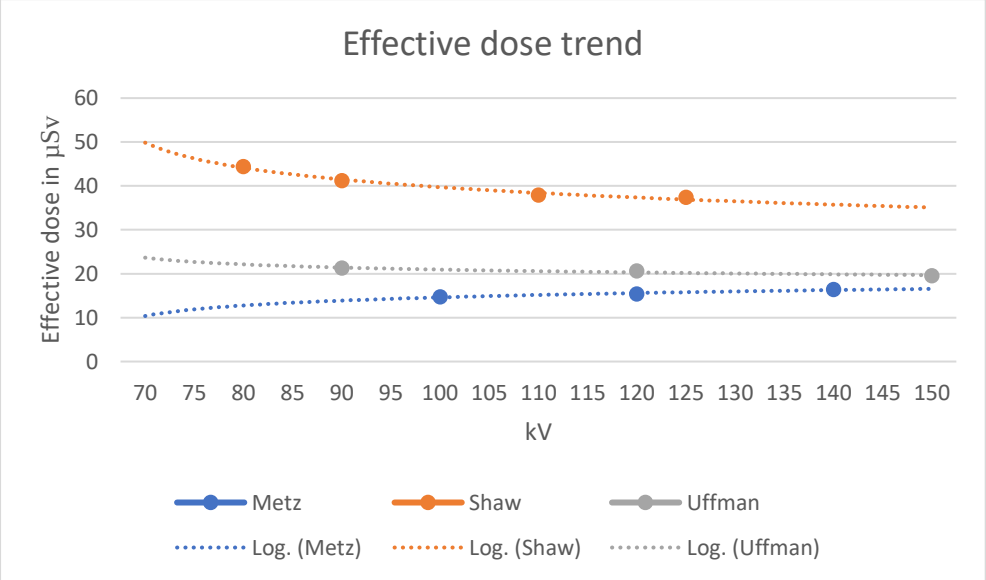

Figure 2 Effective dose trend for PA chest projection

3.2.8.6.2 Image quality results

3.2.8.6.2.1 Lateral chest

Image quality results for the lateral chest projection are reported in Table 37:

Table 37 Image quality results for lateral chest projection

Study	Protocol	IQ Rating	P value
Grewal et al.[115]	A	1: 74% acceptable	
		2: 30% acceptable	
		3: 47% acceptable	
		4: 91% acceptable	
		5: 99% acceptable	
		6: 92% acceptable	
		7: 71% acceptable	
		8: 41% acceptable	
		9: 5% acceptable	
		10: 93% acceptable	
		11: 90% acceptable	
		12: 92% acceptable	
Grewal et al.[115]	B	1: 82% acceptable	0.531
		2: 38% acceptable	0.632
		3: 58% acceptable	0.359
		4: 98% acceptable	0.252
		5: 98% acceptable	0.349
		6: 100% acceptable	0.296
		7: 76% acceptable	0.476
		8: 56% acceptable	0.382
		9: 11% acceptable	0.527
		10: 94% acceptable	0.718
		11: 93% acceptable	0.596
		12: 94% acceptable	0.634
Hamer et al.[116]	**A**	**Mean frequency for score of 1 for global quality: 38 (paired), 11 (unpaired)**	
Hamer et al.[116]	B	Mean frequency for score of 1 for global quality: 38 (paired), 11 (unpaired)	>0.3

3.2.8.6.2.2 PA Chest

Image quality results for the PA chest projection are reported in Table 38:

Table 38 Image quality results for PA chest projection

Study	Protocol	IQ Rating	P Value
Grewal et al.[115]	A	1: 86% acceptable	
		2: 98% acceptable	
		3: 45% acceptable	
		4: 85% acceptable	
		5: 100% acceptable	
		6: 100% acceptable	
		7: 99% acceptable	
		8: 99% acceptable	
		9: 75% acceptable	
		10 :88% acceptable	
		11: 53% acceptable	
		12: 82% acceptable	
		13: 100% acceptable	
		14: 100% acceptable	
		15: 98% acceptable	
		16: 77% acceptable	
	B	1: 83% acceptable	0.833
		2: 91% acceptable	0.493
		3: 57% acceptable	0.189
		4: 80% acceptable	0.392
		5: 98% acceptable	0.308
		6: 97% acceptable	0.322
		7: 100% acceptable	0.121
		8: 98% acceptable	0.352
		9: 77% acceptable	0.307
		10: 85% acceptable	0.833
		11: 64% acceptable	0.302
		12: 80% acceptable	0.392
		13: 100% acceptable	0.408
		14: 100% acceptable	0.589
		15: 96% acceptable	0.622
		16: 81% acceptable	0.016
Bernhardt et al.[114]	**A**	**Ground glass: 0.81**	
		Linear: 0.79	
		Miliary: 0.78	
		Reticular: 0.65	
		Lucent Lung Nodules >10mm: 0.78 **Lucent Lung Nodules ≤10mm: 0.50**	
		Obscured Chest Nodules >10mm: 0.74	

		Obscured Chest Nodules ≤10mm: 0.67	
		Catheters: 0.76	
	B	Ground glass: 0.62	0.45
		Linear: 0.79	0.22
		Miliary: 0.83	0.68
		Reticular: 0.75	0.33
		Lucent Lung Nodules >10mm: 0.91 Lucent Lung Nodules ≤10mm: 0.82	0.04 0.02
		Obscured Chest Nodules >10mm: 0.79 Obscured Chest Nodules ≤10mm: 0.74	0.86 Not reported
		Catheters: 0.80	0.75
	C	Ground glass: 0.80	0.96
		Linear: 0.86	0.52
		Miliary: 0.93	0.25
		Reticular: 0.84	0.001
		Lucent Lung Nodules >10mm: 0.84 Lucent Lung Nodules ≤10mm: 0.75	Not reported 0.32
		Obscured Chest Nodules >10mm: 0.78 Obscured Chest Nodules ≤10mm: 0.78	0.70 Not reported
		Catheters: 0.79	0.80
Hamer et al.[116]	**A**	**Mean frequency for score of 1 for global quality: 38 (paired), 11 (unpaired)**	
	B	Mean frequency for score of 1 for global quality: 38 (paired), 11 (unpaired)	>0.3
Lorusso et al.[99]	A	Aesthetic: 3.68 Diagnostic: 3.77 CEC: A: 3.89 B: 4.01 C: 4.08 D: 3.72 E: 4.11	
	B	Aesthetic: 3.34 Diagnostic: 3.52 CEC: A: 3.50 B: 3.68 C: 3.73 D: 3.30 E: 3.74	>0.05 >0.05 <0.05 <0.05 <0.05 <0.05 <0.05
	C	Aesthetic: 3.36 Diagnostic: 3.40	>0.05 >0.05

		CEC: A: 3.53 B: 3.72 C: 3.80 D: 3.38 E: 3.62	 <0.05 >0.05 >0.05 >0.05 <0.001
Metz et al.[117]	A	Mean AUC: 0.895	
	B	Mean AUC: 0.912	vs technique A: >0.05
	C	Mean AUC: 0.914	vs technique A: <0.05
	D	Mean AUC: 0.868	vs technique A: <0.05 vs technique B/C: <0.001
	E	Mean AUC: 0.852	vs technique A: <0.01 vs technique B/C: <0.001 vs technique D: >0.05
	F	Mean AUC: 0.864	vs technique A: <0.05 vs technique B/C: <0.001 vs technique D: >0.05
	G	Mean AUC: 0.863	vs technique A: <0.01 vs technique B/C: <0.001
	H	Mean AUC: 0.880	vs technique A: >0.05 vs technique B/C: <0.01 vs technique G: >0.05
	I	Mean AUC: 0.876	vs technique A: 0.05 vs technique B/C: <0.01 vs technique G: <0.05
Moey and Shazli[118]	A	Mean IQ score per criteria: A: 3.4 B: 3.4 C: 3.3 D: 3.4 E: 3.3 F: 2.7 G: 3.6 H: 3.3	
	B	Mean IQ score per criteria: A: 3.9 B: 3.5 C: 3.9 D: 3.9 E: 3.9 F: 3.7 G: 3.8 H: 3.7	Overall p<0.05
Shaw et al.[119]	A	Combined score of all observers: Criteria 1: 6 Criteria 2: 8	

		Criteria 3: 6 Criteria 4:8 Criteria 5:8 Criteria 6: 6 Criteria 7: 6 Average score: 6.9	
	B	Combined score of all observers: Criteria 1: 10 Criteria 2: 12 Criteria 3: 11 Criteria 4:12 Criteria 5:12 Criteria 6: 11 Criteria 7: 11 Average score: 11.3	
	C	Combined score of all observers: Criteria 1: 11 Criteria 2: 12 Criteria 3: 9 Criteria 4:12 Criteria 5:12 Criteria 6: 10 Criteria 7: 11 Average score: 11	
	D	Combined score of all observers: Criteria 1: 7 Criteria 2: 7 Criteria 3: 6 Criteria 4: 7 Criteria 5: 8 Criteria 6: 6 Criteria 7: 9 Average score: 7.14	
	E	Combined score of all observers: Criteria 1: 11 Criteria 2: 12 Criteria 3: 11 Criteria 4:12 Criteria 5:12 Criteria 6: 11 Criteria 7: 12 Average score: 11.6	
	F	Combined score of all observers: Criteria 1: 12 Criteria 2: 13 Criteria 3: 9 Criteria 4:12 Criteria 5:12 Criteria 6: 9 Criteria 7: 11	

		Average score: 11.1	
	G	Combined score of all observers: Criteria 1: 7 Criteria 2: 7 Criteria 3: 6 Criteria 4:9 Criteria 5:8 Criteria 6: 6 Criteria 7: 8 Average score: 7.3	
	H	Combined score of all observers: Criteria 1: 13 Criteria 2: 12 Criteria 3: 11 Criteria 4:12 Criteria 5:12 Criteria 6: 9 Criteria 7: 12 Average score: 11.6	
	I	Combined score of all observers: Criteria 1: 10 Criteria 2: 12 Criteria 3: 7 Criteria 4:12 Criteria 5:12 Criteria 6: 10 Criteria 7: 12 Average score: 10.7	
	J	Combined score of all observers: Criteria 1: 6 Criteria 2: 7 Criteria 3: 5 Criteria 4: 9 Criteria 5: 11 Criteria 6: 4 Criteria 7: 6 Average score: 6.9	
	K	Combined score of all observers: Criteria 1: 12 Criteria 2: 12 Criteria 3: 12 Criteria 4:11 Criteria 5:12 Criteria 6: 11 Criteria 7: 11 Average score: 11.6	
	L	Combined score of all observers: Criteria 1: 10 Criteria 2: 11 Criteria 3: 9	

		Criteria 4: 12 Criteria 5:12 Criteria 6: 11 Criteria 7: 12 Average score: 10.9	
Uffman et al.[120]	A	Mean score: 2.95	
	B	Mean score: 3.11	<0.05
	C	Mean score: 2.80	

Shaw et al.[119] narratively reported that tube potential was not found to have a statistically significant effect on VGA score ($p>0.630$), both grid and air-gap significantly improved VGA scores ($P<0.001$), and a grid was superior to air-gap ($p=0.0038$).

3.2.8.7 Optimised technique

3.2.8.7.1 Lateral chest

The results for patient dose and image quality for the lateral chest projection indicate that additional tube filtration is effective method to reduce patient dose with no statistically significant impact on image quality. Two included studies[115,116] both demonstrated that additional tube filtration does not negatively impact upon image quality but can reduce dose.

3.2.8.7.2 PA chest

The results of two included studies[115,116] indicate that additional tube filtration was found to have a positive effect on patient dose with negligible effect on image quality. Six included studies[99,115,117-120] investigated adjustment of kV, the results of which were sometimes contradictory. Further work surrounding kV optimisation needs to be undertaken. One included study[119] investigated use of a scatter reduction technique and indicates that any method of scatter reduction improved image quality, with the anti-scatter grid producing the best image quality level. The use of an anti-scatter grid was also associated with the highest patient dose.

Chapter Four – Discussion

This review found 23 studies evaluating seven different technique modifications for eight body regions. As far as the author can tell, this is the first review conducted that investigates the effect adjustment of radiographic technique parameters has on image quality and patient dose for DDR. Although it is encouraging to see this high number of investigations in this field, there were a number of studies highlighted as having moderate or poor methodological quality. Despite this, the results of this review do provide some information for both research and practice. In the following discussion the results of this review will be situated within the broader field of medical imaging and the findings and implications will be discussed. For ease of readability, the discussion has been structured by first analysing the strengths and limitations of the approach, then by body sections followed by some general remarks on the field and implications for research and practice.

4.1 Abdomen

Projectional radiographs of the abdomen are acquired to evaluate pathology of the abdomen, both soft tissue structures and bony anatomy.[23,98] The AP supine radiograph alone is considered a standard protocol for most clinical indications, apart from the investigation of the possible obstruction, which commonly includes an AP or PA erect abdominal radiograph, and in some institutions, the inclusion of an erect chest radiograph.[23] The AP abdomen radiograph is associated with a relatively high patient dose per image, in terms of ESD and DAP;[121] therefore optimisation of technique is of critical importance for this examination.

4.1.1 Investigated techniques

In the single included study[98] the authors sought to investigate the effect of increasing kV and additional tube filtration to optimise the exposure technique for the AP erect and AP supine abdominal radiograph. The authors acknowledged that increasing kV and filtration can lead to a decrease in image contrast.

A traditional protocol setup for an abdominal radiograph would use AEC with a standard cutoff dose (commonly 2.5µGy). This means that the system will terminate the exposure once this level of detector air kerma (DAK) is received. Marshall and colleagues[122] proposed an alternative automatic exposure control (AEC) regime designed to maintain contrast-detail detectability across a spectrum of different x-ray beam qualities. This regime aims to maintain a constant CNR rather than DAK. This same AEC regime was employed by Jang and colleagues in their investigation.[98] This is why the target DAK for the experimental technique was higher for both erect and supine radiographs. Jang et al.[98] reason that whilst the detector dose is increased, overall patient dose is decreased due to the removal of low energy photons by the additional filtration and increase in photon penetration by the higher kV. Their reasoning was confirmed by their data that shows very similar results for image quality and a significantly lower patient dose.

4.1.2 Implications for clinical practice

The results of this single included study highlight that there exists an opportunity to significantly decrease patient dose for equivalent image quality whilst maintaining a

comparative level of image quality by using additional beam filtration. It may be difficult to implement this clinically as most AEC regimes are set up to maintain constant DAK rather than constant CNR. Sites would need to work closely with local physicists to calculate the required DAK for the optimised technique to maintain CNR if they were to implement a high kV with additional tube filtration technique.

4.2 Extremity

Radiographic evaluation of the adult extremity is performed to investigate a variety of pathological conditions, as well as trauma and foreign body exclusion. In the single included study, an investigation of the exposure parameters used for the DP hand radiograph was undertaken.

4.2.1 Investigated techniques

In the single included study[99] the authors sought to investigate the effect of increasing kV and decreasing mAs to optimise the exposure technique for the DP hand radiograph.

In order to arrive at their experimental technique, the authors used the clinical exposure index (EXI) of the standard technique as a target value. They used techniques with 72 and 82 kV and kept decreasing mAs until the EXI of the experimental technique was as close as possible to that of the standard technique. The reasoning behind this methodology was that the EXI "verifies" that an image is of acceptable quality. Whilst in practice the EXI is used as a guideline to indicate whether the detector has received adequate exposure to create an image of diagnostic *quality*, it is not a measure of the adequacy of an image for *diagnosis*, as such an indicator does not exist.[26] It also does not indicate whether there is an appropriate level of detail contrast between structures of very similar attenuation coefficient, such as those found in the fine trabecular markings of the extremity. This methodology also presents difficulty in terms of external validity, as the calculation of the EXI is a vendor proprietary algorithm; thus if this methodology was applied on a different vendor system it is likely that the exposure parameters found would be different to those found in this study. Whilst there have been efforts to standardise the calculation of EXI, it is evident that variances across vendors still exists; hence external validity cannot be guaranteed.[123]

The choice of using a +20 kV and +30 kV technique for investigation of optimisation is also troublesome, as it appears that these values were picked at random and not based on any pre-experimental trials or previous investigations. The hand represents a very thin anatomy, and traditionally a low kV technique is used in order to preserve the appearance of fine details in this region. The experimental techniques utilise hugely increased kV values, which ultimately were not acceptable to readers. Possibly the authors should have investigated a more moderate increase in kV for this very thin region of interest. Whilst there may not have been the dramatic dose area product reduction associated with the studied techniques, a more moderate increase in kV and possibly a smaller reduction in dose area product may have been more acceptable to viewers.

Also of note is the fact that this study used radiography students, radiographers, and radiologists for the image quality analysis. The authors state that there was no statistically significant difference in the results of the image quality analysis between each of the professional groups, hence the justification for inclusion of student analysis.

4.2.2 Implications for clinical practice

Due to the moderate methodological quality of this study, recommendations for clinical practice cannot be made.

4.3 Shoulder

Radiographic evaluation of the adult extremity is performed to investigate traumatic injuries and a variety of pathological conditions, especially for the identification of calcifications within the muscles of the rotator cuff. In the single included study,[100] an investigation of grid usage for the AP shoulder radiograph was undertaken.

The radiographic grid, used to reduce the background fog produced by scattered radiation, improves overall image contrast. The use of grids for AP shoulder radiographs is mixed across sites, and often depends on the preference of the performing radiographer. This study also investigated only the AP shoulder radiograph. In clinical practice this view would rarely be performed in isolation and would constitute just one part of the series. The orthogonal view to the AP shoulder, the lateral scapula or outlet view (depending on clinical scenario) has the patient positioned such that the part thickness is greatly increased. This projection is rarely performed without a grid. From a workflow perspective, many radiographers choose to perform the entire series with a grid rather than having to switch halfway through a series.

4.3.1 Investigated techniques

In the single included study[100] the authors sought to investigate whether appropriate diagnostic quality could be achieved for AP shoulder images without the use of a radiographic grid. At the clinical site, both grid and non-grid techniques were currently in use. The selection of the technique was based on the radiographer preference, and there was no established protocol for grid usage.

When investigating the technique experimentally, the authors had an “agreed protocol” to alternate the use of grid and non-grid. The “agreed protocol” for randomisation of patients was not sufficiently explained, which impacted upon the methodological quality rating. This is especially significant for investigations of grid usage, as radiographers may have preferentially chosen to perform non-grid imaging on smaller patients.

The authors of this study found that image quality was able to be maintained at greatly reduced dose to the patient by removing the grid. They noted that non-grid images with lower image quality scores were performed on larger patients.

4.3.2 Implications for clinical practice

Further investigation is needed to indicate at what patient thickness the use of a radiographic grid is necessary and justified. For smaller patients, it appears that the use of a radiographic grid is not necessary to achieve images of adequate quality, but further investigation and replication of results in a truly randomised environment is required before this practice can be endorsed.

4.4 Skull

Radiographic evaluation of the adult skull is becoming decreasingly necessary as the access to computed tomography (CT) increases. In the setting of evaluation of adult head trauma, the Royal Australian and New Zealand College of Radiologists recommends skull radiography not be used routinely due to its inability to evaluate intracranial injury.[124] Whilst access to CT has improved, there are still some sites where it is inaccessible, and in these situations skull radiography is routinely performed. It is also routinely performed as part of the skeletal survey to evaluate various pathological conditions.

4.4.1 Investigated Techniques

In the included studies, adjustment of SID and kV were investigated. Both included studies evaluated the lateral skull projection, and one included study[101] evaluated the OF10° projection.

For the study investigating varying kV,[99] as previously outlined in the extremity section, in order to arrive at their experimental technique, the authors used the clinical EXI of the standard technique as a target value. They used techniques with 95 and 105 kV and kept decreasing mAs until the EXI of the experimental technique was as close as possible to that of the standard technique. In this study, the optimised images were consistently found to be of lower diagnostic quality. The quality metrics measured the "visual sharpness" of certain anatomical landmarks. The theory behind increasing kV and decreasing mAs is that more photons will reach the detector due to their higher energy, reducing the number of overall photons required. As the number of photons used to create the image decreases, the amount of noise apparent in the image increases. The authors failed to consider the lower dynamic quantum efficiency (DQE) of digital detectors at higher kV and also the reduction in object detectability due to contrast loss at higher beam energies.[122] If they had considered a constant CNR model, such as that employed by Jang and colleagues[98], they may have been able to maintain the visual sharpness of the standard images in their experimental images.

For the study investigating varying SID,[101] the authors demonstrated that they could successfully decrease patient dose whilst maintaining image quality for OF10° by increasing the SID from 100 cm to 150 cm. For the lateral projection, the standard technique performed at 100 cm SID was demonstrated to be the optimal technique. It is worth noting that in this study the authors used focussed grids outside of their tolerance ranges for the experimental techniques. Using grids outside of their nominated focal range with AEC increases dose required to maintain a constant detector dose, as more of the primary beam is attenuated by the grid. This is because the beam geometry does not match the geometry of the grid. The authors acknowledge this but posit that the effect would have been minimal as they were using mainly the central portion of the detector and grid where the grid lines are virtually perpendicular. In the context of this work, the effect on the overall results would be a possible underestimation of the patient dose reduction.

4.4.2 Implications for clinical practice

It appears that increasing the SID for the OF10° projection is an effective method of reducing the patient dose whilst maintaining an equivalent level of image quality.

Further studies are required to confirm these results, and to get a more accurate reflection of actual patient dose reduction, the grids applied should be used within their focal range. For the lateral skull projection, no change to current clinical practice is recommended.

4.5 Spine

Radiographic evaluation of the adult spine is commonly performed in both the trauma setting and in the outpatient setting. It is routinely requested to evaluate a number of pathologic conditions, such as arthritis, scoliosis, and ankylosing spondylitis, as well as to investigate traumatic injuries, such as fractures, especially traumatic injuries resulting due to a background pathologic condition, such as crush fracture secondary to osteoporosis.[23] The patient dose associated with these examinations is also quite high; the thoracic and lumbar spine examinations represent only 3.8–12.7% of all radiology examinations, but contribute 30.1% of the collective dose to patients;[26] thus efforts to optimise these examinations is of great importance.

4.5.1 Investigated techniques

4.5.1.1 Cervical spine

Two studies[100,102] were included for the cervical spine; both investigated adjusting parameters on the lateral projection. One study investigated the effect of changing SID,[102] and one study[100] investigated the effect of removing the grid. In the study that investigated changing the SID, there was no mention of whether a grid was used. This is of key importance for this type of investigation, because if a focussed grid is used outside of its tolerance range, this could affect the image quality and patient dose results. Despite this, the authors demonstrated that increasing the SID to 210 cm could reduce patient dose and improve image quality. In this study, patient dose was evaluated by using ESD, which lacks an estimation of actual patient risk.

In the study evaluating grid usage[100] there was significant disagreement between reporters, and as a result only the opinion of the most experienced consultant was used for the image quality investigation. This single rater judged that images with and without the grid had similar quality, and no image was undiagnostic. The most concerning aspect of this study was the lack of appropriate randomisation. As outlined in the shoulder section, there was an “agreed protocol” for the randomisation of patients that was not explained. As grid usage in routine clinical practice is based on part thickness, the lack of appropriate randomisation is very concerning in this study. Without appropriate randomisation or reporting of patient demographics for each group there is a risk that all of the patients imaged with a grid were smaller and would therefore produce less scattered radiation. This lack of explanation of the randomisation represents a significant risk to the internal validity of this study and therefore the results will not be included in the recommendations for clinical practice.

It should also be noted here that there was the addition of an image quality criterion regarding the visualisation of the 1st thoracic vertebrae. In clinical practice visualisation of the cervico-thoracic junction is not solely dependent on exposure parameters, patient body habitus and positioning will also affect whether this area is visualised. This criterion was the least fulfilled, with only 58% of images with a grid and 78% of images without a grid meeting the criteria. No comment was made by the authors as to whether the failure to fulfil the criteria was due to an exposure issue or whether it was related to patient positioning or habitus.

4.5.1.2 Lumbar spine

Two of the included studies for the AP lumbar spine[104, 105] were quite similar but unfortunately, due to differences in outcome measurement, meta-analysis was unable to be performed. Results for the AP lumbar spine across studies demonstrated that a lower kV was associated with improved image quality scores. The study by Brindhaban et al.[103] investigated three different DDR systems and showed that for all three systems, the image quality was best at the lowest kV level investigated. In this study this was also associated with the highest patient dose as the AEC cutoff dose was maintained across the varying kV levels. When kV is decreased, mAs must increase in order to maintain a constant detector dose, which is what the AEC measures to determine when to terminate the exposure. System speed is a way of adjusting the AEC cutoff dose. Two of the included studies[104,105] investigated whether they could lower the kV and change the system speed to minimise the increase in mAs required for the lower kV. By changing the system speed from 400 to 800 they effectively halved the AEC cutoff dose. These two studies demonstrated that even though AEC cutoff dose was halved, image quality was able to be maintained by using a lower kV.

4.5.2 Implications for clinical practice

4.5.2.1 Lateral cervical spine

It appears that increasing SID can decrease patient dose and improve image quality. This was not replicated in other studies so a recommendation for clinical practice cannot be made.

4.5.2.2 AP lumbar spine

In all included studies, a lower kV was associated with a higher image quality score. In two of the included studies it was demonstrated that image quality can be matched or improved with lower kV for these projections without negatively affecting patient dose. One study demonstrated that an effective way to implement this in clinical practice is to decrease the kV and increase the system speed so that the AEC cutoff dose is halved.

4.5.2.3 Lateral lumbar spine

The single included study[104] for this projection demonstrated that image quality can be improved without negative impact on patient dose by decreasing the kV. This was not replicated in other studies, so a recommendation for clinical practice cannot be made.

4.6 Paediatrics

Paediatric radiography is uniquely challenging for the radiographer due to the sometimes increased difficulty of performing routine imaging as well as the challenge in selecting appropriate exposure parameters for the widely varying patient habitus. As young children are undergoing rapid development, they are especially sensitive to radiation;[23] therefore efforts to optimise radiographic technique are of the utmost importance. The single included study[106] was investigating the chest radiograph, which is one of the most commonly performed projections for the paediatric population. In the 2018–19 financial year in Australia, 45,832 chest x-rays were performed on children under the age of four years, and 45,792 chest x-rays were performed on children between five and 14 years (sum of examinations claimed through Medicare with codes 58505, 58503, 58500).[125] For the 0–4 years age group, the chest radiograph made up 28% of the total diagnostic radiology services (including fluoroscopy) claimed for this age group, and 5% for the five to 14 years age group.

4.6.1 Investigated techniques

The single included study[106] was a well-designed triple-blinded randomised controlled trial, one of the only examples of a study of this type included in this review. The authors sought to investigate the effect of changing kV on resultant image quality. It was evident that as kV increased, the VGAS score decreased. The authors concluded that they should use the higher kV technique as it led to the lowest DAP measurement. In all instances the higher kV experimental technique had a higher VGAS score than the control technique, but in all age groups except the 7–11 years group the middle kV technique gave a higher VGAS score for equivalent or less dose than the control technique. This raises the question: is this technique optimised or is it just dose reduced? There will be further discussion of technique optimisation versus dose reduction in the general remarks section.

One issue with the included study was that they imaged patients in two different rooms with two different ratio grids. The data from both rooms were combined when analysed. This presents difficulty for two reasons: the room with the higher ratio grid will have a higher patient dose and should produce images that are much sharper as it will remove more of the scattered photons. This difference in technique raises questions surrounding the internal validity of the study. There was also no statement of technique for each patient age group, so the assumption has been made that the grid was used for all age groups. It would be extremely uncommon in Australia or New Zealand to use a grid for a chest x-ray on a patient under the age of eight years, and in a work published by the Queensland Children's Hospital, they do not recommend the use of a grid for any chest radiograph until patients are adult sized.[126]

4.6.2 Implications for clinical practice

This study has shown that lowering the kV consistently produces images of higher diagnostic quality, though sometimes it results in a higher patient dose. More work is needed to find a truly optimised technique.

4.7 Pelvic girdle

Radiographic examination of the pelvic girdle is commonly undertaken in both trauma and outpatient settings. In the trauma setting, hip fractures are commonly seen in elderly populations, especially secondary to a fall. In the 2015–16 financial year, hip fractures accounted for 50,900 hospitalisations, and in those aged over 45 the incidence rate for hip fracture was 199 per 100,000.[127] The radiographic examination of the pelvic girdle also directly irradiates the radiosensitive gonads, which means that efforts to optimise the exposure parameters used for these examinations is of high importance.

4.7.1 Investigated techniques

Of the included studies only one[107] investigated the horizontal beam lateral projection. In this phantom study they investigated adjusting SID, kV, OID, grid usage and filtration. Unfortunately, this study did not present all of the image quality data, and instead focussed on the five lowest dose techniques that provided at least equivocal image quality. There were two techniques that provided higher image quality to that of the reference technique, but it is unknown what the patient dose was for these two images. From this study it appears that additional beam filtration is an effective mechanism to decrease patient dose without negatively impacting image quality.

The remaining studies[99, 109-113] all investigated the AP pelvis projection. Three studies[110-112] investigated the adjustment of mAs on image quality. Two of the included studies[110,111] did this by changing the orientation of the patient on the x-ray table. In standard orientation, the two lateral AEC chambers overlie dense bony anatomy. When the patient is rotated 180°, the lateral AEC chambers mostly overlie soft tissue; thus the AEC cutoff dose is reached much more quickly and the overall mAs is much lower. In both studies it was demonstrated that lowering mAs lowers patient dose, but also negatively impacts image quality. Both studies had statistically significant decreases in image quality when the patient orientation was reversed. One other study[112] investigated the impact of increasing noise on image quality. This study demonstrated that as dose increases, noise decreases and image quality scores increase. Whilst none of these studies met the goal of optimisation, equivalent or higher image quality for equivalent or lower patient dose, they did highlight the fact that possibly lower image quality than is currently accepted would be suitable for diagnosis.

Two studies[99,113] investigated the adjustment of kV on resultant image quality. Both of these studies demonstrated that increasing kV had a negative impact on image quality. Neither of these studies investigated using kV values lower than their current standard. Both studies demonstrated that increasing kV was an effective strategy to reduce patient dose. As highlighted in Jang et al.,[98] maintenance of the CNR is important to maintain object detectability as kV is increased. As both studies used an AEC regimen that maintained constant detector dose, not constant CNR, there may have been a marked decrease in CNR in the higher kV techniques employed. A potential direction for future research would be to repeat these experiments but with new exposure techniques focussed on maintaining CNR as kV increases.

Two studies[108,109] investigated the effect of SID on resultant image quality for the AP pelvis projection. Both studies showed that increasing SID can significantly decrease patient dose without having a statistically significant impact on image quality. One

concern with these experiments is the usage of focussed grids. As has been outlined previously, it is important that focussed grids be used within their tolerance range, as outside this range it can negatively impact patient dose and image quality. The fact that in both studies the higher SID was found to be optimal means that even if there were focal range impacts, this would only have led to an underestimation of the resultant dose reduction and image quality levels. It appears that increasing SID has the potential to be an effective optimisation strategy. It is worthwhile noting that one study[108] did not use a consistent SID as their "extended" group, as maximum SID was limited by reach of the performing radiographer. SIDs for the extended group ranged from 135 to 144 cm. The effective dose measurements were calculated separately, for a 135 cm group and for a 144 cm group, but image quality measurements were combined. This may have led to some skewing of the image quality results and makes it difficult to provide recommendations for clinical practice.

4.7.2 Implications for clinical practice

Increasing the SID for AP pelvis projections has been shown to be an effective optimisation strategy. More work is needed to define if there is an exact SID that is optimal, or if SID should simply be increased as much as possible. Care needs to be taken to ensure that exposure parameters including mAs backup timers are set appropriately when increasing the SID, as overall mAs will need to increase to compensate for the increased attenuation in air because of the inverse square law.

Inclusion of additional beam filtration has shown promise for reducing patient dose whilst maintaining image quality for horizontal beam lateral hip projections. More work needs to be done to clinically validate this, especially with respect to maximum generator output as the inclusion of filtration will lead to a higher mAs requirement in a projection that already uses a significantly large exposure.

4.8 Chest

Chest radiographs are the most commonly performed examinations in most radiology departments, and are the most frequently ordered medical imaging test by general practitioners in Australia.[128] In screen-film (SF) imaging, a high kV technique was used as a method to improve the contrast of the resultant image. Due to the limited dynamic range of SF, a high kV technique was needed in order to visualise structures of vastly different attenuation (e.g. lung vs rib).[120] Using a higher kV also decreases the skin dose to the patient due to the increased penetrating capacity of the beam. The dynamic range of DDR detectors is much wider than that of SF, therefore it is not necessary to use a high kV technique to produce an image with optimal contrast. Multi-frequency image processing is also able to selectively adjust image contrast and brightness based on certain anatomical features, so the association between exposure technique and image contrast has been decoupled. It has also been demonstrated that to maintain a constant SNR, detector dose needs to be increased as kV increases,[129] which gives rise to the question whether a high kV technique is still optimal for chest radiography with a DDR detector.

4.8.1 Investigated techniques

Two studies[115,116] investigated the use of additional beam filtration for the lateral chest projection. Both studies demonstrated that additional tube filtration was an effective method of dose reduction that had no negative impact on image quality. This was especially well highlighted by the study by Grewal et al.[115] that retrospectively investigated two protocols currently in use at the site. One technique used a higher kV with an increased density setting and no filtration, and the other technique used a lower kV with normal density setting and 1mm Al+0.1mm Cu filtration. Subjective image quality analysis revealed preference for the second technique, which also had a 29% lower effective dose to the patient. The second technique also employed a longer SID, which may have accounted for some of the improvements in “sharpness” due to the decreased influence of beam divergence. The study by Hamer et al.[116] corroborated these results, indicating that the introduction of a 0.3mm Cu filter did not have a significant impact on image quality, but lowered DAP by approximately 55%.

For the PA projection most studies investigated the impact that changing kV would have on dose and image quality. Results for this parameter were mixed across studies, and in some cases contradictory.

For studies that were controlled by AEC, as kV increased, effective dose decreased in two out of three studies and increased in one out of three studies. The study by Metz et al.[117] demonstrated that as kV increased, so did effective dose, which contradicts the results by Shaw et al.[119] and Uffman et al.[120] The key difference between these studies is the method by which they calculated effective dose.

Effective dose is a calculation based on a number of assumptions and can be calculated in a variety of ways. As outlined by McCollough and colleagues,[130] effective dose values for the same factors as calculated by different techniques vary widely. They posit that consistency of calculation is the key when comparing techniques for optimisation purposes. This is corroborated by the data above, as the Uffman et al.[120] and Shaw et al.[119] studies both use the same calculation method and appear to show similar results. It

is beyond the scope of this thesis to delve deeply into how the calculations differ, but it does highlight the need for consistency in dose measurement and estimation between studies if comparisons are to be drawn.

A finding common across studies was that as mAs decreased, so did perceived image quality scores. Two studies[117,131] demonstrated statistically significant reductions in perceived image quality and lesion detectability when mAs was reduced. One study[117] investigated the detectability of different types of pathologies commonly encountered on chest radiographs. A key finding from this study was that for lesions in the lucent lung, halving the AEC cutoff dose did not have a significant effect on lesion detectability. This finding highlights the need for further quantification of the actual image quality level required in order to fulfil the diagnostic question being posed of the task.

A single study[119] investigated methods of scatter reduction for the PA chest projection. This investigation found that both an air-gap and an anti-scatter grid improved image quality, and that the anti-scatter grid was the most effective method of image quality improvement. Anti-scatter grid was also found to have the highest effective dose.

4.8.2 Implications for clinical practice

Use of additional tube filtration has been shown to be an effective method of optimisation that decreases patient dose whilst maintaining image quality. Further work needs to be undertaken to find the optimal filtration material and thickness. No recommendations for clinical practice can be made in terms of kV optimisation due to significant methodological heterogeneity.

4.9 General remarks

4.9.1 Optimisation vs minimisation

Studies of radiographic technique optimisation are prevalent in the literature, but it is evident that there are significant differences in what constitutes "optimisation". An optimal technique is one that produces an image sufficient for diagnosis at the minimum dose to the patient.[132] What constitutes an image that is sufficient for diagnosis is difficult to define, because different clinical indications will have different quality requirements – but there is always the risk that an examination may uncover an incidental finding, which will have a different quality requirement. It is the author's opinion that there should be two distinct methodologies in studies of image quality that will help better focus research activities and ultimately lead to appropriate optimisation of radiographic technique parameters.

Many of the included studies[99,101,103,106,107,110-113,119,120] in this review purport to be studies of technique optimisation but are instead simply investigations of dose reduction strategies. Many of the included studies concluded that their "optimised" technique was one that sacrificed some image quality but gave significantly lower patient dose. These "optimised" techniques were still found to produce images suitable for diagnosis, despite being of lesser quality than their reference or standard technique. The author believes that studies classified as optimisation of radiographic technique parameters should be designed to find parameters that will give equivalent image quality for equivalent or lower patient dose. It should be undertaken on the assumption that the currently accepted standard is sufficient for diagnosis.

It is the author's observation that there are actually two distinct types of trials being undertaken in studies of radiographic technique optimisation: studies of true optimisation according to the definition above, and those of minimisation that are designed to find the minimum parameters required to produce an image of diagnostic quality.

For studies of minimisation (those designed to find the minimum parameters required to produce an image quality) the author suggests using a non-inferiority trial design. This study design aims to demonstrate that one technique is not inferior to another for a defined task.[133] In these types of studies, researchers should concentrate only on the sufficiency of the image for diagnosis, not on how "good" the image is. This type of testing will establish a baseline image quality requirement and give a good foundation on which to perform studies of optimisation.

For studies of minimisation, it is also important to consider the task in question. In an ideal world the image quality level required would be matched to the specific diagnostic purpose of each examination. This is impractical and fails to take into account that there may be incidental findings when an examination is undertaken. It would defeat the goal of optimisation if an examination needed to be repeated because the initial very low dose examination (to look for a metallic foreign body, for example) raised questions as to whether there was the presence of an incidental finding (such as a bone lesion) but the level of noise in the image was too high to make a confident diagnosis. Instead the author would propose that researchers aim to establish what constitutes an adequate image for diagnosis. As stated previously, visual appreciation of image noise is very

subjective,[16] and what constitutes an acceptable level of noise depends on both the preference of the observer and on the clinical question being asked.[10,17]

With baseline image quality for general indications established, researchers can then identify specific procedures that may be able to be further optimised, such as examination types that involve repeated imaging. For example, pelvic imaging of young children is performed to first diagnose and then surveil instances of developmental hip dysplasia. This is a relatively high-dose examination of a very radiosensitive portion of the body, to a highly susceptible group – the paediatric population. In this instance, the initial image must be of very high quality in order to appropriately diagnose the pathology. For monitoring purposes, it may be acceptable to have more noise in the image whilst still maintaining the diagnostic capacity of the image.

Once baseline image quality is established by minimisation research, true optimisation research can take place. In alignment with ALARA goals, the aims of this research should be to find technique parameters that give equivalent image quality with reduced patient dose. These types of investigations should again use a non-inferiority hypothesis testing to demonstrate that the optimised technique has at least equivalent image quality, and superiority hypothesis testing in terms of patient dose to find the technique that gives the lowest dose to the patient.

Most included studies used superiority hypothesis testing. Using this model, when there is no statistical significance, this indicates that one intervention was neither better nor worse than the other. It does not show that they are equivalent. It may be that many of the included studies that used superiority hypothesis rejected techniques with equivalent image quality but of lower dose, simply because they did not have statistically significant results. Instead of superiority design, non-inferiority studies are ideal for technique optimisation investigation. Once baseline quality levels have been established, all that is left is to find the technique that maintains this quality level at minimal dose to the patient. It may be tempting to find instead techniques that give better image quality for equivalent patient dose, but this just represents a further opportunity for optimisation.

4.9.2 Parameter selection

In designing studies for optimisation, care should be taken not to let tradition dictate which parameters are investigated. Authors should take special care when designing studies for optimisation that their own biases are not influencing the selection of technique parameters for investigation. One example where this has occurred in the review is for the optimisation of kV for AP pelvis imaging. Both included studies[99, 113] only investigated kV levels higher than that which is currently used, as traditionally it is believed that increasing kV decreases patient dose. An optimisation strategy should investigate the complete range of the parameter being investigated to ensure a thorough investigation has occurred. It was demonstrated in the literature[104, 105] for the AP lumbar spine that lower than currently used kV settings were optimal. The AP lumbar spine and the AP pelvis projection have similar thickness and composition, so potentially these same results would have been replicated. Another example of where this has been successful in practice is in the investigation of techniques for paediatric extremity imaging. Studies of paediatric extremity technique[41,24] have shown that by rejecting the current standard and investigating the full range of each acquisition element, it is possible to significantly increase image quality without negatively impacting patient dose with techniques that have traditionally been considered “unsafe”.

4.9.3 Methodological heterogeneity

One of the most important findings of this review is that significant methodological heterogeneity exists in the included studies. As outlined above, this is largely because studies of "optimisation" may have in fact been better characterised as studies of minimisation, but it is also because there was significant methodological heterogeneity even within true studies of optimisation.

4.9.3.1 Study design

Studies of image quality use both anthropomorphic phantoms and real patients as their subjects, so study design is necessarily different for each of these applications. A major challenge with studies of optimisation is that it would be ideal to subject the same human patient to both the experimental and control technique, but this is unethical due to the increased radiation burden applied to the patient. This means that studies using human subjects must include a significantly large number of patients to ensure a representative cross-section is taken.

Because patient size has such a large effect on image quality and dose, it is important that information about size is captured and accounted for in studies with human subjects. Appropriate randomisation was also not often evident in studies with human subjects. This represents a threat to internal validity of the studies and is especially concerning with respect to patient size. Appropriate randomisation is of key importance in all research, but especially for any body parts large enough to warrant grid usage. As part thickness increases, the amount of scattered radiation produced increases as well; this leads to a reduction in image quality.

4.9.3.2 Patient dose measurements

There were three main measures of patient dose used throughout the literature included within the review. Several studies used dose area product (DAP) as a measure of patient dose. This is troublesome as DAP is a measure of tube output[134] and does not give an accurate indication of actual risk to the patient.[135] DAP fails to take into account how variances in beam quality and patient factors would affect absorption and backscatter. DAP is a very convenient measure, as in most modern systems it is automatically recorded and sent to the Picture Archiving and Communication System (PACS) in the Digital Imaging and Communications in Medicine (DICOM) header.

Entrance surface dose (ESD) is a measure of radiation dose absorbed by the skin, and can be measured by use of thermoluminescent dosimeters (TLDs) on the patient/phantom's skin or calculated from known exposure factors.[136] Effective dose (E) is a calculation based on known parameters that gives an indication of the risk to the patient.[137] The Health Protection Agency[137] and the International Commission on Radiation Protection[138] recommend that effective dose be used to compare doses across and within sites. Some DDR systems also display an estimated air kerma area product based on DAP measurements and an estimated SSD, but these are estimates only and have experimentally been shown to have limited accuracy.[115]

It is the author's opinion that DAP may be an appropriate measure when undertaking a study of optimisation of extremities of adults, due to the low radiosensitivity and low thickness of the part. For studies of larger, more attenuating and scatter producing regions, and those involving paediatrics, effective dose should be used to ensure that the

technique is indeed optimised and demonstrates the true risk reduction to the patient of the optimised technique. Any reduction in effective dose is clinically significant, as there is no threshold for exposure for the induction of radiation induced cancers.[32]

Whilst effective dose is the preferred comparative statistic for expression of radiation risk for studies of radiographic technique optimisation, there are some issues with its usage. Multiple methods of calculation exist, each based on different models, which therefore give different results for the same parameters.[130] This is combined with the variances that exist between individual machines, such as beam profile, anode roughness, and inherent filtration. Further work needs to be done to validate the various methods that exist before a recommendation for the optimal choice for radiography studies, but as a minimum the author would recommend choosing a method that takes into account age and gender variances. Despite its limitations, effective dose is still the only method of dose expression we have that can convey actual patient risk. We are unable to directly measure absorbed dose to real patients, so effective dose is the best option to give us an indication of whether a technique is truly optimised in terms of patient dose.

4.10 Implementing change in clinical practice

The ideal scenario for optimisation research would be to collate all the available evidence and to produce an exposure chart that can be used across the world. Unfortunately, this is not possible due to the variances in clinical equipment and in the site-specific requirements for image quality per radiologist request. For example, anode roughness can lead to decreased tube output[139] and different machines have different levels of inherent tube filtration which has an effect on beam hardness. Instead of an exposure chart, the following is suggested as areas for consideration in future research.

4.10.1 Automatic exposure control

Most systems with automatic exposure control (AEC) are designed to maintain a constant detector dose. An area where equipment manufacturers may be able to assist in optimisation is to design an AEC that instead maintains a set level of CNR. Maintaining CNR means that object detectability remains constant even as kV is increased. When a constant CNR AEC model is employed, the AEC will increase the detector dose required before termination as kV increases to overcome the contrast loss associated with higher kV values.[98] Until this is a possibility, radiographers should work closely with physicists to develop workable clinical solutions. It may be possible to increase kV and increase the density correction step so that the AEC dose is increased when using high kV.

4.10.2 Source-to-image distance

It has been shown across several studies that increasing SID can decrease patient dose without negatively impacting on image quality. When this is applied in clinical practice on large body parts, care must be taken that the increase in SID will not lead to extremely long exposure times or the termination of exposure due to maximum loading being reached. As distance increases, radiation intensity decreases in accordance with the inverse square law. When using an AEC, the AEC will compensate for this, but many AECs also have safety features to prevent unintended overexposure that will terminate the exposure early if it has not reached a certain level within the first milliseconds of exposure. Care should be taken when selecting SIDs for large body regions, and sites should partner with manufacturer engineers and applications specialists to ensure that the system is set up for the new exposure conditions.

4.10.3 Image quality matched to diagnostic purpose

A key future research direction should be the matching of image quality to the diagnostic purpose of the examination. It has been highlighted by a number of studies that minor sacrifices in image quality were acceptable to maintain diagnostic acceptability of the resultant images. This highlights the fact that minimum levels of image quality required for diagnostic imaging need to be established, as previously outlined. An extension to this would be the matching of the image quality level required to the specific diagnostic purpose of the examination, such as that discussed earlier regarding developmental hip dysplasia imaging.

4.11 Strengths and limitations of approach

Due to the wide nature of the review, only studies that incorporated a subjective analysis of image quality performed by an appropriate clinician were included. This led to the rejection of multiple studies that used only objective means, such as measurement of the CNR. These studies may have provided useful data for body regions where few or no studies were included, and they may have provided strength or highlighted a mismatch between the expected and actual results in clinical trials. As image quality is subjective and based on interpreter taste to a certain extent, these objective measures may have added significant information.

A systematic review and meta-analysis is heralded as the gold standard of research, [28] toted as producing the highest level of evidence. In reality, a systematic review is only as strong as the studies included within it. Unfortunately, due to the variable methodological quality of research produced in medical imaging, the strength of the recommendations produced by this review is limited. There is also a high risk that studies that would have met the inclusion criteria were not caught by the search strategy due to the poor indexing of radiography journals, and the fact that many studies are likely unpublished. A number of studies that could have provided further information were excluded because they were not in English. Also, as no Grading of Recommendation, Assessment, Development and Evaluation (GRADE)[140] approach currently exists for this kind of review, and given the heterogeneity of the data, the author could not perform a structured assessment of her certainty/confidence in the main findings using GRADE.

Whilst there were some limitations, there were also several strengths. One of the key strengths of this review was the comprehensive search for both published and unpublished literature, including hand searching of reference lists and contacting a number of authors for more details and information on any of their unpublished works. The protocol was also registered with PROSPERO, and critical appraisal was undertaken by two reviewers with in-depth knowledge of radiographic technique.

4.12 Limitations of the review

A very limited number of implementable changes in clinical practice were uncovered as a result of this systematic review. This is due to the significant methodological heterogeneity within the included studies, as well as the limited quality and number of studies meeting inclusion criteria.

A significant number of studies investigated technique optimisation only on anthropomorphic phantoms. Whilst these phantoms are representative of human tissue, they lack the variation in terms of body habitus and clinical condition encountered within the general population. The author believes that whilst phantom testing is a good initial investigation, techniques need to be validated in clinical populations prior to being implemented permanently.

Testing on anthropomorphic phantoms also limits the amount of pathology that can be accurately represented. The ideal test of image quality is how well it can demonstrate subtle pathology – that is, pathology that is borderline visible. These are the most difficult to detect and represent the biggest risk to the patient if an important but subtle lesion goes undetected. This is why validation with clinical subjects is important and necessary.

A number of studies[109, 113-115, 117, 118, 120] used hard copy images to review from. This restricted the windowing and levelling ability of the interpreters. A key advantage of digital radiography is the ability to manipulate the image after acquisition, and to look at it with different window widths and levels to enhance certain anatomical features. By using hard copy images for review, this functionality was not available to the reviewers. As a result, images that were suitable for diagnosis may have been downgraded due to a simple contrast and brightness issue.

In terms of the equipment used, one factor that was not investigated was the age of equipment used. As far as I can tell, there have been limited improvements in the acquisition technology that would have an impact upon the results of this investigation. It appears that key focus for innovation has been devoted to making detectors lighter and more portable. Whilst it is unlikely that there has been an impact on results, it cannot be definitively ruled out that equipment age had an effect on results.

Finally, five parameters for optimisation were identified. Of the included studies, only chest imaging included studies that investigated all five parameters. Further research needs to be undertaken to investigate all available methods of image quality optimisation, not just those that have traditionally been thought to be effective. As the technology has changed vastly, a comprehensive investigation of all available parameters is needed in order to ensure the technique proposed as optimal is in fact the best possible technique for the patient.

Chapter Five – Conclusions

This systematic review represents a critical first step towards the goal of optimising technique parameters for direct digital radiography systems for all patient types and body regions. Although this work has revealed limited practicable changes to techniques that can be implemented into clinical practice immediately, it has highlighted some key directions for future research.

A key focus for future research should first be defining minimum image quality level requirements for general clinical indications. This should be done by employing a non-inferiority study design as outlined in the optimisation vs minimisation section. From here, researchers will be able to undertake true studies of technique parameter optimisation. It is evident from the published literature that in many circumstances the currently accepted level of image quality exceeds that which is required for diagnosis. We need to clarify what constitutes an adequate image before we use it as a baseline upon which to define an optimised technique.

Chapter Six – References

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Chapter Seven – Appendices

7.1 Appendix I: Search strategy

7.1.1 Search strategy for PubMed

Run on 17/6/18

17/6/18 – 218 Results

((((“kV”[tw] OR “kilovoltage”[tw] OR “tube potential”[tw] OR “tube voltage”[tw] OR “mA”[tw] OR “tube current”[tw] OR “beam filter”[tw] OR “beam filtration”[tw] OR “SID”[tw] OR “source-to-image distance”[tw] OR “source to image distance”[tw])))
AND ((“Radiographic Image Enhancement”[mh:noexp] OR “Radiation Dosage”[mh] OR “Phantoms, Imaging”[mh] OR “Image Quality”[tw]OR “optimisation”[tw] OR “optimization”[tw]OR “improv*”[tw] OR “CNR”[tw] OR “Contrast-to-noise ratio”[tw] OR “Contrast to noise ratio”[tw] OR “SNR”[tw] OR “Signal-to-noise ratio”[tw] OR “Signal to noise ratio”[tw] OR “SdNR”[tw] OR “Signal difference to noise ratio”[tw] OR “Signal-difference-to-noise-ratio”[tw]))) AND ((“Digital Radiography”[tw] OR “flat panel detector”[tw] OR “flat-panel detector”[tw] OR “FPD”[tw] OR “direct capture”[tw] OR “indirect capture”[tw] OR “DR”[tw] OR “CCD”[tw] OR “charge coupled device”[tw] OR “SSD”[tw] OR “solid state detector”[tw] OR “solid-state detector”[tw]))

7.1.2 Search strategy for Embase

Run on 17/6/18

('radiological parameters'/mj OR 'kv':ti,ab OR 'kilovoltage':ti,ab OR 'tube potential':ti,ab OR 'tube voltage':ti,ab OR 'ma':ti,ab OR 'tube current':ti,ab OR 'beam filt*':ti,ab OR 'tube filt*':ti,ab OR 'sid':ti,ab OR 'source-to-image distance':ti,ab OR 'source to image distance':ti,ab) AND ('radiography'/mj OR 'radiation dose'/mj OR 'imaging phantom'/mj OR 'image enhancement'/exp/mj OR 'image quality':ti,ab OR 'optimisation':ti,ab OR 'optimization':ti,ab OR 'improv*':ti,ab OR 'cnr':ti,ab OR 'contrast-to-noise ratio':ti,ab OR 'contrast to noise ratio':ti,ab OR 'snr':ti,ab OR 'signal-to-noise ratio':ti,ab OR 'signal to noise ratio':ti,ab OR 'sdnr':ti,ab OR 'signal difference to noise ratio':ti,ab) AND ('digital radiography':ti,ab OR 'flat panel detector':ti,ab OR 'flat-panel detector':ti,ab OR 'fpd':ti,ab OR 'direct capture':ti,ab OR 'indirect capture':ti,ab OR 'dr':ti,ab OR 'ccd':ti,ab OR 'charge coupled device':ti,ab OR 'ssd':ti,ab OR 'solid state detector':ti,ab OR 'solid-state detector':ti,ab) AND (1997:py OR 1998:py OR 1999:py OR 2000:py OR 2001:py OR 2002:py OR 2003:py OR 2004:py OR 2005:py OR 2006:py OR 2007:py OR 2008:py OR 2009:py OR 2010:py OR 2011:py OR 2012:py OR 2013:py OR 2014:py OR 2015:py OR 2016:py OR 2017:py OR 2018:py)

7.1.3 Search strategy for Scopus

Run on 17/6/18

((TITLE-ABS-KEY("kV" OR "kilovoltage" OR "tube potential" OR "tube voltage" OR "mA" OR "tube current" OR "beam filt*" OR "tube filt*" OR "SID" OR "source-to-image distance" OR "source to image distance"))AND(TITLE-ABS-KEY("Image Quality" OR "optimisation" OR "optimization" OR "improv*" OR "CNR" OR "Contrast-to-noise ratio" OR "Contrast to noise ratio" OR "SNR" OR "Signal-to-noise ratio" OR "Signal to noise ratio" OR "SdNR" OR "Signal difference to noise ratio" OR "Signal-difference-to-noise-ratio"))AND(TITLE-ABS-

KEY("Digital Radiography" OR "flat panel detector" OR "flat-panel detector" OR "FPD" OR "direct capture" OR "indirect capture" OR "DR" OR "CCD" OR "charge coupled device" OR "SSD" OR "solid state detector" OR "solid-state detector")) AND NOT INDEX(medline)) PUBYEAR > 1996

7.1.4 Search strategy for CINAHL

Run on 17/6/18

((AB “kV”) OR (AB “kilovoltage”) OR (AB “tube potential”) OR (AB “tube voltage”) OR (AB “mA”) OR (AB “tube current”) OR (AB “beam filt*”) OR (AB “tube filt*”) OR (AB “SID”) OR (AB “source-to-image distance”) OR (AB “source to image distance”)) AND ((MM Radiography+) OR (MM Radiation Dose) OR (MM imaging phantom) OR (AB “Image Quality”) OR (AB ”optimisation”) OR (AB ”optimization”) OR (AB ”improv*”) OR (AB ”CNR”) OR (AB ”Contrast-to-noise ratio”) OR (AB ”Contrast to noise ratio”) OR (AB ”SNR”) OR (AB ”Signal-to-noise ratio”) OR (AB ”Signal to noise ratio”) OR (AB ”SdNR”) OR (AB ”Signal difference to noise ratio”) OR (AB ”Signal-difference-to-noise-ratio”)) AND ((AB “Digital Radiography”) OR (AB “flat panel detector”) OR (AB “flat-panel detector”) OR (AB “FPD”) OR (AB “direct capture”) OR (AB “indirect capture”) OR (AB “DR”) OR (AB “CCD”) OR (AB “charge coupled device”) OR (AB “SSD”) OR (AB “solid state detector”) OR (AB “solid-state detector”))

7.2 Appendix 2 – Critical appraisal tool

Critical Appraisal Checklist for Imaging Studies

Reviewer_____Date_____

Author _____Year_____Record Number

		Yes	No	Unclear	Not applicable
1.	Was the sample recruited and allocated appropriately?	☐	☐	☐	☐
2.	Was the sample studied similar for the study and across groups (if groups are present)?	☐	☐	☐	☐
3.	Was the study sample reflective of real world patients/populations?	☐	☐	☐	☐
4.	Were there appropriate measures in place to ensure compliance with protocols to ensure consistent and standard delivery of investigated technique parameters?	☐	☐	☐	☐
5.	Were appropriate measures in place during data collection and analysis to ensure a consistent and similar or standardised sample?	☐	☐	☐	☐
6.	Were there measures in place to ensure imaging equipment is performing at the same specification (within appropriate tolerance) within and (potentially) across imaging equipment?	☐	☐	☐	☐
7.	Were outcomes measured in a valid way?	☐	☐	☐	☐
8.	Were outcomes measured in a standard and consistent way?	☐	☐	☐	☐
9.	Were outcomes measured in a reliable way?	☐	☐	☐	☐
10.	Were there comparisons made or was there a control group?	☐	☐	☐	☐
11.	Was appropriate statistical analysis used?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments (Including reason for exclusion)

_____

_____

7.3 Appendix 3 – Data extraction tool template

Study	Examination	Population	Participant	Detectory Type	Detector Material	Outcome Evaluation	Evaluation Method	Control Technique						Optimised Technique					
								kVp	mAs	Filter	Grid	SID	Pt Dose	kVp	mAs	Filter	Grid	SID	Pt Dose

7.4 Appendix 4 – Summary of included studies

First Author/Year	Region	Study Design	Participants	Intervention	Dose Outcome	Image Quality Outcome
Jang/2018[98]	Abdomen	Retrospective observational	Adults referred for erect and supine AP abdomen radiographs	Increased kV, additional 0.1mm Cu filtration	Measured DAP, calculated E by PCXMC software (Monte Carlo modelling)	VGA based on modified CEC guidelines, 5-point scale
Bernhardt/2004[114]	Chest	Crossover	Anthropomorphic chest phantom with simulated lesions	Decreased kV	Measured ESD, calculated E by Huda and Bisseur method	VGA of lesion detectability, 5-point scale
Grewal/2012[115]	Chest	Retrospective observational	Ambulant adults who were referred for PA and Lateral projections	Decreased kV, added 0.1mm Cu + 1mm Al filtration, increased SID	Calculated ESD based off measured KAP, calculated E by PCXMC software (Monte Carlo modelling)	VGA based on modified CEC guidelines, 3-point scale
Hamer/2005[116]	Chest	Case-control and crossover	Ambulant adults referred for PA chest radiographs and anthropomorphic chest phantom	Additional 0.3mm Cu filtration	Measured DAP for patients, measured ESD and calculated absorbed dose for phantom	VGA based on modified CEC guidelines, 7-point scale
Lorusso/2015[99]	Chest Pelvis Extremity Skull	Crossover	Anthropomorphic phantoms	Increasing kV	Measured DAP	VGA based on modified CEC guidelines on 5-point scale,

						plus questions about diagnostic and aesthetic quality
Metz/2005[117]	Chest	Crossover	Anthropomorphic phantom with simulated lesions	Increasing kV, decreasing mAs	Measured ESD, calculated E based on 1990 IRCP tissue weighting factors	VGA of lesion detectability, 5-point scale
Moey/2017[118]	Chest	Crossover	Ambulant adults between 60-80kg and 20-60 years of age	Decreasing kV	Measured DAP, calculated E by CALDose_X 5.0 software (Monte Carlo modelling)	VGA based on modified CEC guidelines, 4-point scale
Shaw/2013[119]	Chest	Crossover	Anthropomorphic phantom	Decreasing kV, scatter reduction	Measured DAP, calculated E by PCXMC software (Monte Carlo modelling)	VGA based on modified CEC guidelines, 5-point scale
Uffman/2005[120]	Chest	Crossover	Adults aged >45 years referred for routine chest radiography	Decreased and increased kV	Estimated KAP based on tube output, calculated E by PCXMC software (Monte Carlo modelling)	VGA of anatomical features visibility, 5-point scale

Guo/2013[106]	Paediatrics	RCT	Children aged <14 years referred for chest radiography	Decreased kV	Measured DAP	VGA of anatomical features visibility and noise level
Charnley/2016[107]	Pelvis	Crossover	Anthropomorphic phantom	Changing kV, changing OID, increasing SID, grid use, addition of 0.1mm Cu filtration	Measured DAP	VGA based on modified CEC guidelines, 5-point scale
England/2015[108]	Pelvis	RCT	Adults referred for non-traumatic pelvic radiographs	Increasing SID	Calculated ESD and E based on exposure parameters by QADDS software	VGA based on modified CEC guidelines, 3-point scale
Fauber/2011[113]	Pelvis	Crossover	Anthropomorphic phantom	Changing kV	Measured ESD	VGA of noise visibility, ranking of images
Harding/2014[110]	Pelvis	RCT	Adults referred for pelvis imaging performed on table (trolley patients excluded)	Decreasing mAs (changing patient orientation)	Calculated ESD and E based on exposure factors and calibration data by QADDS software	VGA based on modified CEC guidelines, 3-point scale
Heath/2011[109]	Pelvis	Crossover	Anthropomorphic phantom	Changing SID	Calculated ESD and E based on exposure	VGA based on modified CEC

					factors and calibration data by QADDS software	guidelines, 5-point scale
Manning-Stanley/2012[111]	Pelvis	Crossover	Anthropomorphic phantom	Decreasing mAs (changing patient orientation)	Calculated ESD and E based on exposure factors and calibration data by QADDS software	VGA of anatomical features visibility, 3-point scale
Persliden/2002[112]	Pelvis	Crossover	Anthropomorphic phantom	Decreasing mAs	Measured ESD, calculated E by PCXMC software	VGA of usefulness for diagnosis, 5-point scale
Roberts/2006[100]	Shoulder C-Spine	RCT	Patients referred for shoulder and c-spine imaging performed on the erect bucky	Grid usage	Measured ESD	VGA according to DIMOND III criteria, dichotomous scale
Joyce/2013[101]	Skull	Crossover	Anthropomorphic phantom	Increasing SID	Measured ESD	VGA based on modified CEC guidelines, 4-point scale
Brindhaban/2011[103]	L-Spine	Crossover	Anthropomorphic phantom	Increasing kV	Measured ESD, calculated E (method not stated)	VGA based on modified CEC guidelines, 5-point scale
Geijer/2009[104]	L-Spine	Crossover	Anthropomorphic phantom	Changing kV, decreasing mAs,	Measured entrance dose without	VGA of anatomical feature

				additional tube filtration	backscatter, calculated E by PCXMC software	visibility, 5-point scale
Geijer/2005[105]	L-Spine	Crossover	Anthropomorphic phantom	Changing kV	Fixed E used, calculated by PCXMC software	VGA based on modified CEC guidelines, 5-point scale
Joyce/2008[102]	C-Spine	Crossover	Cadaver	Increasing SID	Measured DAP, measured ESD	VGA of anatomical feature visibility, 3-point scale

7.5 Appendix 5 – Critical appraisal results

First Author	Recruitment	Similar sample	Real-world patients	Protocol compliance	Standard-ised sample	Equipment calibrated	Valid	Consistent	Reliable	Comp-arison/ Control	Approp-riate stats	Notes
Bernhardt[114]	N/A	Yes	No	Yes	Yes	Unclear	Yes	Yes	Unclear	Yes	Unclear	Moderate
Brindhaban[103]	N/A	Yes	No	Yes	Yes	Unclear	Yes	Unclear	Unclear	Yes	Unclear	Moderate
Charnley[107]	N/A	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Good
England[108]	No	Yes	Yes	Unclear	No	Yes	Yes	Yes	Yes	Yes	Yes	Good
Fauber[113]	N/A	Yes	No	Yes	Yes	Yes	Unclear	Unclear	Unclear	Yes	Yes	Moderate
Geijer[104]	N/A	Yes	No	Yes	Yes	Unclear	Yes	Unclear	Unclear	Yes	Yes	Moderate
Geijer[105]	N/A	Yes	No	Yes	Yes	Unclear	Yes	Unclear	Unclear	Yes	Yes	Moderate
Guo[106]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Good
Hamer[116]	Unclear	Yes	Yes	Unclear	Yes	Unclear	Yes	Yes	Unclear	Yes	Yes	Moderate
Heath[109]	N/A	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Good
Jang[98]	No	Yes	Yes	Unclear	Yes	Yes	Yes	Unclear	Yes	Yes	Unclear	Moderate
Joyce[102]	N/A	Yes	No	Yes	Yes	Unclear	Unclear	Yes	Yes	Yes	Yes	Moderate
Joyce[100]	N/A	Yes	Yes	Unclear	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	Good
Lorusso[99]	N/A	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Moderate
Manning-Stanley[111]	N/A	Yes	No	Yes	Yes	Yes	Unclear	Yes	Unclear	Yes	Yes	Moderate

Metz[117]	N/A	Yes	No	Yes	Yes	Unclear	Yes	Yes	Unclear	Yes	Yes	Moderate
Moey[118]	Unclear	Yes	Yes	Yes	Yes	Unclear	Yes	Yes	Unclear	Yes	Yes	Good
Persliden[112]	N/A	Yes	No	Yes	Yes	Unclear	Yes	Unclear	Yes	Yes	Yes	Moderate
Shaw[119]	N/A	Yes	No	Yes	Yes	Yes	Yes	Yes	Unclear	Yes	Yes	Good
Uffmann[120]	Yes	Yes	No	Unclear	Yes	Yes	Yes	Yes	Yes	No	Yes	Good
Roberts[100]	Unclear	Yes	Yes	No	Unclear	Yes	Yes	Yes	Yes	Yes	Unclear	Moderate
Harding[110]	Unclear	Yes	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Good
Grewal[115]	No	Unclear	Yes	Unclear	Unclear	Yes	Yes	Yes	Yes	Yes	Yes	Moderate

7.6 Appendix 6 – Image quality criteria for studies of AP pelvis

Study	Image Quality Criteria
England et al.[108]	A. visually sharp reproduction of sacrum B. visually sharp reproduction of intervertebral foramina C. visually sharp reproduction of pubic and ischial rami D. visually sharp reproduction of sacroiliac joints E. visually sharp reproduction of femoral necks F. visually sharp reproduction of spongiosa and corticalis G. visually sharp reproduction of trochanters.
Fauber et al.[113]	A. amount of noise visible B. overall quality of image.
Lorusso et al.[99]	A. visually sharp reproduction of the sacrum and its intervertebral foramina B. visually sharp reproduction of the pubic and ischial rami C. visually sharp reproduction of the sacroiliac joints D. visually sharp reproduction of the necks of the femora E. visually sharp reproduction of the trabecular bone of the trochanters.
Persliden et al.[112]	A. symmetrical reproduction of the pelvis as judged by the imposition of the symphysis pubis over the midline of the sacrum B. visually sharp reproduction of the sacrum and its intervertebral foramina C. visually sharp reproduction of the pubic and ischial rami D. visually sharp reproduction of the sacroiliac joints E. visually sharp reproduction of the necks of the femora which should not be distorted by foreshortening or rotation F. visually sharp reproduction of the spongiosa and corticalis, and of the trochanters.
Heath et al.[109]	Visualisation of anatomical features (5-point scale): A. ilium B. ischium C. pubis D. sacroiliac joints E. femoral neck/trochanters F. acetabulum G. sacrum/sacral foramina H. overall trabecular pattern. General image quality features (3-point scale) A. sharpness/mottle B. density C. contrast.
Harding et al.[110]	A. iliac crests B. sacrum C. intervertebral foramen D. pubic and ischial rami E. sacroiliac joints F. femoral necks G. spongiosa and corticalis H. trochanters.

Manning-Stanley et al.[111]	Grading of anatomical areas: A. sacrum and its intervertebral foramen B. pubic and ischial rami C. sacroiliac joints D. femoral necks E. spongiosa and corticalis (trabeculae and cortical bone) F. trochanters.

7.7 Appendix 7 – Image quality criteria for studies of lateral chest

Study	Image Quality Criteria
Grewal et al.[115]	European Guidelines A. performed at full inspiration and with suspended respiration B. arms raised clear of the thorax C. superimposition of the posterior lung borders Reproduction of the trachea D. reproduction of the costo-chronic angles E. visually sharp reproduction of the heart, the aorta, mediastinum, diaphragm, sternum and thoracic spine. Modified Criteria A. reproduction of ten vertebral bodies (performed at deep inspiration) B. superimposed reproduction of the posterior coastal arcs (not rotated thorax) C. reproduction from the 7th cervical vertebra to the bottom of the posterior costophrenic sinus (reproduction of the whole thoracic cavity) D. visually sharp reproduction of the peripheral vessels and diaphragm (performed with suspended respiration) E. visually sharp reproduction of the posterior border of the heart and/or aorta F. visualisation of the vessels through the cardiac pattern.
Hamer et al.[116]	Features of unobscured lung: A. retrosternal pulmonary vessels B. retrocardiac pulmonary vessels C. retrocardiac peripheral bronchi. Features of obscured lung: A. peripheral vessels obscured by heart shadow or diaphragm. Features of central airways: A. trachea B. carina C. mainstem bronchi. Features of mediastinum (other than central airways): A. pulmonary hilum B. posterior heart border. Features of skeleton of thorax: A. thoracic vertebrae B. sternum. Features of global image quality: A. image contrast B. noise C. motion blur.

7.8 Appendix 8 – Image quality criteria for studies of PA chest

Study	Image Quality Criteria
Grewal et al.[115]	European Guidelines: A. performed at deep inspiration (as assessed by the position of ribs above the diaphragm either 6 anteriorly or ten posteriorly) B. symmetrical reproduction of the thorax C. medial border of the scapulae to be outside the lung field D. reproduction of the whole rib cage above the diaphragm E. reproduction of the vascular pattern in the whole lung particularly the peripheral vessels F. visually sharp reproduction of the trachea and proximal bronchi, the borders of the heart and aorta G. visually sharp reproduction of the diaphragm and costophrenic angles H. visualisation of the retrocardiac lung and the mediastinum I. visualisation of the spine through the heart shadow. Modified Criteria: A. reproduction of the coastal arcs either six anteriorly or ten posteriorly (performed at deep inspiration) B. the spinal apophysis of the dorsal vertebras are equidistant from the inner borders of the clavicle (not rotated thorax) C. reproduction from the seventh cervical vertebra to the bottom of both costophrenic sinus (reproduction of the whole thoracic cavity) D. visually sharp reproduction of the peripheral vessels and both hemi diaphragms (performed with suspended respiration) E. visually sharp reproduction of the borders of the cardiac silhouette F. visualisation of the lung vessels through the cardiac silhouette G. the lower dorsal spine is no more than faintly appreciable and visualisation of the intervertebral spaces.
Bernhardt et al.[114]	Presence of simulated patterns: A. ground glass B. linear C. miliary D. reticular E. nodules >10mm over obscured chest F. nodules ≤ 10mm over obscured chest G. nodules >10mm over lung H. nodules ≤ 10mm over lung I. catheter.
Hamer et al.[116]	Features of unobscured lung: A. peripheral apical and basal vessels B. peripheral apical and basal bronchi. Features of obscured lung: A. azygoesophageal recess B. retrocardiac vessels C. vessels obscured by diaphragm.

	Features of central airways: A. trachea B. carina C. mainstem bronchi. Features of mediastinum (other than central airways): A. pulmonary hilum B. lateral heart borders C. left descending aortic border D. paraspinal stripe. Features of skeleton of thorax: A. thoracic vertebrae B. sternoclavicular joints C. rib. Features of global image quality: A. image contrast B. noise C. motion blur.
Lorusso et al.[99]	A. visually sharp reproduction of the trachea and proximal bronchi B. visually sharp reproduction of the borders of the heart and aorta C. visually sharp reproduction of the diaphragm and lateral costophrenic angles D. visually sharp reproduction of the retrocardiac lung and the mediastinum E. visualisation of the spine through the heart shadow.
Metz et al.[117]	Visualisation of simulated lesions: A. nodules of various sizes (5-15mm) B. polylobulated lesions C. interstitial-nodular lesions D. interstitial-reticular lesions.
Moey and Shazli[118]	A. inspiration B. rotation C. lung vascular patterns D. trachea, bronchi, heart borders, diaphragm and costophrenic angle E. density F. contrast G. sharpness H. collimation.
Shaw et al.[119]	A. reproduction of the whole rib cage above the diaphragm B. visually sharp reproduction of the vascular pattern in the whole lung C. visually sharp reproduction of the trachea and proximal bronchi D. visually sharp reproduction of the borders of the heart and aorta E. visually sharp reproduction of the diaphragm and costophrenic angles F. visualisation of the retrocardiac lung and mediastinum

	G. visualisation of the spine through the heart shadow.
Uffman et al.[120]	Visibility of anatomical features: A. lung parenchyma without rib superimposition B. lung parenchyma with rib superimposition C. perihilar vessels D. peripheral vessels (within a 2-cm wide subpleural space) E. costophrenic recess F. cardiophrenic recess G. retrocardiac area H. carina I. heart contours J. lower thoracic spine.