

REVIEW ARTICLE

A paediatric X-ray exposure chart

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Abstract

The aim of this review was to develop a radiographic optimisation strategy to make use of digital radiography (DR) and needle phosphor computerised radiography (CR) detectors, in order to lower radiation dose and improve image quality for paediatrics. This review was based on evidence-based practice, of which a component was a review of the relevant literature. The resulting exposure chart was developed with two distinct groups of exposure optimisation strategies – body exposures (for head, trunk, humerus, femur) and distal extremity exposures (elbow to finger, knee to toe). Exposure variables manipulated included kilovoltage peak (kVp), target detector exposure and milli-ampere-seconds (mAs), automatic exposure control (AEC), additional beam filtration, and use of antiscatter grid. Mean dose area product (DAP) reductions of up to 83% for anterior–posterior (AP)/posterior–anterior (PA) abdomen projections were recorded postoptimisation due to manipulation of multiple-exposure variables. For body exposures, the target EI and detector exposure, and thus the required mAs were typically 20% less postoptimisation. Image quality for some distal extremity exposures was improved by lowering kVp and increasing mAs around constant entrance skin dose. It is recommended that purchasing digital X-ray equipment with high detective quantum efficiency detectors, and then optimising the exposure chart for use with these detectors is of high importance for sites performing paediatric imaging. Multiple-exposure variables may need to be manipulated to achieve optimal outcomes.

Introduction

The Royal Children's Hospital, Brisbane (RCH), through a process of equipment replacement 2008–2012 introduced three new digital radiography (DR) systems – two Philips Digital Diagnost (Eindhoven, Netherlands), one Siemens Ysio (Erlangen, Germany), and two needle phosphor computerised radiography (CR) systems – Agfa DX-S (Mortsel, Belgium). These systems offered potential for significant dose reduction and improvement in image quality compared to previously used equipment, due to having detectors with higher detective quantum efficiency. Equipment with relatively high detective quantum efficiency should be able to produce similar or improved image quality with equivalent or less radiation dose to equipment with an inferior detective quantum efficiency.¹

A quality review of exposures suitable for the new DR and CR systems was required. This review was to be

based on evidence-based practice from published articles, to include peer-reviewed journal articles, white papers, and guidelines related to paediatric DR (which limits the time frame of relevant articles to approximately the last 15 years). Relevant literature was chosen via online keyword searches in journal websites and an internet search engine (google.com). Further investigation of relevant references within these articles was also carried out until a sufficient sample of literature was reviewed for the purposes of the exposure chart optimisation process.

The literature review includes white papers and peer-reviewed papers written by, or with involvement from multiple DR equipment vendors – Siemens, Philips, Carestream (Rochester, NY), and Agfa. Some studies (including studies related to equipment vendors) were rejected from the review, as the studies were based on older powder phosphor CR or film/screen technology, no longer used at RCH.

Information from the Image Gently website and the associated American Society of Radiologic Technologists (ASRT) white paper 'Best Practices in Digital Radiography' was useful in the literature review.^{2,3} Information provided by the European Guidelines on Quality Criteria for Diagnostic Radiographic Images (in Paediatrics) was reviewed.^{4,5} The European Guidelines are considered to be the most comprehensive paediatric guidelines that have been published. However, they were written in 1996 for analogue film/screen technology prior to the widespread introduction of digital imaging. Information from these guidelines was reviewed taking into account technological changes, while bearing in mind that the laws of physics have not changed. The European Guidelines have not since been updated in this format. The International Commission on Radiological Protection (ICRP) publication 121, published in 2013, contains multiple recommendations for paediatric DR, but is lacking in projection-specific information when compared to the European Guidelines.⁶ Feedback was also obtained from peer paediatric hospital sites at an Australian paediatric radiography conference (2012), where the exposure chart was presented during its development process.⁷

The aim of this review was to develop a radiographic optimisation strategy to make use of DR and needle phosphor CR detectors, in order to lower dose and improve image quality for paediatrics. It is suggested that the publication of this study and exposure chart could act as a benchmark for other medical imaging departments, and to promote discussion on digital X-ray exposure optimisation for paediatrics. It is intended to demonstrate an application of evidence-based research used in the creation of an exposure chart.

Background

Exposure groups based on patient size variability

There are considerable ranges of patient size for paediatrics, and exposures must be suitable for each patient size group. Draft United States Federal Drug Administration (FDA) guidelines recommend that vendors need to consider paediatric subgroups for control settings and protocols on X-ray equipment.⁸

Diagnostic reference levels (DRL) are dose guidelines that should not be consistently exceeded in normal practice on patients of a standardised size. In the European Union, the standardised ages for paediatrics are typically 0, 1, 5, 10, and 15 years.^{9–11}

The Philips Digital Diagnost software utilised allows for seven different patient size groups. As the RCH is a paediatric only hospital, all seven size groups were modified so as to be based around children from full-term baby to adult (large adolescent) sizes based on patient age. For the Siemens Ysio, additional presets were created for each age group and projection to allow for age group functionality. The following age groups were chosen, partially based on vendor recommendations and European DRL age groups:

- 0–6 months.
- 6–18 months.
- 18–36 months.
- 3–7 years (average 5 years).
- 8–12 years (average 10 years).
- 13–17 years (average 15 years).
- Adult size.^{9–11}

The age groups were based on exposures suitable for tissue thickness (in the direction of the X-ray beam) of a patient of 'average/standard size' in that age group for each projection. Measurements, literature, and review of imaging within each age group (to adjust exposures as necessary) were used for exposure chart development.¹¹ Due to variations in tissue thickness for a specific age, changes to the default radiographic parameters are required when patients are smaller or larger than average for their age group. This requires paediatric radiographers to have good knowledge of average patient sizes per age group to achieve accurate exposures. This may not be a realistic expectation in nonpaediatric specialist sites, or for new practitioners in specialist sites.

Image Gently and the associated ASRT white paper recommend that exposure charts should be based on tissue thickness. This theoretically should be more accurate than age-based groups, as patient thickness can vary considerably for a specific age.^{2,3} For example, 'the largest 3-year-old's abdomen thickness is the same as the smallest 18-year-old'.³ A CT-based study by Kleinman et al. concluded 'results suggest that pediatric body dimensions should be determined using callipers for individual patients before they undergo diagnostic imaging procedures that entail radiation risks to avoid substantial over- or underexposure that may result from reliance on age-based X-ray exposure techniques'.¹²

The exposure charts at RCH use age groups, based around average tissue thickness for that age group and projection. This was developed before the Image Gently and ASRT recommendations of using a thickness-based exposure chart. Consideration has been given to modifying the exposure charts from age groups to

thickness-based groups. However, concerns from radiographers that would need to be addressed include:

- Standardising measurement locations for each projection (e.g. is a forearm measured at the elbow, mid-shaft, or wrist?).
- Risk of calliper use distressing younger children, or children with learning disabilities.
- Risk of calliper use deemed inappropriate (e.g. measuring adolescent girls chest thickness).
- Increased examination time in busy clinics due to additional time taken to perform calliper measurements.
- Infection control risks of using callipers with multiple patients.
- Technical considerations with thickness-based exposure preset programming and linking with projection-specific image processing.

No evidence could be found in literature of these calliper use concerns. However, no literature could be found that described a real-world use of callipers in a busy X-ray department. Image Gently and other organisations have yet to produce detailed information on how to develop a thickness-based exposure chart for clinical DR. As use of callipers and thickness-based exposure charts is deemed to be best practice, this should be investigated further for future iterations of this exposure chart.

Methodology

Projections

To simplify optimisation strategies, the exposure chart was developed around two different categories – *body exposures* and *distal extremity exposures*.

The *body exposures* optimisation strategy was used for projections involving the trunk, head, humerus, and femur. The trunk and head contain organs with relatively high radiosensitivity, including the lungs, colon, breast, gonads, stomach, thyroid, and eyes.¹³ An optimisation strategy was required to simultaneously decrease patient dose and improve image quality, made possible by the relatively high detective quantum efficiency of the CsI:TI/a-Si DR detectors and CsBr:Eu²⁺ needle phosphor CR detectors, as has been mentioned in the reviewed literature.^{14–16}

Distal extremity exposures range from elbow to finger, knee to toe in all age groups, and whole-limb projections in the 0- to 36-month age range. The peripheral skeleton generally has a relatively low radiosensitivity compared to the trunk, and generally results in lower effective doses than for *body exposures*.¹⁷ It is important to note that

babies and younger children have highly radiosensitive red bone marrow in long bones, while older children and adults have red bone marrow mainly in the axial skeleton.¹⁸ An optimisation strategy was required to allow for accurate diagnosis of subtle fractures, periosteal reactions, and early callus formation, while still conforming to the as low as reasonably achievable (ALARA) principle. Image quality needs to be adequate for accurate radiological diagnosis, as there may be serious medico-legal implications of the diagnosis. Optimisation strategies for paediatric extremities need to take into account the softer bone structure in young children, and relatively low tissue thickness for some projections (e.g. a baby's finger is less than 1 cm thick).

Kilovoltage peak manipulation

For a constant detector exposure, increasing kilovoltage peak (kVp) will:

- Decrease the tube current time product/milli-ampere-seconds (mAs) required to achieve a constant detector exposure.
- Decrease entrance skin dose and effective dose.
- Decrease image contrast.
- Increase scattered radiation.^{2,11,16,19–21}

The ASRT white paper advises 'the best practice in digital imaging (for children) is to use the highest kVp within the optimal range for the position and part coupled with the lowest amount of mAs needed to provide an adequate exposure to the image receptor'.² For *body exposures*, this principle of using a high kVp technique is followed, which typically results in lower patient attenuation, and therefore dose for the same detector exposure. Siebert advises that 'the optimal kVp is usually higher for bone to soft tissue contrast and for thicker objects'.¹⁶ The kVp is increased in each ascending age/size group due to increases in tissue thickness requiring more photon penetration. Multiple studies were reviewed in the optimisation of kVp, but many of these were not paediatric specific.^{2,4,5,16,19–25}

For *distal extremity exposures*, optimisation of kVp was based on two studies by vendor Philips. Instead of adjusting kVp and mAs around a constant detector exposure, these studies investigated the concept of lowering kVp and increasing mAs to achieve a constant patient dose, but with an increase in contrast-to-noise ratio (CNR).^{19,20} The detector exposure decreases in this scenario, resulting in a lower exposure index (EI). These studies used mean absorbed dose. At RCH, entrance skin dose, easily derived from dose area product (DAP), was used instead for optimisation purposes. The DAP is displayed on the control console postexposure, and

recorded in the DICOM header. For paediatric distal extremities, mean absorbed dose and entrance skin dose are 'closely related' and thus the deviation in dose measurements should not significantly decrease accuracy.²⁰ The kVp and mAs levels were reviewed and modified for each projection, with kVp optimised for sufficient contrast and mAs optimised for sufficient signal-to-noise ratio (SNR). Further articles were used for *distal extremity* mAs optimisation, explained in the detector exposure and mAs section of this study. *Distal extremity* kVp varies between 40 kVp for a baby hand of 1 cm thickness, up to 66 kVp for an adult size knee of 12 cm thickness.

Table 1 shows the DAP ($\text{cGy}\cdot\text{cm}^2$) at varying kVp and mAs. As collimation (18×18 cm) and source image distance (SID) (110 cm) are constant in these measurements, then this is directly proportional to entrance skin dose for a body part of the same thickness. 40 kVp/4 mAs has a similar DAP as 50 kVp/2 mAs and 60 kVp/1.25 mAs, yet the CNR is significantly superior at 40 kVp/4 mAs.

Radiographic dose optimisation strategies for lowering dose are traditionally based around increasing kVp and decreasing mAs around a constant detector exposure – high kVp technique. However, this causes a reduction in image quality/CNR.¹⁵ In the case of *distal extremity exposures* it could be argued that despite the kVp being lowered, the highest kVp for the required diagnosis is still being used. This is due to the previously utilised kVp being far too excessive for adequate CNR for some projections. For example, prior to the optimisation process, 52 kVp was used to image a structure only 1 cm thick, resulting in poor CNR. 40 kVp is now used instead. Education on the theory and requirements of this optimisation process was required for radiographers.

Uffman et al. have also investigated the same principle of lowering kVp and increasing mAs, around constant

patient dose instead of constant detector exposure for adult chest radiography.^{21,22} Carestream Health have also written a white paper, with a basic overview of maximising dose efficiency for paediatric imaging through optimisation of kVp.²³ Considerable medical physicist input would be required for further work in this area at RCH for *body exposures*, as effective dose needs to be calculated for accuracy, instead of the more easily obtainable DAP and entrance skin dose that was used for *distal extremity exposure* optimisation.

Additional beam filtration

Additional beam filtration removes more lower energy X-rays, thereby raising the average beam energy for a constant kVp. Commonly used filters are made from copper (Cu) or aluminium (Al). For a constant kVp and detector exposure, additional beam filtration will:

- Increase mAs.
- Reduce entrance skin dose.
- Reduce effective dose by a lesser amount (depending upon projection).
- Reduce CNR.^{15,19,20,24,26,27}

Many peer-reviewed papers recommend differing thicknesses of added beam filtration for paediatrics and adults of up to 3 mm Cu.^{24,26,27} The European Guidelines recommended 0.1 mm Cu + 1 mm Al or 0.2 mm Cu + 1 mm Al additional beam filtration for use with film/screen and older generator technology.^{4,5,28} In the latter case, additional beam filtration was also required for some generators that could not cope with very short exposure times resulting from high kVp technique.⁴ Additional beam filtration is used for *body exposures* at RCH. For consistency, the additional beam filtration was standardised at 0.1 mm Cu + 1 mm Al for the Philips Digital Diagnost and 0.1 mm Cu for the Siemens Ysio. Additional beam filtration is selected automatically when using the appropriate projection and age group exposure preset.

ICRP Publication 121 does not recommend use of additional beam filtration in neonates and very small infants due to the low kVp used.⁶ This is inconsistent with other literature and the European Guidelines.^{4,24} Further optimisation of kVp, choice of beam filtration, and mAs to improve CNR may be required for some 0–36 months *body exposures*, as well as humerus and femur exposures, where 0.1 mm Cu + 1 mm Al additional beam filtration appears to compromise CNR in practice. Evaluation by a medical physicist is recommended.

For *distal extremity exposures*, additional beam filtration preferentially filters out lower energy X-rays, lowering contrast, and therefore negatively affects CNR.^{19,20} Thus,

Table 1. DAP ($\text{cGy}\cdot\text{cm}^2$) at varying kVp and mAs, with constant collimation size and SID.

	40 kVp	50 kVp	60 kVp
1 mAs	–	–	1.04
1.2 mAs	–	–	1.25
1.6 mAs	–	1.05	1.68
2 mAs	–	1.33	2.09
2.5 mAs	–	1.66	–
3.2 mAs	1.03	2.06	–
4 mAs	1.32	–	–
5 mAs	1.66	–	–

kVp, kilovoltage peak; mAs, milli-ampere-seconds/tube current time product; DAP, dose area product; SID, source image distance.

no additional beam filtration is used for *distal extremity exposures* at RCH.

Detector exposure, automatic exposure control, and mAs manipulation

With other exposure factors being constant, an increase in mAs will:

- Increase detector exposure (also known as the indicated equivalent air kerma) and IEC62494-1 standard EI – as more X-ray photons will reach the detector.²⁹
- Improve image quality – increased CNR and SNR.
- Increase radiation dose to the patient.

Throughout the literature review, there was limited information on detector exposures typically used for digital paediatric radiography in clinical practice. This may be due to the variations in technique and available equipment used at different sites.

The IEC62494-1 standard EI is based on the average segmented detector exposure (indicated equivalent air kerma), multiplied by 100. Thus, an incident detector exposure of 2.5 μGy should theoretically result in an EI of 250. This is equivalent to a speed class of 400. The sensitivity of automatic exposure control (AEC) devices can be adjusted, by modifying the detector exposure or speed class at which the exposure is terminated.

For *body exposures*, target detector exposure was generally reduced from 2.5 μGy (~400 speed) to 2 μGy (~500 speed), allowing for a 20% reduction in mAs, and a simultaneous improvement in image quality (perceived SNR) by taking advantage of the relatively high detective quantum efficiency of the digital detectors. Repeat radiographs are rarely required unless the detector exposure is below ~1 μGy (~1000 speed).

ICRP publication 121, Image Gently, and the associated ASRT white paper recommend caution when using AEC with smaller children due to the small size of the anatomy of interest in relation to AEC sensors.^{2,3,6} For this reason, plus variations in tissue density within the sensor area, AEC is generally not used at RCH for children below 36 months (routine skull projections excepted). Instead, manual exposures are deemed to be more consistent and accurate. All DR units used at RCH have a useful feature (available as standard) where only AEC sensors inside of the collimated X-ray beam are activated to avoid underexposure. This is most useful in the 3- to 7-year age group, due to the width of the collimated X-ray beam and anatomy in relation to AEC sensor location. However, radiographers still need to use caution if the collimated area, and thus active AEC sensor, extends beyond the skin edge, as an underexposure could result. Use of gonad or bladder shielding close to active AEC sensors can result in

an overexposure, and thus manual exposures are used in these scenarios.²⁵

For *body exposures*, tube current (mA) is kept as high as possible (for small focal spot), to maximise image sharpness and minimise exposure time. Large focus is generally only used for very thick body parts such as swimmers views and thoracolumbar spines on adolescents.

For *distal extremity exposures*, the chosen kVp and mAs combinations result in detector exposures of between 2.5 μGy (~400 speed) and 5 μGy (~200 speed) depending on the projection and clinical requirements. Studies comparing different CR and DR detector types for extremity imaging, and pathology detectability using CR and DR, were useful in the development of appropriate detector exposures.^{14,30,31} However, these studies were not specific to paediatrics. All *distal extremity exposures* at RCH use fine focus to maximise image sharpness, and rarely require use of AEC.

Antiscatter grid selection

In cases where scattered radiation is significant (thicker tissue and use of higher kVp), then for a constant detector exposure, use of an antiscatter grid will:

- Improve image contrast by decreasing scattered radiation reaching the detector.
- Increase radiation dose to the patient.^{2,13}

The Image Gently programme and associated ASRT White Paper recommend grid use above 10–12 cm thickness.^{2,3} Generally, grids are only used at RCH for age groups where the average tissue thickness is ~13–14 cm, which is in excess of the recommendations by the Image Gently programme. The exception to this is for skull projections where grids are used at RCH for all exposures for subtle fracture/pathology detection (for example in cases of nonaccidental injury). This is consistent with conference feedback from other Australian paediatric imaging sites.⁷ The literature from a European site shows that grids are not used for patients up to 10 years of age for some projections such as anterior–posterior (AP) pelvis, with a thickness of ~16 cm.^{11,25} Conference feedback found that an Australian paediatric imaging site does not use grids for AP pelvis projections up to ~10 years of age.⁷ However, RCH radiologists have expressed concerns that less grid use may result in subtle lesions being missed due to image degradation from scattered radiation. Evaluation of grid use will thus require further research at RCH to balance image quality versus radiation dose. It should be noted that as patients are currently not measured for thickness at RCH, judgement as to whether to use a grid is based upon the radiographer's visual perception of patient thickness,

Table 2. Summary of postoptimisation exposure techniques.

Area	Body exposures	Distal extremity exposures
Target detector exposure (indicated equivalent air kerma) and speed class	2 μ Gy detector exposure 500 speed	2.5–5 μ Gy detector exposure 400–200 speed
Typical EI range (IEC62494-1 standard)	100–300 EI depending upon projection/age group	200–500 EI depending upon projection/age group
kVp optimisation	Optimised for adequate image quality at low dose (high kVp technique)	Optimised for subtle fracture detection (low kVp technique)
Additional beam filtration	0.1 mm Cu (+1 mm Al)	None required
Antiscatter grid	>13–14 cm thickness. >20 cm chest. All skull X-rays. Low bucky-factor grids used.	None required

kVp, kilovoltage peak; EI, exposure index; Cu, copper; Al, aluminium.

which is not an optimal method. Further evaluation is recommended for measurement techniques.

Grid use at RCH is as follows:

- AP/posterior–anterior (PA)/lateral skull, lateral thoracolumbar spine, and lateral abdomen – all thicknesses.
- AP/PA/lateral chest, and AP/lateral cervical spine – large adolescents only (\sim >20 cm thickness for AP/PA chest).
- AP/PA abdomen, AP pelvis, AP thoracolumbar spine – 3 years and over (\sim >13–14 cm thickness).

The European Guidelines and ICRP121 both recommended the use of low attenuation grids.^{4,6} This is typically achieved by using low grid ratios, or grids with low attenuation properties. For the Philips Digital Diagnost, and out of bucky CR exposures, a grid ratio of 8:1 is used. For the Siemens Ysio, a grid ratio of 15:1 is used for in-bucky projections, and a ‘forgiving’ grid ratio of 5:1 for wireless detector projections. It should be noted that Siemens Ysio 15:1 ratio grid is more radiolucent than the very high grid ratio would suggest, due to use of low attenuating materials, and is thus suitable for paediatrics. Grids can be removed from all buckys and detectors, which is essential for paediatric radiography where many projections (including those using AEC) do not require grids.

Antiscatter grids are not required for any *distal extremity exposures*, as tissue thicknesses are low (1–14 cm) and kVp is relatively low. Scattered radiation is therefore minimal.

SID selection

The SIDs used at RCH are all in accordance with vendor recommendations, and were unchanged from when using older technology equipment. Information from the relevant literature reviewed either did not mention SID,

or did not suggest any significant changes to the SIDs in use.^{2–5,13,32} This may be a suitable area for further literature review and research in the future.

Most *body exposures* are taken at 110–115 cm SID. Lateral cervical spines are taken at 150 cm. Erect chest X-rays are taken at 180 cm. Full leg/full spine imaging is performed at 180 cm (using CR). All *distal extremity exposures* are taken at 110–115 cm SID.

Image processing technologies

All the DR and CR equipment used at RCH have multifrequency processing, which can maintain optimal image quality at lower mAs, and is thus useful for optimal paediatric digital imaging.^{6,16,33} The Philips Digital Diagnost has default paediatric image processing algorithms, and these are utilised to optimise image quality. Different algorithms are required for different age groups, grid status (in or out), and projection. For the Siemens Ysio, custom image processing settings were developed in liaison with the vendor’s application specialist. The Agfa DX-S CR uses Agfa’s Musica² processing which is examination independent.

Table 3. Mean DAP reduction for AP/PA abdomen X-rays due to optimisation process.

Age	Preoptimisation mean DAP (cGy*cm ²)	Postoptimisation mean DAP (cGy*cm ²)	Percentage reduction in mean DAP (%)
0 to <1 year	2.89	1.78	38.4
1 to <3 years	11.8	2.01	83.0
3 to 7 years	26.49	8.16	69.2
8 to 12 years	102.61	20.26	80.3
13 to 17 years	111.85	34.66	69.0

DAP, dose area product; AP, anterior–posterior; PA, posterior–anterior.

Table 4. Body exposure chart – part 1 (version 2.2 11 December 2013).

	Emergency room						
	Newborn	Baby	Child	Small	Normal	Large	Extra large
Chest/shoulder/humerus	0–6 months	6–18 months	18–36 months	3–7 years	8–12 years	13–17 years	Adult size
Chest AP erect in chair 180 cm	X	73/2	73/2	81/1.2	X	X	X
Chest PA/AP erect 180 cm	X	73/2	73/2	85/1 ¹	90/1 ¹	90/1.2 ¹	125/1.2 ¹ G
Chest supine 110 cm	63/1.6	66/1.6	66/1.6	70/1.2	73/1.6	77/2	85/2.5 G
Chest lateral supine 110 cm	70/1.6	X	X	X	X	X	X
Chest lateral 180 cm	X	77/2.5 ¹	90/2.5 ¹	100/2 ¹	110/1.6 ¹	110/2 ¹	125/3.5 ¹ G
Humerus/shoulder AP	63/2	63/2	63/2	63/2.5 ¹	66/3.1 ¹	66/6.3 ¹ G	66/8 ¹ G
Humerus/shoulder lateral	63/2	66/2	66/2.5	66/3.1 ¹	70/6.3 ¹ G	70/10 ¹ G	70/12 ¹ G
Clavicle AP	63/2	63/2	63/2	63/2.5	66/2.5	66/3.1	66/4
Abdomen/pelvis/femur	0–6 months	6–18 months	18–36 months	3–7 years	8–12 years	13–17 years	Adult size
Abdomen AP/PA	63/2	66/2	66/2.5	70/4 ¹ G	73/5 ¹ G	77/8 ¹ G	81/10 ¹ G
Abdomen barium AP/PA	63/2	66/2	66/2.5	81/2.5 ¹ G	81/3.1 ¹ G	85/6.3 ¹ G	85/8 ¹ G
Abdomen lateral	66/3.1 ¹	73/3.1 ¹ G	73/4 ¹ G	77/6.3 ¹ G	81/8 ¹ G	85/10 ¹ G	85/12 ¹ G
Pelvis AP/frog legs	63/2	66/2	66/2.5	70/4 ¹ G	73/5 ¹ G	77/8 ¹ G	81/10 ¹ G
Femur AP/Obl. No grid	63/1.6 ¹	63/2 ¹	63/2 ¹	66/2 ¹	70/2 ¹	70/2.5 ¹	X
Femur AP/Obl. grid	X	X	X	70/3.1 ¹ G	70/4 ¹ G	73/5 ¹ G	73/6.3 ¹ G
Hip horizontal beam lateral	66/2.5	66/2.5	66/3.1	81/16 G	81/31 G	85/50 G	85/63 G

Exposures shown in kVp/mAs format. 110 cm source image distance unless otherwise stated: 0.1 mm copper + 1 mm aluminium additional beam filtration. G, grid exposure 8:1 ratio. AP, anterior–posterior; PA, posterior–anterior; kVp, kilovoltage peak; mAs, milli-ampere-seconds/tube current time product.

¹Use automatic exposure control (500 speed for chest/abdomen, else 400 speed at specified kVp when practical).

Use of table

Beam attenuation by the table (for a constant detector exposure) will increase patient dose and/or reduce image CNR.¹⁹ This is due to the table adding another attenuating layer. This is more of an issue for tables of higher radiopacity (such as cantilevered tables), and when using lower kVp. When possible (e.g. if wireless detector is available or the wall detector can be flipped to horizontal position), nongrid *body exposures* and *distal extremity exposures* taken through the table are avoided to optimise image quality.

Exceptions

Stitched full-leg and full-spine (scoliosis/kyphosis) projections slightly differ from the above optimisation

strategies. A lower target detector exposure of 1.25 μ Gy (~800 speed) is utilised. As the images are required only for measurements, the low image quality (perceived low SNR) is accepted by radiologists at RCH. For single-exposure CR stitching, an acrylic wedge filter is used instead of additional beam filtration. PA projections are used where possible for scoliosis imaging to minimise dose to radiosensitive organs such as breast tissue near the anterior surface.^{6,13,15} *Distal extremity* imaging using plaster of paris (POP) results in modifications in the kVp and mAs to increase photon penetration through the plaster.

Results

Table 2 shows a summary of exposure techniques used at RCH after the optimisation process, taking into account

Table 5. Body exposure chart – part 2 (version 2.2 11 December 2013).

	Emergency room						
	Newborn	Baby	Child	Small	Normal	Large	Extra large
Spine	0–6 months	6–18 months	18–36 months	3–7 years	8–12 years	13–17 years	Adult size
Neck soft tissue 150 cm	66/2.5 ¹	66/3.1 ¹	66/3.1 ¹	70/2.5 ¹	73/3.1 ¹	73/3.1 ¹	73/4 ¹
C spine AP	66/2 ¹	66/2 ¹	66/2 ¹	70/2 ¹	70/2.5 ¹	70/3.1 ¹	70/8 ¹ G
C spine peg	70/2 ¹	70/2.5 ¹	70/2.5 ¹	73/2.5 ¹	73/4 ¹	73/4 ¹	73/8 ¹ G
C spine lateral 150 cm	66/2.5 ¹	66/3.1 ¹	66/3.1 ¹	70/4 ¹	73/5 ¹	73/6.3 ¹	77/12 ¹ G
C spine swimmers 150 cm	X	X	X	81/25 ¹ G	81/40 ¹ G	81/50 ¹ G	81/80 ¹ G
T spine AP	66/2 ¹	66/2.5 ¹	66/2.5 ¹	73/5 ¹ G	77/6.3 ¹ G	81/8 ¹ G	81/10 ¹ G
T spine lateral	73/4 ¹ G	73/4 ¹ G	73/5 ¹ G	77/6.3 ¹ G	81/8 ¹ G	85/10 ¹ G	85/12 ¹ G
L spine AP	66/2 ¹	66/2.5 ¹	66/2.5 ¹	73/6.3 ¹ G	77/8 ¹ G	81/10 ¹ G	81/12 G
L spine lateral	73/4 ¹ G	73/4 ¹ G	73/5 ¹ G	77/8 ¹ G	81/16 ¹ G	85/20 ¹ G	85/25 ¹ G
Skull and face	0–6 months	6–18 months	18–36 months	3–7 years	8–12 years	13–17 years	Adult size
Skull AP	73/4 ¹ G	73/6.3 ¹ G	73/8 ¹ G	73/10 ¹ G	73/12 ¹ G	77/12 ¹ G	77/12 ¹ G
Skull Townes	73/6.3 ¹ G	73/10 ¹ G	73/12 ¹ G	73/16 ¹ G	73/20 ¹ G	77/20 ¹ G	77/20 ¹ G
Skull lateral	70/4 ¹ G	70/6.3 ¹ G	70/8 ¹ G	70/10 ¹ G	70/12 ¹ G	73/12 ¹ G	73/12 ¹ G
Mandible PA	70/4 ¹ G	70/5 ¹ G	70/6.3 ¹ G	73/6.3 ¹ G	73/8 ¹ G	73/10 ¹ G	73/10 ¹ G
Mandibles lateral oblique	70/5 ¹ G	70/6.3 ¹ G	70/8 ¹ G	73/8 ¹ G	73/10 ¹ G	73/12 ¹ G	73/12 ¹ G
Zygomatic Arch	66/3.1	66/4	66/4	66/5	66/6.3	66/6.3	66/6.3
Stenvers/Rev. Stenvers	70/6.3 G	73/6.3 G	73/6.3 G	73/8 G	73/12 G	73/16 G	73/16 G
Face/sinus PA 35 degrees	73/6.3 ¹ G	73/8 ¹ G	73/10 ¹ G	73/12 ¹ G	73/12 ¹ G	73/16 ¹ G	73/16 ¹ G
Face/sinus PA 45 degrees	73/8 ¹ G	73/10 ¹ G	73/12 ¹ G	73/16 ¹ G	73/16 ¹ G	73/20 ¹ G	73/20 ¹ G
Face/sinus lateral	70/3.1 ¹ G	70/5 ¹ G	70/5 ¹ G	70/6.3 ¹ G	70/8 ¹ G	70/10 ¹ G	70/10 ¹ G

Exposures shown in kVp/mAs format. 110 cm source image distance unless otherwise stated: 0.1 mm copper + 1 mm aluminium added beam filtration. G, grid exposure 8:1 ratio. AP, anterior–posterior; PA, posterior–anterior; kVp, kilovoltage peak; mAs, milli-ampere-seconds/tube current time product.

¹Use automatic exposure control (500 speed for chest/abdomen, else 400 speed at specified kVp when practical).

target detector exposure, typical EI range, kVp optimisation strategy, additional beam filtration, and antiscatter grid use. For *body exposures*, the target EI and detector exposure, and thus the required mAs were typically 20% less after optimisation.

Table 3 shows an example of mean DAP reduction obtained through manipulation of exposure factors for AP/PA abdomen X-rays during the optimisation process. DAP was recorded in the DICOM header. Exposure factors manipulated to obtain these dose reductions included kVp, additional beam filtration, AEC sensitivity, AEC chamber selection, and lower grid ratio.

The exposure charts in Tables 4–6 were developed by RCH radiographers for use with a Philips Digital Diagnost DR system installed in the Emergency Department at RCH. Most exposures are also suitable for the Agfa DX-S CR system with needle phosphor detectors used in the same room. The other X-ray rooms at RCH

have slightly different exposures, but the same optimisation principles were applied.

Discussion

The exposure charts, shown as Tables 4–6 are not intended for use verbatim, and may be unsuitable for use with other equipment, due to variations in:

- Detector material and detective quantum efficiency.
- Generator and tube output.
- Additional beam filtration options.
- Antiscatter grid ratio, type, and bucky factor.
- Table attenuation.
- Image processing algorithms.
- Clinical/diagnostic requirements.

With DR equipment usually installed with vendor-created exposure presets and image processing algorithms,

Table 6. Distal extremity exposure chart (version 2.2 11 December 2013).

	Emergency room						
	Newborn	Baby	Child	Small	Normal	Large	Extra large
Upper	0–6 months	6–18 months	18–36 months	3–7 years	8–12 years	13–17 years	Adult size
Finger	40/3.1	40/3.1	40/3.1	46/2	46/2	46/2	46/2
Hand PA/oblique	40/3.1	40/3.1	40/3.1	46/2	46/2	48/2	48/2
Hand lateral	40/4	42/4	42/4	50/2	50/2	52/2	52/2
Wrist/scaph. PA/Obl.	40/3.1	40/4	40/4	48/2	50/2	50/2	52/2
Wrist/scaph. lateral	40/4	42/4	42/4	52/2	55/2	55/2	57/2
Bone age	40/3.1	40/3.1	40/3.1	50/1.25	50/1.25	50/1.25	50/1.25
Forearm	50/1.6	50/1.6	50/1.6	50/2	52/2	52/2	55/2
Elbow	50/1.6	50/1.6	50/2	52/2	55/2	55/2	57/2
Lower	0–6 months	6–18 months	18–36 months	3–7 years	8–12 years	13–17 years	Adult size
Toes	40/3.1	40/3.1	40/4	46/2	48/2	48/2	48/2
Foot DP/oblique	40/4	42/4	42/4	48/2.5	50/2.5	55/2	55/2
Foot/ankle lateral	42/4	42/4	42/4	52/2	57/2	57/2	60/2
Ankle AP/mortice	42/4	44/4	44/4	55/2	60/2	60/2	63/2
Axial calc./cobey	52/2.5	55/2.5	55/2.5	60/2	60/2.5	60/2.5	60/3.2
Tib/fib AP	55/1.6	55/1.6	55/1.6	57/1.6	60/2	63/2	63/2
Tib/fib lateral	55/1.6	55/1.6	55/1.6	57/1.6	60/1.6	63/1.6	63/1.6
Knee AP	55/1.6	57/1.6	57/1.6	60/2	63/2	63/2	66/2
Knee lateral	55/1.6	57/1.6	57/1.6	60/1.6	63/1.6	63/1.6	66/1.6
Knee skyline	X	X	X	60/2.5	63/3.1	63/3.1	66/4
Plaster of paris (POP)	0–6 months	6–18 months	18–36 months	3–7 years	8–12 years	13–17 years	Adult size
Hand/wrist POP	57/1.6	57/1.6	57/1.6	60/2	60/2	60/2	60/2
Forearm POP	57/2	57/2	57/2	60/2	60/2	60/2	60/2
Elbow POP	60/2	60/2	60/2	60/2.5	60/2.5	60/2.5	60/2.5
Foot POP	57/2	57/2	57/2	60/2	60/2.5	60/2.5	60/2.5
Ankle POP	57/2	57/2	57/2	60/2.5	60/2.5	60/2.5	60/2.5
Tib/fib/knee POP	60/2	60/2	60/2	60/2	60/2.5	63/2.5	63/2.5
Whole limb (not stitched)							
Whole limb upper	50/1.6	52/1.6	55/1.6				Do not X-ray distal extremities
Whole limb lower	55/1.6	57/1.6	60/1.6				through table in emergency

Exposures shown in kilovoltage peak (kVp)/tube current time product/milli-ampere-seconds (mAs) format. 110 cm source image distance: no grid: no additional beam filtration.

AP, anterior–posterior; PA, posterior–anterior; DP, dorsi-plantar; POP, plaster of paris.

equipment vendors have an important role to play in the optimisation of paediatric exposures. Digital imaging vendors should follow FDA guidelines by making it simple for radiographers to select presets for different paediatric patient sizes. Each preset should have appropriate exposure factors, and linked image processing algorithm. These features are currently only offered by a few equipment vendors. It should be noted that during the literature review it was observed that some equipment vendors are considerably more involved in published research than others.

While there is a body of useful literature to assist with the development of a paediatric exposure chart, many gaps in the literature have been identified. Areas where more literature would be useful include:

1 Measuring paediatric patient thickness with callipers in a clinical environment.

2 Optimisation of the kVp, mAs, and additional beam filtration combination for common paediatric projections, detector types, and pathology detectability requirements.

3 Effects of grid use on paediatric pathology detectability with digital X-ray detectors.

Development of a paediatric exposure chart requires the involvement of radiographers, radiologists, and equipment vendors. Additionally, considerable medical physicist involvement is essential for a site to fully optimise its paediatric exposure chart. An accurate and effective method of measuring patient thickness is recommended, and exposures would need to be optimised for each projection, age/size group, and equipment combination. Variations may also be required for specific pathologies or diagnostic requirements. At RCH, there are in excess of 300 projection and age group

combinations per X-ray room, and five digital X-ray devices. Thus, a full optimisation process would involve an extensive study, which would require appropriate resources.

In hindsight, there is minimal variation in exposures in the 6–18 months and 18–36 months age groups, thus these groups could have been merged.

Conclusion

This literature review was a component of an extensive review of paediatric exposures at RCH which also contained scientific tests. An overview of outcomes from the optimisation process is described below. Mean DAP was reduced for AP/PA chest, AP abdomen, AP pelvis, and AP/lateral skull projections in all age/size groups. These dose reductions were due to manipulating multiple-exposure variables as discussed in this study. In the case of AP abdomen, the mean DAP was reduced by up to 83% compared to preoptimisation levels. The mean DAP is now below the three-quarter percentile for German and Austrian DRLs.^{10,11} The relatively high detective quantum efficiency of the installed digital X-ray equipment has typically allowed for reductions in target detector exposure (and thus mAs) of ~20%, resulting in reductions to patient dose while maintaining or in many cases improving image quality (SNR and CNR). For some *distal extremity exposures*, it was possible to improve image quality by lowering kVp and increasing mAs around a constant entrance skin dose.

It is recommended that purchasing digital X-ray equipment with high detective quantum efficiency detectors, and then optimising the exposure chart for use with these detectors, is of high importance for sites performing paediatric imaging. Multiple-exposure variables may need to be manipulated to achieve optimal outcomes.

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Conflict of Interest

The author declares no conflict of interest.

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