Experimental article – Reducing effective dose to a paediatric phantom by using different combinations of kVp, mAs and additional filtration whilst maintaining image quality

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KEYWORDS

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ABSTRACT

Purpose: To determine whether using different combinations of kVp and mAs with additional filtration can reduce the effective dose to a paediatric phantom whilst maintaining diagnostic image quality.
Methods: 27 images of a paediatric AP pelvis phantom were acquired with different kVp, mAs and additional copper filtration. Images were displayed on quality controlled monitors with dimmed lighting. Ten diagnostic radiographers (5 students and 5 experienced radiographers) had eye tests to assess visual acuity before rating the images. Each image was rated for visual image quality against a reference image using 2 alternative forced choice software using a 5-point Likert scale. Physical measures (SNR and CNR) were also taken to assess image quality.
Results: Of the 27 images rated, 13 of them were of acceptable image quality and had a dose lower than the image with standard acquisition parameters. Two were produced without filtration, 6 with 0.1mm and 5 with 0.2mm copper filtration. Statistical analysis found that the inter-rater and intra-rater reliability was high.
Discussion: It is possible to obtain an image of acceptable image quality with a dose that is lower than published guidelines. There are some areas of the study that could be improved. These include using a wider range of kVp and mAs to give an exact set of parameters to use.
Conclusion: Additional filtration has been identified as amajor tool for reducing effective dose whilst maintaining acceptable image quality in a 5 year old phantom.

INTRODUCTION

It is the responsibility of the radiographer to select the correct exposure factors to produce an image that is diagnostically acceptable whilst maintaining a reasonably low dose to the patient[1]. Ionising radiation has been shown to cause cancer from its early use[2]. Whilst children are developing, their cells are rapidly dividing compared to adults, making them more predisposed to increased DNA damage and malignant changes later in life[3]. It has been estimated that radiation exposure in the first 10 years of life has an attributable lifetime risk4 therefore dose is of high consideration especially in paediatric examinations. It is important to ensure dose is kept as low as reasonably achievable (ALARA)[5] as stated in the International Commission on Radiological Protection (ICRP) guidance[6], whilst maintaining image quality.

Due to the associated risks of ionising radiation, it is essential to optimize image quality. This can be achieved by altering exposure factors and using additional filtration. Filtration works by hardening the beam, meaning more useful X-rays reach the image receptor and the low energy X-rays are filtered out without reducing image quality[5]. Using copper filtration has been shown to be more efficient and filter more lower energy photons than by using aluminium filtration[7]. Research also demonstrates that additional filtration of 0.2mm Cu can reduce dose up to 40%[8].

Dose reference level have been set by the ICRP[6] because of the wide variations in patients' habitus. However the guidance was put in place in 1996 and requires updating to come into line with modern imaging and acquisition equipment.

This article investigates dose and image optimization in relation to use of copper filtration, for paediatric pelvis imaging.

MATERIALS AND METHODS

Material

To simulate a paediatric pelvis a phantom (ATOM Dosimetry Verification Phantom Model 705)[10], was used with the characteristics of a 5 year old child.

The images were produced by varying kVp and mAs in set combinations based on European guidelines[10]. Copper filtration was also varied: none; 0.1mm; and 0.2mm[9] (Table 1). In total 27 images were acquired.

Table 1: Set combinations with kVp, mAs and copper filtration

kVp Filters	50	60	70
None	5/ 3.6/ 2.2 mAs	5/ 3.6/ 2.2 mAs	5/ 3.6/ 2.2 mAs
0.1mmCu	5/ 3.6/ 2.2 mAs	5/ 3.6/ 2.2 mAs	5/ 3.6/ 2.2 mAs
0.2mmCu	5/ 3.6/ 2.2 mAs	5/ 3.6/ 2.2 mAs	5/ 3.6/ 2.2 mAs

A SIEMENS POLYDOROS IT 30/55/65/80 X-ray unit combining an OPTILIX 150/30/50C X-ray tube with an inherent filtration of 1.0mm aluminium were used. Images were acquired using an Agfa CR 24 x 30 image receptor and processed in an Agfa CR 35-X digitizer. All equipment was subject to regular quality control tests and the results fell within manufacturer specifications.

Images were acquired in the AP standing position without using air gap technique. An SID of 115cm was used and the collimation field size 21.8cm by 18.6cm at the image receptor. The phantom was not moved throughout the image acquisition to ensure the positioning and tube parameters remained the same. No grid was used as this is not standard practice in paediatric imaging[8].

Ten participants (5 experienced and 5 student radiographers) took part in the image appraisal using the 2 Alternate Forced Choice (2AFC) software. Images were displayed on a dual LCD colour monitors system (SIEMENS DSC 1904-D) at 1280 X 1024 resolution. The reference image remained fixed on one monitor and the 27 acquired images were viewed randomly on the second monitor. Each participant performed the image appraisal twice. Image appraisal was performed with a low level of ambient light, in accordance with the European Guidelines[10].

Visual image quality analysis

The reference image was agreed by a small focus group as being the lowest acceptable image quality so that any image that scored below the reference image could be excluded. The criteria for choosing the reference image were selected from the European Guidelines[10] (Table 2).

Table 2: Pelvis image criteria

Item	Pelvis image criteria
1.	Symmetrical reproduction of the pelvis
2.	Visualization of the sacrum and its intervertebral foramina
3.	Reproduction of the necks of the femora which should not be distorted
4.	Visualization of the trochanters consistent with age
5.	Reproduction of spongiosa and cortex

To evaluate visual image quality, 2AFC software was used with a series of three questions for each image, with the purpose of observing three separate areas of the pelvis and scoring them. The questions focused on the right hand side of the pelvis as this was the location of the ROI. The questions were selected from previous research that used similar methods[8,11] excluding the soft tissue questions because the phantom did not contain tissue (Table 2).

A 5 point Likert scale was used so that each of the five responses had a numerical value which was used to score each image (Table 3). To measure image quality an average score was obtained from each image.

Table 3: Criteria used for evaluation

Questions	
How well can you visualize the right femoral neck? How well can you visualize the right sacro iliac joint? How well can you visualize the sacral foramina?	
Likert Scale	Numerical Scale
Much worse than	1
Slightly worse than	2
Equal to	3
Better than	4
Much better than	5

Physical image quality assessment

To measure physical image quality, SNR and CNR calculations were performed. Both programs used the right side of the pelvis to perform the calculation as it was clearer to visualise the structures and place the region of interest (ROIs).

SNR and CNR calculations were made using ImageJ software, by placing a ROI on two contrasted homogeneous structures of the simulated soft tissue and femoral head. The ROI was placed in the same location on all 27 images to get a true value for comparison.

To compare the dose of each image, a DAP reading was taken and the PCXMC software was used to calculate the effective dose as a comparison with image quality.

Visual acuity

Adequate eyesight is essential to make accurate interpretations for optimal patient care and cannot be compensated with technology[12]. Although the observers' training, experience, viewing time and distance from the image are important variables, visual acuity is relatively easily to measure and correct[13]. Therefore, to ensure the ten participants had normal visual function, eye tests were performed before the image appraisal. Participants received a visual assessment, including visual acuity (ETDRS chart – CSV 1000 and LogMAR Good-Lite chart), contrast sensitivity (CSV-1000E) and stereopsis (Randot). As it is shown on appendix 1, all participants were within the normal standards, therefore all qualify to participate in the research.

Statistical analysis

To investigate the intra-rater reliability the data for the different assessments for each observer were compared by means of the Intraclass Correlation Coefficient (ICC). To investigate the inter-rater reliability the mean scores of both assessments for each observer were compared with the mean scores of the other observers by means of the ICC.

Intra-rater reliability (timepoint 1 vs. timepoint 2)	Intraclass correlation coefficient	P-value
Observer 1	0.587	0.001
Observer 2	0.890	0.001
Observer 3	0.905	0.001
Observer 4	0.945	0.001
Observer 5	0.786	0.001
Observer 6	0.840	0.001
Observer 7	0.850	0.001
Observer 8	0.925	0.001
Observer 9	0.849	0.001
Observer 10	0.916	0.001
Mean	0.849	0.001
Inter-rater reliability	0.872	0.001

RESULTS

Intra- and inter-rater reliability

The intra-rater reliability of all observers was high (ICC > .79), except for observer 1 (ICC=0.587). The inter-rater reliability, the agreement between observers, was also high (ICC=0.872) (Table 4).

Image quality

Figures 1 to 5 have points that have specific meanings, the blue points represent the experimental images, the red point represents the image with the lowest acceptable image quality and the green point represents the image with the standard parameters.

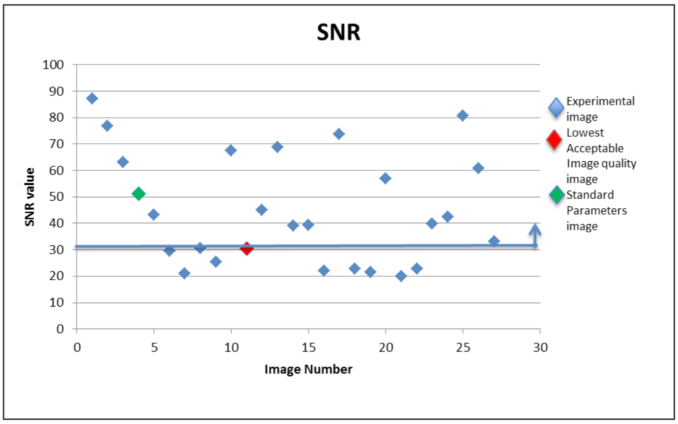

Figure 1: SNR from each image. The images above the line have acceptable image quality. The green (▯) is the standard parameter image and the red (▯) is the lowest acceptable image quality level.

Figure 1 shows that 18 out of the 27 images (66.7%) have a SNR score above or the same as the lowest acceptable image quality level.

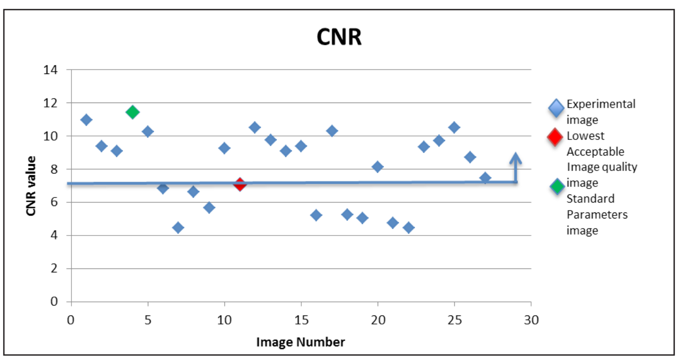

Figure 2: CNR from each image. The images above the line have acceptable image quality. The green (▯) is the standard parameter image and the red (▯) is the lowest acceptable image quality level.

Figure 2 shows that 18 out of the 27 images (66.7%) have and CNR score above or the same as the lowest acceptable image quality level.

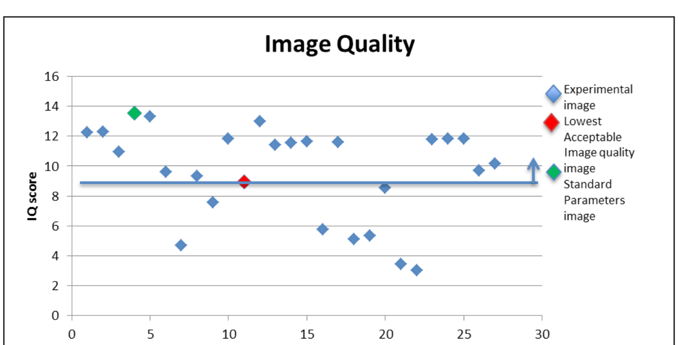

Figure 3: Image quality scores for each image. The green (▯) is the standard parameter image and the red (▯) is the lowest acceptable image quality level.

Figure 3 shows that 19 out of the 27 images (70.35%) have an image quality score above or the same as the lowest acceptable level, as scored using the visual evaluation. Two images have very low image quality, numbers 21 (70 kVp, 5 mAs and 0.2mm Cu filter) and 22 (70 kVp, 3.6 mAs and no filter).

Dose

Figure 4 shows that 23 out of the 27 images (85.2%) have an effective dose below or the same as that of the image acquired with the standard parameters.

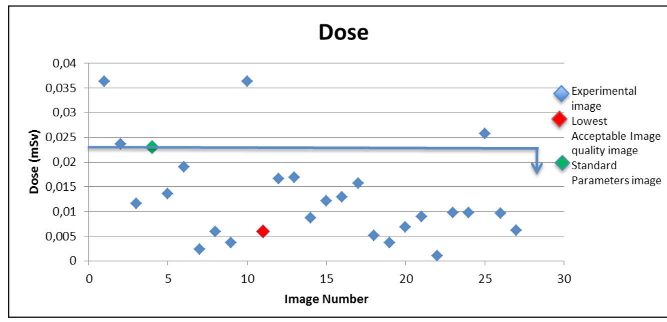

Figure 4: Effective dose (mSy) for each image. The green (▯) is the standard parameter image and the red (▯) is the lowest acceptable image quality level.

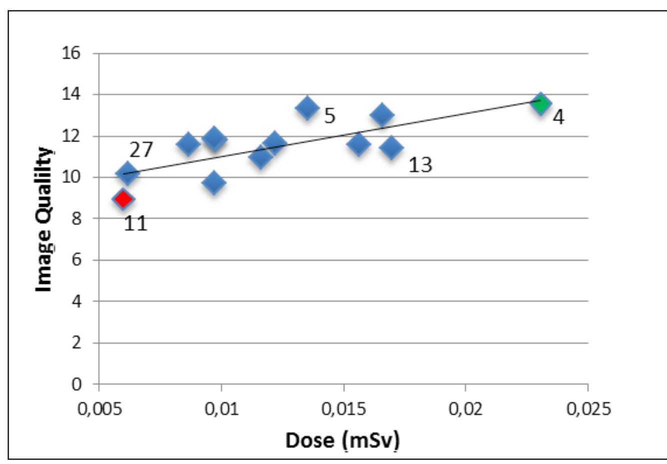

Figure 5: How the dose in mSv increase, in relation to how the image quality increase at the same time.

Using figures 1 to 4, images that were acceptable in every category were identified and only these images were expressed in figure 5.

Figure 5 shows that when dose increases, the image quality also increases, with a correlation coefficient of R=0.745. This means that there is a strong relationship between the dose and image quality. This is demonstrated by the image with the standard parameters, produced without any additional filter, having the highest dose

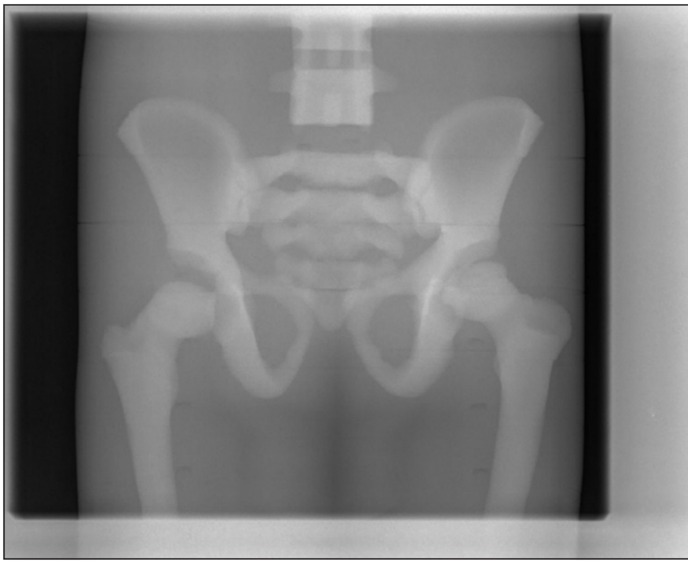

Figure 6: Image with the standard parameters.

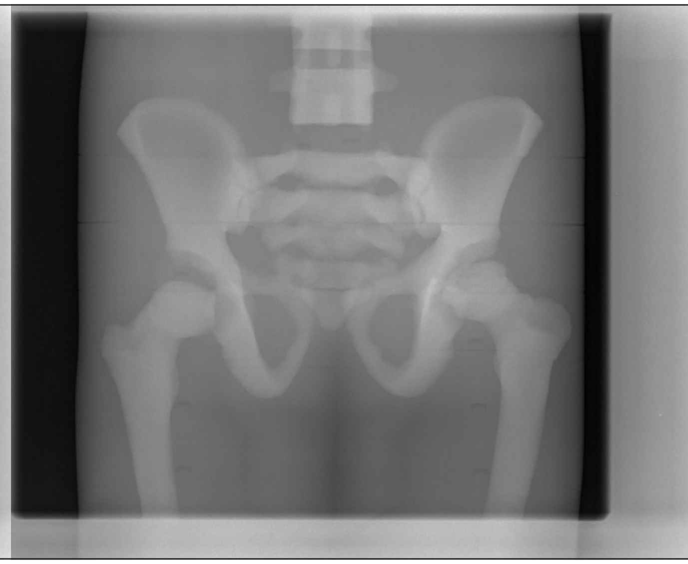

Figure 7: Image 5 (60kVp/3.6mAs/0.1mmCu).

and image quality level. The divergence of the line is not straight. Figure 5 (60 kVp / 3.6 mAs / 0.1mm Cu) has a similar image quality to image 4 (60 kVp / 3.6 mAs / 0mm Cu), but with a lower dose. These images were obtained with the same parameters, with the addition of a 0.1mm filter on figure 5.

Image 27 (70 kVp / 2.2 mAs / 0.2mm Cu) has a better image quality than the lowest acceptable image, image 11 (50 kVp / 5 mAs / 0.1mm Cu) and only a slight increase in dose.

Finally, it is interesting to see that of all the images in figure 5, only 2 of these were produced without additional filtration, images 4 (60 kVp / 3.6 mAs / 0mm Cu) and 13 (50 kVp / 3.6 mAs / 0mm Cu). However, image 4 represents the standard parameters.

DISCUSSION and CONCLUSION

The aim of this study was to reduce effective dose to a paediatric phantom by using different acquisition parameters and additional filtration whilst maintaining image quality. These results suggest that dose reduction is possible by changing kVp, mAs and additional filtration. The final graph shows that 85% of the images that were accepted in all categories were produced using additional filtration.

This research has shown that in practice the use of 50 kVp and filtration instead of 60 kVp and no filtration allows enough image quality (visualized and measured) and decreases the dose.

As expected, the results show that copper filtration is helpful in reducing dose without reducing image quality to an unacceptable standard[8]. From the results it is also clear that 0.1mm of copper filtration is similarly useful to 0.2mm. It can be seen that it is possible to obtain an image of acceptable image quality (13.55 vs 13.3) with a dramatically reduced dose by nearly two (23.05 µSv vs 13.55 µSv), this is image 5 (60 kVp / 3.6 mAs / 0.1mm Cu). This has important implications for clinical use, as the European Commission guidelines10 published in 1996 have the potential to be updated to accommodate the possibility of dose reduction by routinely using 0.1mm of Cu filtration on patients of this size. The parameters used to produce this image were 50 kVp and 3.6 mAs with 0.1mm of copper filtration. These are below the recommended parameters[10] in the guidelines with the addition of copper filtration, further suggesting the need for an update of the guidelines.

Another point on the graph that has been highlighted represents an image of higher image quality than the lowest acceptable (10.15 vs 8.95), with only a minor increase in dose (6.18 µSv vs 5.98 µSv). This is image 27 (70 kVp / 2.2 mAs / 0.2mm Cu). The clinical implications of this are that, for a small increase of 0.2 µSv, there is an increase in image quality that is justified. This means that higher quality images can be obtained with an acceptably low dose reducing the potential for repeated examinations due to poor visualisation. In children this is especially relevant, due to their higher risk of malignancy[2,9] and the gonads in the region of the examination[6].

Some areas of the study have been identified that could be improved upon. These include using a wider range of kVp and mAs to give an exact set of parameters to use, rather than a suggestion, which is given here. Another point is that the limits of the kVp tested were quite close together, only altering by 20 kVp. It is possible that another set of parameters outside of these limits produces a diagnostically acceptable image, with a dose lower than ICRP guidelines. Another area for future work is to have a group of observers that includes professionals with higher levels of experience, such as radiologists and reporting radiographers. Their experience may cause them to rate the images differently to the group of observers used here. It would be beneficial to know whether student radiographers can identify poor and good image quality as well as professionals with years of clinical experience.

In conclusion, additional copper filtration has been identified as a major tool for reducing effective dose whilst maintaining an acceptable image quality in a 5 year old phantom. It is suggested that the European Commission guidelines be updated to recommend lower parameters and 0.1mm of copper filtration in patients of this size.

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Appendix A

Visual Function[1]	Standard/Average	Participants Results
1. Visual acuity		
Distance	0.0 LogMAR	-0.13 ± 0.07 (20/15) LogMAR[2]
Near Distance	1 M	0.40 ± 0.00 (20/20) M
3. Contrast Sensitivity		
3 cpd	1.61 ± 0.21	1.84 ± 0.10
6 cpd	1.66 ± 0.23	2.08 ± 0.20
12 cpd	1.08 ± 0.32	1.92 ± 0.11
18 cpd	0.56 ± 0.35	1.45 ± 0.14
2. Stereoacuity	60	40 ± 0.0

[1] All subjects who normally wore corrective lenses were asked to wear them during vision testing.

[2] All subjects had best visual acuities LogMAR of 0.0 (20/20) or better for distance