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

J. Tugwell, C. Everton, A. Kingma, D.M. Oomkens, G.A. Pereira, D.B. Pimentinha, C.A.I. Rouiller, S.M. Stensrud, E. Kjelle, J. Jorge, P. Hogg

Abstract

Aim: A quantative primary study to determine whether increasing source to image distance (SID), with and without the use of automatic exposure control (AEC) for antero-posterior (AP) pelvis imaging, reduces dose whilst still producing an image of diagnostic quality.
Methods: Using a computed radiography (CR) system, an anthropomorphic pelvic phantom was positioned for an AP examination using the table bucky. SID was initially set at 110 cm, with tube potential set at a constant 75 kVp, with two outer chambers selected and a fine focal spot of 0.6 mm. SID was then varied from 90 cm to 140 cm with two exposures made at each 5 cm interval, one using the AEC and another with a constant 16 mAs derived from the initial exposure. Effective dose (E) and entrance surface dose (ESD) were calculated for each acquisition. Seven experienced observers blindly graded image quality using a 5-point Likert scale and 2 Alternative Forced Choice software. Signal-to-Noise Ratio (SNR) was calculated for comparison. For each acquisition, femoral head diameter was also measured for magnification indication.
Results: Results demonstrated that when increasing SID from 110 cm to 140 cm, both E and ESD reduced by 3.7% and 17.3% respectively when using AEC and 50.13% and 41.79% respectively, when the constant mAs was used. No significant statistical (T-test) difference ($p = 0.967$) between image quality was detected when increasing SID, with an intra-observer correlation of 0.77 (95% confidence level). SNR reduced slightly for both AEC (38%) and no AEC (36%) with increasing SID.
Conclusion: For CR, increasing SID significantly reduces both E and ESD for AP pelvis imaging without adversely affecting image quality.

Keywords: Effective dose Entrance surface dose Image quality Computed radiography

Introduction

Optimisation, a strategy of reducing dose to the patient whilst still producing an image of diagnostic quality, is imperative in radiography and is recommended by both the International Commission on Radiological Protection[1] and the European Medical Exposure Directive.[2] This principle is important for all examinations that involve ionizing radiation, however it is especially important for high dose examinations. European figures identified pelvic and hip radiography to be third biggest contributor to dose from medical imaging in the UK, with an annual frequency of 39 per 1000 of population.[3] Pelvic radiography is a high dose examination that irradiates radiosensitive organs such as the gonads; consequently there have been numerous attempts to reduce the amount of radiation to patients from this examination.[4,5] Increasing the Source to Image Distance (SID) is a simple and economical method which has been investigated for reducing the dose of an antero-posterior (AP) pelvis. Previous studies exploring this technique have been primarily focused on film-screen based radiography[6,7] with limited data on computed radiography (CR)[8e10] and direct digital radiography[4] (DDR). With the advent of new digital imaging systems in radiography departments and subsequent reports regarding 'dose creep',[11—13] it is important to focus on keeping the dose as low as reasonably practicable whilst producing an image of diagnostic quality for digital radiography.

The purpose of this study was to determine whether increasing SID for AP pelvis, with and without the use of the automatic exposure control (AEC) for a CR system, reduces dose whilst still producing an image of diagnostic quality.

Methods

Imaging equipment

All exposures were performed using a Wolverson Acroma X-ray unit (high frequency generator with VARIAN 130HS standard X-ray tube) with a total filtration of 3 mm Al. The unit incorporated a moving grid (ratio of 12:1, focused at 110 cm ± 15 cm) mounted in the table Bucky. The same image receptor (35 cm × 43 cm Agfa CR imaging plate) was used throughout the study and processed using a 35-X reader with a spatial resolution of 10 pixels per mm and grey scale resolution of 12 bits per pixel.[14] Routine quality assurance was performed prior to image acquisition to verify CR reader performance, tube mA, kV, exposure time and collimation, to ensure reliability and consistency of the equipment utilised.[15]

Phantom and imaging technique

All radiographic exposures were undertaken using an anthropomorphic pelvis phantom positioned on the X-ray table for a standard AP examination.[16] The initial acquisition parameters of 110 cm SID using the outer AEC chambers, 75 kVp, and fine focal spot[16e18] were selected to acquire the reference image for visual grading analysis. A series of images were then produced at increasing SID (90 cm to a 140 cm), with two images acquired at each 5 cm interval, one using the AEC and the other using a constant mAs of 16 mAs. 16 mAs was derived from the initial standard acquisition parameters utilising the AEC. Collimation was adjusted to the region of clinical interest (iliac crest, greater trochanters and proximal third of femurs) for each SID increment, such that the area of phantom irradiated remained constant.[19] To mimic clinical conditions the appropriate look up table (LUT) for pelvis radiography was used. No alteration of the window width and level was made.

Visual analysis of image quality

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

Using a 5-point Likert scale, seven radiographers with a mini- mum of five years clinical practice experience assessed and scored images. The image quality criteria (Fig. 1) was adapted from Euro- pean Guidelines on Quality Criteria for Diagnostic Radiographic Images22 in conjunction with scales used in other literature4,23 and an unpublished psychometric image quality scale (Chronback's Alpha >0.8). Images were displayed on two 24.1 inch NEC (EA243WM) monitors with a resolution of 2.3 megapixels. Moni- tors were calibrated for Digital Imaging and Communications in Medicine (DICOM) grayscale standard display function and to the recommended specification of the Royal College of Radiologists.24 To determine that display quality consistency of the dual screen monitors was maintained a visual pattern check was undertaken prior to every radiographer doing the visual analysis. Lighting conditions were maintained at a dimmed and consistent ambient level throughout the visual image quality experiment. The radiographers were blinded to the acquisition parameters of the images they were provided with a set of instructions on what to do in the experiment and they were prohibited from manipulating the images.

Signal to noise ratio (SNR)

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

Radiation dose calculations

Dose Area Product (DAP) readings were recorded. An average of three readings was taken for each image acquisition. Entrance surface dose (ESD), including backscatter, was measured at the surface of the phantom using an Unfors Calibration device (Unfors Equipments, SE) and averaged in the same manner.

Effective dose (E), organ doses and effective risk were calculated from the DAP using Monte Carlo simulation software (PCXMC).26 The reliability of this software is supported by literature demonstrating results in close agreement with dose measurements and calculations of other phantom models.27e29 Effective risk was estimated for the ages of 15 and 60 to compare the lifetime cancer risks.

Magnification

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

Statistical analysis

For visual image quality data, intraobserver variability was evaluated by Intraclass Correlation

Coefficient (ICC) using a 2-way random effect model for absolute agreement.30 Image quality data was assessed using t-tests with a probability level of $p < 0.05$ (95%) regarded as significant.

Results

Radiation dose

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

Effective risk

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

Image quality

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

Magnification

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

Discussion

The results suggest that increasing SID from 110 cm to 140 cm reduces ESD and E by 17.3% and 3.7% respectively when utilising the AEC. Further reduction of ESD (50.13%) and E (41.79%) was identified when the AEC was not utilised. Data from our study is similar to Heath et al.,4 who found a dose reduction of 7.9% when SID was increased from 110 cm to 140 cm using the AEC. Woods and Messer10 found a larger reduction in dose when they utilised the AEC (33.7%), but smaller reduction when a constant baseline mAs was used for each increment (45.2%). Other studies6e9 also identified dose reduction when increasing SID.

Our data demonstrates that dose reduction can be identified with as little as 5 cm SID increments, which is of interest because earlier studies suggest that increments of 10 cm are needed to see a dose reduction effect. In addition, the majority of previous studies4,7,8 either utilised the AEC or increased mAs when increasing SID to compensate for dose reduction with regard to the Effective dose inverse

square law, therefore maintaining a constant dose at the receptor. Brennan et al.6 found an increase of 60% in mAs at increased SID when utilising the AEC. This study used constant mAs (derived from the standard acquisition parameters used for the reference image). Brennan found that image quality could still be maintained without the need for a consequent increase in dose (mAs value) at increased SID increments.6 The use of AEC is not always an option in cases such as trauma, paediatric radiography or for patient with metallic implants, so it is imperative that we understand the consequences of increasing SID for these types of imaging if this dose reducing technique is to be implemented into clinical practice.
Even though our study demonstrated increasing SID, with and without AEC, to be a successful dose reducing technique without a significant detrimental impact on image quality, radiographers should be cautious when implementing the technique in clinical practice. For instance, our data demonstrates that femoral head diameter reduces as SID is increased; this may lead to issues with revealing a consistent decrease in image quality when SID was increased. A reasonable explanation for this would be that objective physical measures of image quality are more sensitive to changes in pixel values with regards to noise and signal. The human eye may not be able to distinguish between this amount of change in an image.31

Further work

This study was performed using a single CR system and there- fore the outcomes would need to be confirmed on different digital systems. Furthermore, the images were acquired using an anthropomorphic pelvis phantom, this decreases the clinical relevance of the study as there is no disease present when comparing image quality; the results need to be confirmed using patients of various body habitus in practice. interpretation if images are acquired at different SID for the same patient.4 Radiographers could annotate and document the SID utilised for the images for reference of the reporting clinician raising awareness of the potential magnification differences from previous images. Our study did not explore the potential image quality benefits of increasing SID on geometric unsharpness. Further work needs to be done on the significance of magnification reduction in clinical practice and the impact it may have on calculations for pre-operative measurements and whether there are geometric unsharpness implications. There were minor differences between image quality using Image J and the 2AFC software in our study with the SNR results.

Conclusion

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

Conflict of interest statement

None.

Acknowledgements

The authors acknowledge Erasmus for financial support.

References

1. European Commission. Council directive 97/43/Euratom on health protection of individuals against the dangers of ionizing radiation in relation to medical exposure, and repealing directive 84/466/Euratom. *Off J Eur Communities* 1997;L180(40):22.
2. International Commission on Radiological Protection. *Radiological protection and safety in medicine, ICRP publication 73*. Annals ICRP 26. Oxford: Pergamon Press; 1996.
3. Hart D, Wall BF, Hillier MC, Shrimpton PC. *Frequency and collective dose for medical and dental X-ray examinations in the UK*. Health Protection Agency; 2008. Report HPA-CRCE-012.
4. Heath R, England A, Ward A, Charnock P, Ward M, Evans P, et al. Digital pelvic radiography: increasing distance to reduce dose. *Radiol Technol* 2011;83(1): 20e8.
5. Doolan A, Brennan PC, Rainford LA, Healy J. Gonad protection for the antero-posterior projection of the pelvis in diagnostic radiography in Dublin hospi- tals. *Radiography* 2004;10:15e21.
6. Brennan PC, McDonnell S, O'Leary D. Increasing film-focus distance (FFD) re- duces radiation dose for X-ray examinations. *Radiat Prot Dosim* 2004;108(3): 263e8.
7. Grondin Y, Matthews K, McEntee M, Rainford L, Casey M, Tonra M, et al. Dose-reducing strategies in combination offers substantial potential benefit to fe- males requiring X-ray examinations. *Radiat Prot Dosim* 2004;108(2):123e32.
8. Poletti J, Mclean D. The effect of source to image-receptor distance on effective dose for some common X-ray projections. *Br J Radiol* 2005;78:810e5.
9. Farrell KRC, Abbott C, Round K, Willis SJ, Yalden R, Knapp KM. Pelvic projection radiography: increasing the source to image distance provides diagnostic im- ages at reduced dose. In: *Proceedings of the UK radiological congress*; 2008. p. 16.
10. Woods J, Messer S. Focusing on dose. *Synergy Imaging Ther Pract* 2009 September:16e20.
11. Maa WK, Hogg P, Tootell A, Manning D, Thomas N, Kane T, et al. Anthropo-morphic chest phantom imaging e the potential for dose creep in computed radiography. *Radiography* 2013;19:207e11.
12. Gisbon D, Davidson R. Exposure creep in computed radiography, a longitudinal study. *Acad Radiol* 2012;19(4):458e62.
13. Uffmann M, Schaefer-Prokop C. Digital radiography: the balance between image quality and required radiation dose. *Eur J Radiol* 2009;72:202e8.
14. CR 35-X Digitizer. *Small footprint digitizer for the complete range of clinical application*. Agfa Health Care; 2007. http://radonmedicalimaging.com/pdf/ agfa_CR_35-X.pdf [online accessed 16.08.13], pp. 3e4.
15. Institute of Physics and Engineering in Medicine (IPEM). *IPEM report 91 rec-ommended standards for the routine performance testing of diagnostic X-ray imaging systems*. 2nd ed. York: IPEM; 2005.
16. Whitley AS, Sloane C, Hoadley G, Moore AD, Alsop CW. The hip, pelvis and sacroiliac joints. In: *Clark's positioning in radiography*. 12th ed. London: Hodder Arnold; 2005. pp. 141e62.
17. Bontrager KL, Lampignano JP. *Handbook of radiographic positioning and tech- niques*. 7th ed. St. Louis: Mosby; 2005.
18. Aldrich J, Duran E, Dunlop P, Mayo J. Optimization of dose and image quality for

computed radiography and digital radiography. *J Digital Imaging* 2006;19(2): 126e31.
19. Williams L. Pelvis and hips. In: Carver B, Carver E, editors. *Medical imaging: technique, reflection and evaluation*. Philadelphia: Churchill Livingstone/Elsev- ier; 2006. pp. 121e33.
20. Hogg P. Software for image quality evaluation using a forced choice method. In: *United Kingdom radiological conference*. Manchester/London, UK: British Insti- tute of Radiology; 2012. p. 139.
21. Pelli DG, Farell B. *Handbook of optics. Fundamentals, techniques, and design*, vol. 1. New York: McGraw-Hill; 1995.
22. European Commission. *European guidelines on quality criteria for diagnostic radiographic images*; 1996. EUR 16260 EN.
23. Manning-Stanley A, Ward A, England A. Options for radiation dose optimisa- tion in pelvic digital radiography: a phantom study. *Radiography* 2012;18: 256e63.
24. The Royal College of Radiologist. *Picture archiving and communication systems (PACS) and quality assurcance*. 2nd.ed. London: The Royal College of Radiolo- gists; 2012.
25. Hein LR, Campos KA, Caltabiano PC. Low voltage and variable-pressure scan- ning electron microscopy of fractured composites. *Micron* 2012;43:1039e49.
26. Tapivaara M, Lakkisto M, Servomaa A. *PCXMC: a PC-based Monte Carlo program for calculating patient doses in medical X-ray examinations*. Helsinki: Finnish Centre for Radiation and Nuclear Safety; 1997. Report STUK-A139.
27. Schmidt PWE, Dance DR, Skinner CL, Smith IA, McNeill JG. Conversion factors for the estimation of effective dose paediatric cardiac angiography. *Phys Med Biol* 2000;45:3095e107.
28. Schultz FW, Geleijns J, Spoelstra FM, Zoetelief J. Monte Carlo calculations for assessment of radiation dose to patients with congenital heart defects and to staff during cardiac catheterization. *Br J Radiol* 2003;76:638e47.
29. Helmrot E, Pettersson H, Sandborg M, Alte´n JN. Estimation of dose to the un- born child at diagnostic X-ray examinations based on data registered in RIS/ PACS. *Eur Radiol* 2007;17:205.
30. Rosner B. *Fundamentals of biostatistics*. Belmont: CA: Duxbury Press; 2005.
31. Smith SW. *The scientist and engineer's guide to digital signal processing*. San Diego: California Technical Publishing; 1997. p. 650.

Table 1 - Demonstrating femoral head diameter difference at varying SID

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

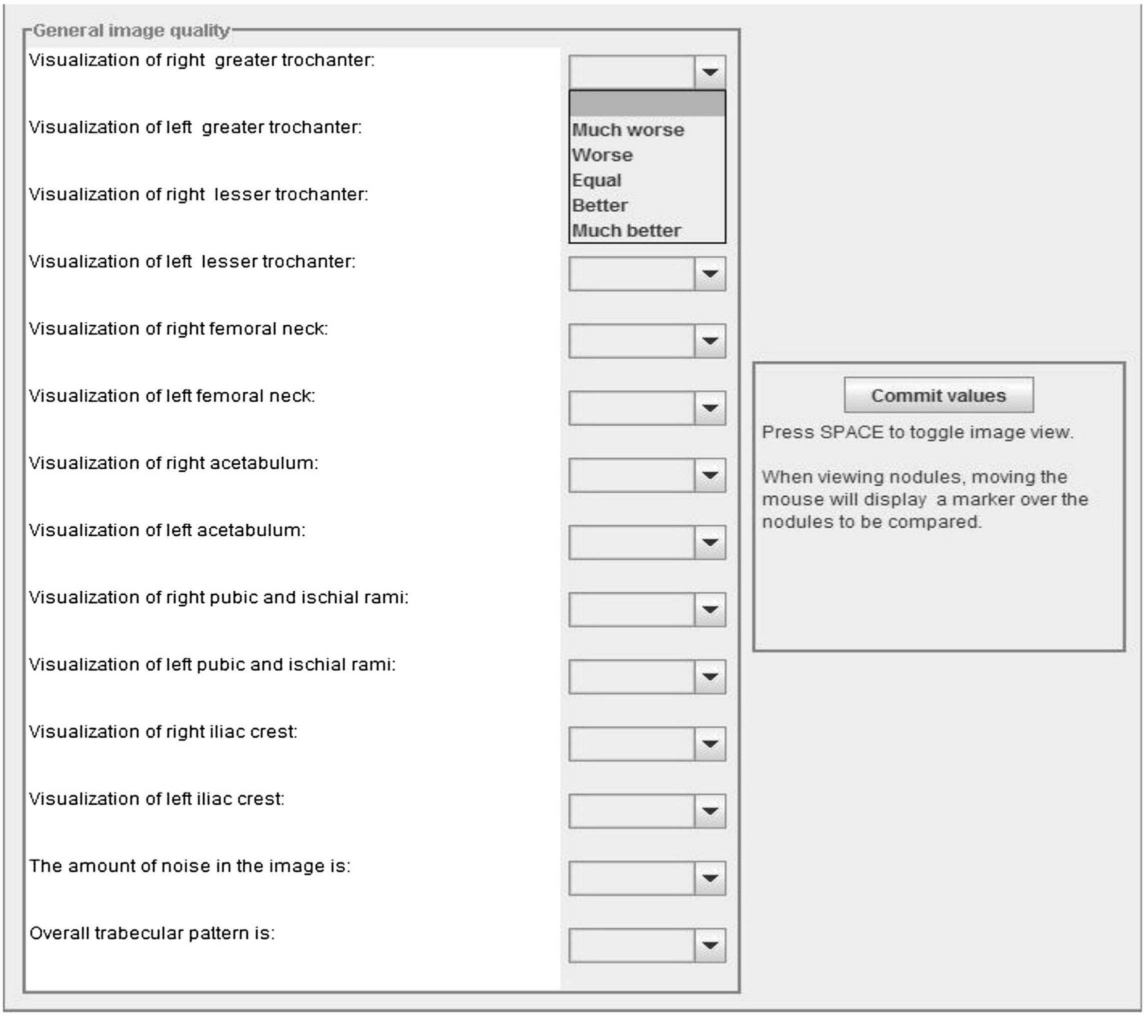

Figure 1. Image quality criteria items and the 5-point Likert scale for the observer's response.

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

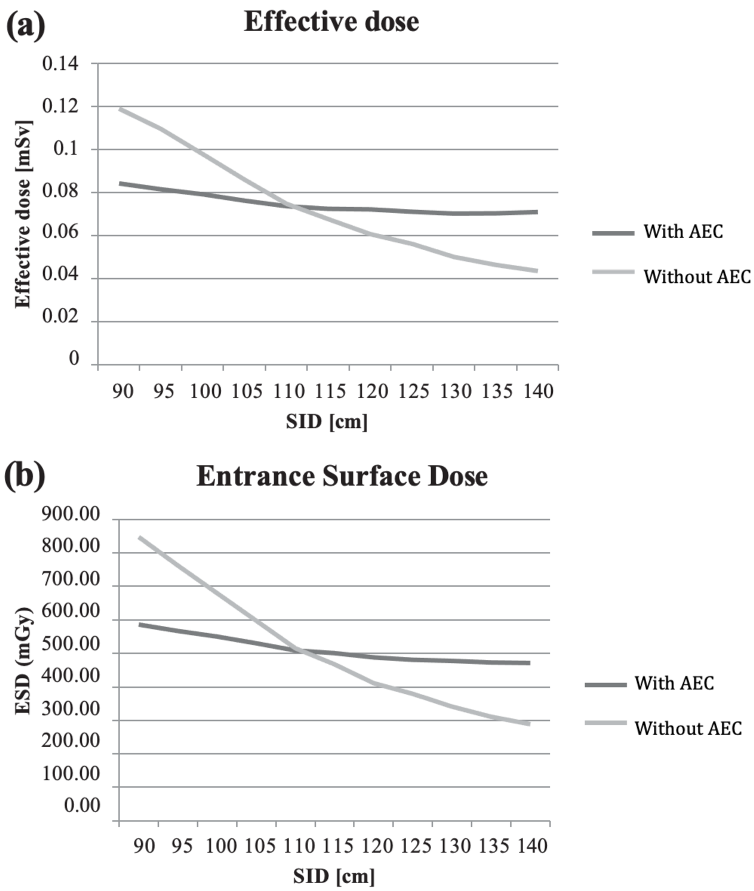

Figure 3. a) Relation between subjective (IQ) and objective (SNR) measurement of image quality, whilst increasing the SID (cm), considering the use of AEC. b) Relation between subjective (IQ) and objective (SNR) measurement of image quality, whilst increasing the SID, when not considering the use of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