IMPACT OF THE ANODE HEEL EFFECT ON IMAGE QUALITY AND EFFECTIVE DOSE FOR AP PELVIS: A PILOT STUDY

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ABSTRACT

Purpose: Using phantoms, this pilot study aims to outline a method and generate initial data to determine whether the anode heel effect has an impact on image quality and the effective dose.

Methods and Materials: A dosimetry phantom and an anthropomorphic adult phantom were positioned with feet towards anode and then cathode and exposed using 75, 80 and 85 kVp; using 18, 22 and 28 mAs. Twelve images were taken and assessed for physical and visual quality by signal to noise ratio and two alternative forced choice (2AFC) with 19 observers.

Results: From 2AFC data, no significant statistical differences (p=0.811) were found in image quality. Effective dose results show no significant statistical difference (p=0.207) between the two orientations.

Conclusion: No significant reduction in visual image quality or effective dose exists betweeen the two orientations. Limited data has been provided by this pilot study so the results should be treated with caution. However the method appears to generate useful information for the aim of the study and we suggest larger datasets of 2AFC and dose values should be generated to determine whether differences exist.

Introduction

Due to the biological effects of radiation, it is essential to achieve the lowest patient radiation dose whilst acquiring clinically acceptable images (1). To achieve this, optimisation studies need conducting with the factors that affect image quality and radiation dose being manipulated in a controlled fashion. Examples of the factors include: exposure factors, source to image distance (SID), grid / no grid, filtration, detector characteristics and image processing options (2,3). Patient orientation across the anode-cathode axis could also have an impact on image quality and dose to patient. This is because radiation dose is not uniform across this axis with the radiation field intensity decreasing towards the anode from the cathode (4,5). This intensity variation is often referred to as the anode heel effect. According to Harding et al (2013), patient orientation should be considered for each examination and with the anode heel effect in mind this could have consequences for image quality and dose to patient (6)source-to-skin distance and kVp data facilitated the calculation of entrance surface dose (ESD.

Research into AP pelvis by Mraity et al (2016) (7) was the most significant study found during the literature review; it investigated the impact of the anode heel effect on gonad radiation dose. Mraity et al established there is a significant difference in testicular dose between *feet towards anode* and *feet towards cathode*; no significant difference existed for the ovaries. Mraity et al recommended further work be conducted to determine whether there is a difference in effective dose and image quality for the two orientations.

Our work builds on that of Mraity et al. Using an anthropormorphic pelvis phantom and an ATOM adult dosimetry phantom, our paper aims to present a method and initial data to determine whether image quality and effective dose differences exist between feet towards anode and feet towards cathode for AP pelvis imaging using Digital Radiography (DR).

Methods and materials

An anthropormorphic pelvis phantom was imaged with feet towards cathode and then feet towards anode using a DR (Aero DR System, Konica Minolta) system; the images were evaluated for quality (IQ) using physical and visual measures. An adult dosimetry phantom (ATOM, 701B, CIRS) using TLDs (TLD-100H (Li F Mg, Cu (P-100H) and TLD reader (Harshaw TLD reader) were exposured with feet towards anode and then feet towards cathode and effective dose was calculated (8,9)

Acquisition conditions for ATOM and anthropormorphic phantoms are indicated in **Table 1**.

Estimation of effective dose using TLDs

TLDs were inserted into an adult male ATOM phantom. TLDs were used as they are sensitive and give accurate measurements of the radiation received by ograns within the phantom. The ATOM phantom consists of multiple slices, each slice containing multiple holes to locate TLDs in order to accurately estimate organ doses (10). After each exposure a Harshaw 3500 TLD reader (Thermo Scientific, USA) was used to read the exposed TLDs. Prior to exposure, TLD quality control tests were conducted (8).

TLDs were only loaded into the area in and around the pelvis. Initial AP pelvis exposures identified which holes did not need filling (eg chest / head) as no exposure was recorded into the TLDs. In only using a limited number of TLDs the experimental process was speeded up. The time to conduct one

Table 1: Phantom acquisition conditions

Anthropormorphic pelvis phantom		Atom phantom	
Additional Filtration	0	Additional filtration	0
SID	110cm	SID	110cm
kVp	75,80,85	kVp	75,80,85
mAs	18,22,27	mAs	18,22,27
Collimation	43x45	Collimation	43x45
Image receptor type	DR	Image receptor type	DR

adult ATOM phantom dose measurement using all TLDs and not just the pelvis area, including TLD insertion, removal and reading is approximately one full day. For our experiment TLDs were read on the same day as exposure in order to reduce the risk of addional error caused by background radiation or the fading of charge within the TLD. TLDs were also used to esytablish background radiation; this were not loaded into the ATOM phantom. For each set of acqisition factors three exposures were made and then averaged to minimise random error.

Organ dose was calculated by summing the TLDs charge/dose values in each organ and dividing by the total numbers of TLDs in that organ; this value was multiplied by the relevant tissue weighting factor, W_T (see **Figure 1**).

Organ	Tissue weighting factor
Gonads	0.08
Bone marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Breast	0.12
Bladder	0.04
Liver	0.04
Oesophagus	0.04
Thyroid	0.04
Skin	0.01
Bone (surface)	0.01
Salivary glands	0.01
Brain	0.01
Remainder	0.12
Total	1.00

Figure 1: Tissue weighting factors defined by ICRP1034.

Summation of calculated organ doses for the entire body gives the Effective Dose, E (mSv),

$$E = \sum_T W_T \cdot H_T$$

Where

E is the effective dose absorbed by the entire body

W_T is the tissue weighting factor defined by ICRP1034

H_T is the equivalent dose absorbed by tissue T

Equation 1: Calculation for effective dose[4]

Physical analysis of IQ

The signal-noise ratio (SNR) was calculated with ImageJ (10–12). Regions of interest (ROI) were placed at various points around the pelvis as illustrated in **Figure 2**. Given that exact positioning of the anthropomorphic phantom for ‘feet to anode’ and ‘feet to cathode’ could not be replicated exactly, ROIs had to be positioned manually for each orientation so that for feet to anode and feet to cathode were similar for all images in both conditions (13).

Visual assessment of image quality

Images were processed on an Agfa Digital radiography (DR) unit; the pelvis look up table was used for image display. Observers were not allowed to alter display settings during visual assessment of image quality. Visual assessment was conducted in

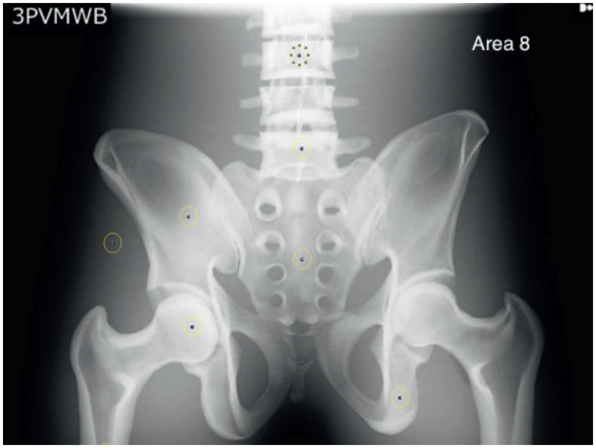

Figure 2: Position of ROIs within the anthropomorphic phantom

Table 2: Criteria used to evaluate the image quality

Criteria	
1.	Clear visualisation of the right and left trochanters.
2.	Clear visualisation of the femoral necks.
3.	Clear visualisation of the left and right iliac crest.
4.	Clear visualisation of the left and right ischial rami.
5.	The noise ratio in the image is.
6.	The overall image quality.

dimmed lighting which remained constant throughout the experiment. Various approaches exist to the visual assessment of image quality; these include absolute visual grading (14) and two alternate forced choice (2AFC) (15). 2AFC has many benefits, including the potential to minimise inter and intra observer variability through the provision of a reference image against which all experimental images are compared (16). Using 2AFC, images were visually assessed using quality criteria derived from various sources (17,18). The criteria used for judging image quality are indicated in **Table 2**. A 5 point Likert scale was used for scoring as seen in **Table 2**.

The 2AFC reference image was chosen by calculating the SNR for all images, with use of different regions of interest from the pelvic area (L5, iliac crest, sacrum, pubis, femur head and femur). The average SNR was selected as the reference image. The reference image was acquired as follows- feet to anode, 75kVp and 18 mAs.

Twenty-four observers evaluated the images. These included 19 student radiographers and 5 qualified radiographers. Prior to evaluating the images the observers were given an explanation of what they were required to do. Images were displayed on two 2.4 MP HD NEC monitors EA243WM (NEC Europe, London, UK) which had been calibrated to the DICOM Grey Scale Standard. As a quality control measure for observer performance, the reference image was reviewed on a blinded basis by the observers against itself; this provided a simple method to assess intra-observer reliability. From the original twenty-four observers, five assessed the reference image with a higher error than the allowed 5.56% error margin and were excluded from the analysis, resulting in a total of 19 observers. In order to evaluate the reliability of the observers, the Intra Class Correlation (ICC) was calculated. ICC proves beneficial in providing a method for calculating the inter-rater agreement measures between observers for all images graded as specified by Cicchetti et al as can be seen in **Table 3** (19).

Before statistical analysis of the data could be performed, a normality test was used (Shapiro-Wilk) to determine the type of data acquired during the experiment; this determined the statistical tests which could be used (parametric / non parametric). The results for the effective dose, testes dose, physical and visual image quality data were normally distributed justifying the use of a parametric T-test.

Results

Effective dose

Figure 3 shows the percentage change in effective dose between feet to cathode and feet to anode. The difference bewteen the two orientations is not significant (P=0.207). Dose to testes was compared using T-test and no significant difference was found between the two orientations.

ICC inter-rater agreement measures	Level of sigificance
< 0.40	Poor
0.40 - 0.59	Fair
0.60 - 0.74	Good
0.75 - 1.00	Excellent

Table 3: Corresponding levels of significance for ICC inter-rater agreement measures

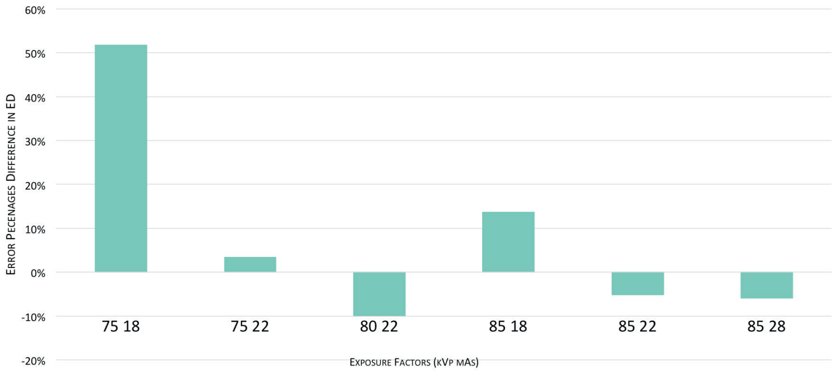

Figure 3: Percentage error difference in Effective Dose vvsvsexposure

Table 4: Average SNR values for the two orientations across the central ray.

kVp/mAs	Orientation Feet to anode Average SNR	Feet to cathode Average SNR
75/18	40.691	37.277
75/22	40.416	39.752
80/22	41.888	39.631
85/22	42.167	40.004
85/18	41.875	41.643
85/28	42.147	41.784

Physical assessment of image quality

The average SNR values were calculated for each exposure as can be seen in **Table 4**. Through the calculation of these averages, differences between varying exposure parameters for physical image quality were analysed for the entire image, allowing a comparison to be made between the physical and visual methods of analysis.

Table 5 illustrates SNR for all exposure factors for both orientations. A significant difference (P<0.05) was found between the two orientations for the SNR. The regions of interest data towards the extreme edge of the central ray, where the anode heel effect is pronounced, this can be seen in **Table 5**.

(P) values of SNR for all the regions of interest			
Region of interest	SNR average feet to Anode	SNR average feet to cathode	*(P) values
Area 1 - Femur head	33.469	30.290	0.04
Area 3 - Pubic	30.718	27.033	0.01
Area 4 - Sacrum	28.613	25.666	0.06
Area 5 - L5	34.413	31.059	0.25
Area 6 - Iliac	29.115	25.989	0.06
Area 7 - Femur	22.850	19.175	0.00

Table 5: NR P-values for both phantom orientations

Visual assessment of image quality

Analysis of the image quality was performed using paired T-test in SPSS. Analysis showed there is no statistically significant difference (P = 0.811) in visual quality for either orientation.

In order to increase the reliability of the data provided by the observers, measurements of the Intra-Class correlation (ICC) of the observers was found to be fair at 0.506 (inter observer variability).

Evaluation of observer variability

The reference image was included to assess intra observer variability. The error margin was set to 6% as there were only 6 criteria for each pair of images to be evaluated, resulting in a 5.56% error by evaluating a single image criteria in comparison to the reference image. Of the 24 observers, 16 assessed the reference image as being equal to itself on all 6 criteria. Three observers had a 5.56% error and were therefore included. Five observers, consisting of four students and one qualified radiographer, assessed the reference image either much better or much worse compared to itself, with errors ranging from 11% to 33% and were therefore excluded from the final analysis. **See figure 4**.

Discussion

The aim of this pilot study was to investigate the impact of anode heel effect on image quality and effective dose. Overall, the outcome demonstrates that there is no statistical difference in both visual image quality and effective dose for either orientation, however a significant difference for SNR was found.

This result could be beneficial in the clinical setting, where images are judged for image quality using visual techniques as ultimately diagnoses are made visually. It is likely, based on the results from the visual

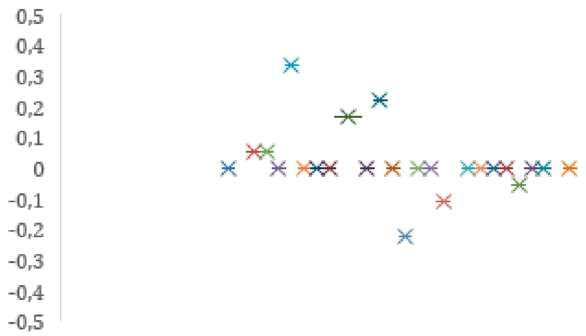

Figure 4: Percentage Error in observers' performance

image quality assessment, placing a patient in either orientation should result in the same visual image quality. However, it should be noted that due to this study involving a singular anthropomorphic phantom with no pathology, a human/clinical study perhaps using cadavers should be performed as to assess the applicability of the study findings within a clinical setting.

Although no statistical difference was found in visual image quality, SNR contradicted the visual image quality results showing a statistically significant difference between the orientations. This finding is expected because the dose to the detector varies from anode to cathode, because of the anode heel effect; in turn this variation will impact on noise. Whilst the physical method of assessing image quality has demonstrated a significant difference in image quality it is probably not important clinically as it is likely there will be no impact on visual image quality or lesion detection performance, though the latter still needs to be established in a further study. However the difference between the visual and physical measures is important to highlight, because this suggests that a physical measure such as SNR in isolation of a visual measure could have limited value and lead to a false conclusion.

For the SNR measurement, ROI number 8 was placed on L3. When comparing the image collimation to collimation that would be used in clinical practice, the upper limit was found to be under L3 ruling the area of ROI8 not diagnostically relevant and was therefore excluded. Closer collimation may have improved the overall image quality and would be the main point of focus if the study were to be repeated.

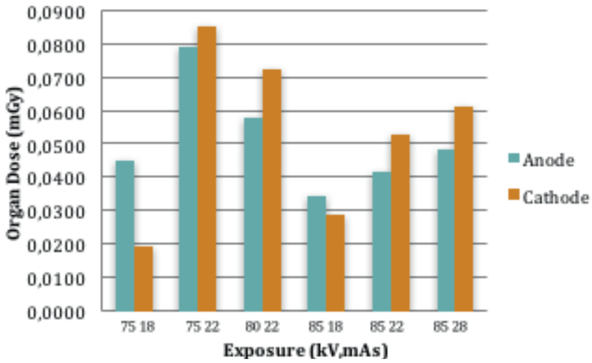

Figure 5: Dose to testes (mGy) from varying exposures

For the set of effective dose data, one exposure with 75 kV and 18 mAs was cathode dominant by 48.25%. 75 kVp and 22 mAs represented the lowest value of this side, where 85 kVp and 18 mAs scored inbetween. The other exposures were anode dominant for effective dose. Apart from the 75 kVp and 18 mAs exposure which showed a much larger ED percentage difference which may be due to miss-centring or miss-collimating the dosimetry phantom. Despite accurate marking of the centre and collimation area, there is still room for error to occur. This may be the reason behind obtaining different ED values over the set of exposure factors.

Figure 5 highlights the considerable difference in testes dose between 75 kVp /18 mAs. Although this is different to Mraity's results, this outcome was most likely caused by a limitation in the amount of available data - in comparison with Mraity et al we performed very few measurements.

Future Work

Our study reports on a limited set of acquisition conditions in comparison to those reported in Mraity's work. We propose our work be extended to include all the acquisition conditions indicated in Mraity's work and SNR, 2AFC and effective dose be recalculated and assessed statistically to determine whether significant differences do exist. Despite this limitation in our work the method for data acquisition and analysis appears to be fit for purpose and an extension to our study using the same approach is warranted. A larger number of observers would also help to verify the reduction in dose to testes noted by Mraity, removing one of the main limitations from this study.

Conclusion

There is no statistical difference in both visual image quality and effective dose for either orientation, however a significant difference for SNR was found. Given we performed our work on a phantom, further research should be considered before directly implementing in practice, consequently we recommend a human study to consider image quality on anode heel orientation using cadaver. We also suggest extending the work to include a lesion detection performance study to assess whether any difference exists for anode-cathode orientation. Given the limited data collected in our study the results should be treated with caution.

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