AP versus PA positioning in lumbar spine computed radiography: image quality and individual organ doses

Davey, Enda. BSc(Hons)

England, Andrew. BSc(Hons), PgCert, MSc, PhD

Directorate of Radiography, University of Salford, Manchester,

United Kingdom.

Correspondence to:- Dr Andrew England, Directorate of Radiography, University of Salford, Allerton Building, Frederick Road, Manchester, M5 4WT, United Kingdom. Tel: +44 (0)161 2950703 (a.england@salford.ac.uk)

ABSTRACT

Purpose: Radiological imaging examinations must be optimised in order to ensure that the radiation dose is kept as low as reasonably possible (ALARP). The aim of this study was to compare anteroposterior (AP) and posteroanterior (PA) projections of the lumbar spine, at various kVp increments, in order to establish optimum parameters.

Methods: An anthropomorphic phantom was imaged in both the AP/PA projections and at various kVp increments. Acquisitions were undertaken using a Wolverson Acroma X-ray unit and processed using an Agfa computed radiography (CR) unit. The entrance surface dose was recorded and converted to effective and organ doses using PCXMC 2.0 software. Five observers were then asked to evaluate the images, using a two-alternative force choice (2AFC) approach and a scale based on EC guidelines.

Results: The PA projection lowered the mean effective dose by 19.8% and also the mean absorbed dose to the stomach (70.4%), colon (61.1%), remainder tissues (33.2%), ovaries (7.3%) and testes (15.9%). However, this was at the expense of slightly inferior image quality, not statistically significant. For AP projections, a higher kVp is a further option for dose reduction.

Conclusion: Dose optimisation requires the production of an image that is acceptable for the purpose intended. Based on ALARP, and when taking into consideration the dose reductions in this study, it may now be time to routinely use PA projections when imaging the lumbar spine. The use of a higher kVp should also be considered as an option but would be more useful for AP projections.

Introduction

Lumbar spine radiography is classified as a relatively high dose examination which irradiates the radiosensitive reproductive organs of both males and females. Radiographic imaging of the lumbar spine accounts for 2.1% of all conventional X-ray examinations and 2.2% of the collective dose within the United Kingdom (UK) (1). One simple but effective method of radiation dose reduction is the replacement of the traditionally performed anteroposterior (AP) projection with the posteroanterior (PA) projection. Martin (2007), in a recent review of the literature, found evidence that PA projections are often favoured over an AP projection on occasions where radiosensitive organs are lying closest to the anterior surface of the body (2). Despite this it is still common practice for the majority of UK departments to perform lumbar spine examinations using the AP position.

A preference for AP positioning comes from the fact that positioning the spine closer to the image receptor minimises magnification and distortion (3). Previous research has suggested that although PA projections do demonstrate increased magnification this is generally considered to be significant enough to drastically affect the quality of the resultant image (4). Tsuno and Shu (1990) established that PA projections of lumbar vertebrae had less shape distortion when compared to an AP with a further advantage that the PA delivered a lower radiation dose to radiosensitive organs (5). More recently, Brennan and Madigan (2000) confirmed that a PA technique dramatically reduces the entrance surface dose (ESD) by up to 38.6% in female patients. Further phantom based experimental work by Brennan and Madigan highlighted that the internal dose can be reduced by up to 38.9%, with no significant decreases in image quality (4). The work by Brennan and Madigan does, however, carry limitations. At the time of their study it was not possible to compare

effective doses since conversion coefficients were not available. Theoretically, using a PA projection favours radiation dose reductions since the abdominal organs are located further away from the X-ray beam entrance. To understand this further individual organ dose calculations are needed, however, to the authors' knowledge no study has specifically examined radiation dose reductions to the stomach, colon or remainder tissues, which are now classified as the three most sensitive tissues directly irradiated during an AP lumbar spine projection (6).

Further dose optimisation may be possible by increasing the energy of the X-ray beam. As kVp increases X-rays become more penetrating and are more likely to reach the image receptor rather than being attenuated within the patient. This results in reduced patient radiation dose, however, at higher beam energies there may be a resultant negative impact on image quality. When using film-screen the European Commission has issued guidance for the selection of appropriate beam energies for AP/PA projections (75-90 kVp) (7). However, studies have demonstrated that higher kVp values than those recommended by EC can be implemented without significant detrimental effects to image quality (8, 9). Doherty et al. (2003) demonstrated that an effective dose reduction of 29.9% for AP lumbar spine projections was possible when using higher beam energies (8). In the same study image quality was reduced by 18.3% but all images produced were still considered diagnostically acceptable.

The aim of the current study was to compare AP and PA projections of the lumbar spine, at various kVp increments, using computed radiography (CR), in order to establish the optimum parameters for this radiographic examination.

Material and methods

Imaging equipment and phantom

The study was conducted in a university imaging department using a Wolverson Acroma X-Ray unit (Wolverson X-ray Ltd, Willenhall, UK) with a Varian 130 HS X-ray tube (Varian Medical Systems, Palo Alto, CA) with an inherent filtration of 3 mm aluminium. An Agfa (Agfa-Gevaert, Mortsel, Belgium) 35 x 43 cm computed radiography (CR) image receptor was used for acquisition and images were processed using an Agfa CR 35-X digitiser with a spatial resolution of 10 pixels/mm and a grey scale resolution of 12 bits per pixel. All exposures included the use of a 10:1 reciprocating grid with (40 line/cm frequency) and a broad focal spot size of 1.2 mm (maximum dimensions 1.7 mm by 2.4 mm). Equipment quality assurance testing, in line with IPEM 91 (10), was performed prior to image acquisition which included an assessment of voltage accuracy, which was found to be within tolerance.

An anthropomorphic RS102 female PIXY (Radiology Support Devices, Long Beach, CA) phantom (156 cm tall, 48kg weight) was used for all image acquisitions. Formal university ethical review was not required since all acquisitions were on phantoms and within an experimental protocol.

Phantom positioning

A fixed source-to-image-distance (SID) of 115 cm was used together with automatic exposure control (AEC) using the central chamber. A tube potential of 75 kVp was selected and when combined with the above factors allowed the production of a reference image that was consistent with typical clinical imaging parameters. These exposure parameters

were established following a brief consultation with four local departments and after reviewing recommendations in the EC guidelines (7).

For all exposures the collimated field was adjusted to include the twelfth thoracic vertebra superiorly and the sacro-iliac joints inferiorly. The use of fixed collimation was essential in order to ensure it did not impact on phantom radiation dose or image quality, as the amount of scattered radiation varies when different volumes of tissue are irradiated (11). Anatomical markers were purposefully omitted from the imaging process to avoid bias as this could enable observers to determine the orientation of the projection.

For AP projections the phantom was positioned supine in accordance with standard radiographic technique (12), ensuring that the median sagittal plane was coincident with, and at right angles to the midline of the tabletop and bucky. The vertical central ray was centred towards the midline of L3 at the level of the lower costal margin.

For PA projections the phantom was positioned prone. In order to ensure the centring point was replicated, masking tape was applied to and wrapped around the torso of the phantom with its superior border directly at the level of the horizontal line of the AP centring point. The diameter to the left and right of the vertical line in the AP projection was measured using a ruler and then replicated in the PA orientation. Collimation was once again fixed and consistent with the AP projection.

Experimental technique

For each projection (AP/PA) the kVp increment was varied by 5 kVp from 75 to 110 kVp. In order to ensure continuity and minimise error the same imaging plate was used throughout

the study. Image acquisition was repeated three times for each kVp increment and at each orientation (AP/PA).

Dosimetry

Entrance surface dose (ESD) was measured using a Mult-O-Meter 407L (Unfors Instruments, Billdal, Sweden) positioned on the phantom at the centre of the collimated field. In order to increase the accuracy of dose measurement the ESD was measured three times and an average value was calculated. ESD measurements were converted to effective dose (ED) estimations using the Monte Carlo dosimetry simulation software PCXMC 2.0 (STUK, Helsinki, Finland). PCXMC is a computer program for calculating patients' organ doses and effective doses in medical x-ray examinations (radiography and fluoroscopy) using Monte Carlo modelling (13). The doses are calculated in 29 organs and tissues and the program calculates the effective dose with tissue weighting factors from the ICRP 103 publication (14).

The mean effective (ICRP 103, 2007) and absorbed doses to the stomach, colon and remainder tissues were recorded, as these are classified as the three most sensitive tissues irradiated during an AP lumbar spine radiography (6). Absorbed doses to the ovaries and testes were also recorded in order to compare findings between the two projections.

Image quality assessment

The evaluative panel consisted of five final year radiography students, who at the time of the study were < 6 months away from qualification. Each of the raters had previously participated in visual grading analysis (VGA) experiments and were deemed sufficiently experienced to undertake image analysis. Images were assessed under standardised

viewing conditions using two EA243WM MultiSync (NEC Corporation, Tokyo, Japan) 2.3 megapixel monitors. Ambient lighting, less than 50 lx (15) and the distance of the chair from the monitor were kept constant. Details of how the images were acquired were blinded to all raters.

Two-alternative forced choice (2AFC) software (16) was used to present the acquired images to the raters. This allowed the presentation of the reference image concurrently alongside the comparator images on the monitor but in a randomised order. A further advantage of this software was that it prohibited zooming and window width or level adjustments. Previous research has reported on the benefits of 2AFC in that it permits easier detection of differences in quality when compared to an absolute method where observers are asked to evaluate images utilising criteria without a comparison reference image (17). Raters were invited to evaluate the images using image quality criteria adapted from the Guidelines from the Commission of European Communities (CEC)(Table 1)(7). Definitions regarding the visibility of anatomical structures were compared to the reference image and evaluated using a 5 point Likert scale (Table 2). These guidelines were deemed appropriate for VGA and have been successfully employed in a range of previous studies (4, 9). Weighting factors previously employed by Brennan and Madigan (4) were applied to each anatomical criterion based on their level of importance as outlined in Table 1. In the report by Brennan and Madigan (4) weighting factors had been established by three clinicians, with a minimum of five years clinical experience. Brindhaban et al. (2005) also employed weighting factors in their research in order to account for the significance of visually sharp reproduction of anatomy compared to simple reproduction (9).

[INSERT TABLES 1 & 2 – HERE]

Finally, magnification was assessed and compared between the AP and PA projections using the software program Image J (National Institute of Health, Bethesda, MD). This was assessed in the same manner as that employed by Heriard, Terry & Arnold (1993) who determined the magnification differences between the two projections by measuring the transverse diameter of the vertebral body of L3 (16).

Statistical analysis

All data were transferred into a Microsoft Excel (Microsoft, Redmond, Washington) spreadsheet. For image quality assessments weighting factors were applied in order to calculate the total image scores for each image, at kVp, for each orientation. Subsequent statistical analysis was performed using SPSS Statistics 20 (IBM Corp, Armonk, NY), in order to assess differences in image quality scores between raters using an intra-class correlation co-efficient (ICC). The Shapiro Wilk test was used to confirm the approximate distribution of the data. If the data was approximately normally distributed ($P \geq 0.05$) then they were summarised as mean values plus or minus their respective standard deviations. If the data were not normally distributed ($P < 0.05$) then median values together with the inter-quartile range (IQR) were reported.

Results

Image quality

Total (weighted) image quality scores for both the AP and PA projections, for each kVp increment, are presented in Table 3 and Figure 1. An image quality score of 48 was considered equal to the reference image after weighting factors were applied.

[INSERT TABLE 3 & FIGURE 1 – HERE]

The reliability of individual image quality scores between raters must be considered. The ICC value for the five students was 0.85 (95% confidence interval, 0.72 to 0.94). An ICC value of 0.85, according to Rosner (2011), indicates very good reproducibility (18).

Magnification

The transverse diameter of the L3 vertebral body was 25 mm and 27 mm for AP and PA projections, respectively. As a result the PA projection demonstrated a magnification factor of 1.08 times greater than the AP.

Dosimetry

From an evaluation of the dosimetry calculations (Figures 2 – 5) it is evident that the PA projection results in a significantly reduced effective dose for all tube potentials studied. The mean ED reduction was 19.8% (range, 17.9 to 22.8%). As expected a trend was noted where kVp increases the ED for both orientations was seen to progressively decrease.

[INSERT FIGURES 2 - 5 – HERE]

Individual organ/tissue doses were compared by kVp and between the AP and PA projections. It was evident (Figure 3A) that the PA projection reduced the absorbed dose to the stomach by a maximum 74.0% at 75 kVp and a minimum of 66.9% at 110 kVp. It was also clear that the PA projection reduced the absorbed dose to the colon (Figure 3B). The maximum dose reduction (68.3%) was seen at 70 kVp with a minimum dose reduction of 56.6% seen at 110 kVp. The PA projection also reduced the absorbed dose to the remainder tissues (Figure 3C). The maximum reduction in absorbed dose was again experienced at 75 kVp (36.0%) with a minimum reduction of 29.3% at 110 kVp.

With respect to gonadal dose, the PA projection also reduced the absorbed dose to the testes by a maximum of 24.7% at 70 kVp a minimum of 8.7% at 80 kVp. The absorbed dose to the testes appears to increase with an increase in tube potential (Figure 4A). The PA projection resulted in a reduction in the absorbed dose to the ovaries of 22.8% at 70 kVp (maximum) and 3.7% at 110 kVp (minimum) (Figure 4B).

Figure 5 demonstrates the relative (percentage) absorbed dose reduction to the stomach, colon, remainder tissues, ovaries and testes across each kVp. Figure 5 clearly indicates that the most significant dose reduction is to the stomach, followed by the colon and remainder tissues.

Discussion

The results of this study demonstrate that by switching to a PA projection a mean reduction in effective dose of 19.8% is achievable (range = 17.9% to 22.8% across the 70 kVp to 110 kVp range). Similar reductions (mean, range) in the absorbed dose to the stomach (70.4%, 66.9% to 74.0%), colon (61.1%, 56.6% to 68.3%), remainder tissues (33.2%, 29.3% to 36.0%), testes (15.9%, 8.7% to 24.7%) and ovaries (7.3%, 3.7% to 22.8%) are also achievable. Dose reductions can be explained by the fact that the radiosensitive organs are closer to the anterior surface than the posterior surface and, therefore, in the PA projection they lie further away from the beam entrance surface when compared to an AP projection. As previously stated Tsuno and Shu (1990) confirmed this and added that the abdominal structures are well protected by the filtering process from the posterior musculature and spine (5).

Findings from this study are novel in that comparisons between projections, with respect to dose reductions, for the stomach, colon and remainder tissues have not previously been reported when using AECs. Previously ED had not been directly calculated for the PA projection due to a lack of dose conversion coefficients (4). Chaparian and colleagues (2014) have attended a comparison of ED between the AP and PA projections, however, their study neither utilised an AEC nor included the use of a phantom or patient (19). With respect to the absorbed dose to the ovaries and testes findings from this study are not consistent with the magnitude dose reductions reported by Heriard et al., (1993) (20). They reported, based on film-screen systems, that when using the AP projection there is a 216% increase in dose to the ovaries and 900% for the testes. A thorough comparison between findings from our study and those from Heriard et al. are difficult since there were variations in the study methodology, in particular the dosimetry techniques. Heriard et al. utilised TLDs and applied a reduction of 50% to the set mAs for the PA projection when compared to the AP. Justification for this was that the authors sought to take into account the compression effect of the abdomen from a PA projection. We did not utilise this approach in our methods, we used a rigid anthropomorphic phantom and as such the AP thickness of the abdomen did not change. It is likely that for actual patients tissue displacement would further affect the radiation dose for PA lumbar spine radiography. Work by Brennan and Madigan (2000) suggests a reduction of 1.8 cm in the AP diameter of the abdomen when the patient was moved from supine to a prone position. This reduction in body part thickness permits the implementation of lower mAs values since a thinner body part requires less radiation exposure in order to produce a diagnostically acceptable image (21). In order to confirm our findings and demonstrate further dose reductions from compression a clinical study involving patients is required.

Dose reduction methods for all abdominal organs are essential since they cannot be shielded. Similarly the use of lead rubber shielding for the testes and ovaries is often omitted due to difficulties with accurate placement (22), especially during the lateral projection. Poor positioning of gonad protection can create artefacts on images which may obscure important anatomical data or pathology and result in a repeat examination being required (3).

In our study, when increasing the X-ray beam energy both the ESD and ED reduced (AP and PA). This trend has also been reported by Doherty, O'Leary & Brennan (8). With respect to individual organ doses an unexpected trend was noted for the testes. For AP projections, at higher beam energies the absorbed dose to the testes began to increase rather than decrease. A possible explanation for this may be the fact that the testes are situated outside of the collimated field during an AP lumbar projection (23). At higher beam energies this increase in testicular (absorbed) dose may be due to the greater intensity and surrounding penetration of scattered radiation. This highlights an area which would warrant further investigation. Dose calculations in this study were based on the PCXMC software. PCXMC provides an option for calculating patients' organ doses and the effective dose. It has several advantages which should be noted. Firstly, as Servomaa and Tapiovaara (1998) reported, dose calculations with PCXMC agree well with doses calculations provided by the National Radiation Protection Board (24). Computation of organ doses can be undertaken for patients of different ages and sizes in freely adjustable X-ray projections and can take into consideration other examination parameters (25). There are, however, limitations which include possible mismatches between the irradiated organs, e.g. if the field size is correct but the irradiated organ volumes may be incorrect (26).

A total of 15 images were assessed against the reference image by five student raters. A score of 48 was considered equal to the reference image once weighting factors were applied. Scores between 31 and 47 signified "slightly" decreased image quality. The image quality scores obtained in this investigation demonstrate that observers generally higher image quality scores for AP projections, irrespective of the kVp. When evaluating paired kVp images (AP and PA) there was a general trend of overlapping error bars (Figure 1). It is, therefore, questionable as to whether there were true differences in image quality between projections. A trend was observed of decreasing image quality when increasing the kVp, this affected both projections. There is, however, an explanation as to why the AP projections may have been visually preferable to a PA. The raters used in this study have significantly greater experience in viewing AP projections (normal clinical practice) than PA. When using 2AFC methodology it plausible that minor differences in image quality could be the result of familiarity with a projection. A further consideration is magnification; image quality may have been scored lower for PA projections because of magnification. Post evaluation comments from the raters revealed that the appearances of the sacral foramina varied considerably between the AP and PA projections. Magnification should, however, should have had a minimal effect on image quality. The PA projection demonstrated a magnification factor of a mere 1.08 times greater than the AP projection. This is broadly in line with previous research which established a magnification factor of 1.03 (20) and also suggested a minimal effect of visual (perceptual) image quality. Our findings regarding the AP projection were largely supported in the work by Brennan & Madigan (2000), again no statistically significant differences in image quality scores between projections were found (4). In our individual analysis of all 40 PA projections there were only three occasions where PA projections were marked superiorly or equal to the AP projection (for paired kVp

increments). With regards to the reference image, only two PA projections were assigned a score greater than 48. However, since the principle of optimisation advocates acceptable rather than optimal image quality, in some cases this "slight" reduction in image quality may well be considered acceptable when balanced against the significant ED and individual organ dose reductions. The criteria and definition of an "acceptable" image would require further input and expertise from experienced radiologists, reporting radiographers and referrers.

When comparing to the literature it must be acknowledged that previous studies comparing image quality between the AP and PA projections relied on film-screen with evaluations on light boxes. It may well be that more subtle differences in image quality are perceivable under digital viewing conditions, such as those employed in this investigation and that this may explain minor differences between acquisition modalities.

With respect to increasing beam energies, no significant decreases in mean image quality scores were noted for the AP projection until images were acquired in excess of 100 kVp. A 12.1% reduction in image quality was noted at 100 kVp with respect to the reference image, however, this dropped by 30.8% and 41.3% at 105 kVp and 110 kVp, respectively. This would suggest that beam energies above those recommended by EC may be utilised (AP projection) but that the upper limit should be below 90 kVp. The compromise in image quality at higher beam energies may well be diagnostically acceptable depending on the nature of imaging. For example, based on our opinion, follow up imaging of a lumbar spine fracture may not necessarily require the same level of radiographic detail as an image evaluating a suspected fracture (primary diagnosis). This may also be the case for serial investigations of scoliosis (27) or the monitoring of other conditions (28).

A reduction in image quality at higher kVps is to be expected in part due to reduced contrast as a result of the increased scatter. A further influencing factor is likely to be the reduction in signal to noise ratio due to the decreased mAs determined by the central AEC chamber as the kVp rises (21). With the widespread introduction of digital radiography systems the traditional relationship between tube potential and image contrast (film-screen systems) has been redefined. It is possible that if this investigation were to be repeated, using digital radiography, then the decrease in image quality seen at kVps in excess of 100 may potentially be less significant.

There are further factors that must be considered prior to implementing any changes to standard radiographic positioning. The PA position of a patient for lumbar spine radiography will require the careful consideration of the condition of the patient. It is likely to be practically unsuitable for patients following trauma, those with severe abdominal pain, serious respiratory difficulties or mobility problems. Patient comfort is also another factor; intuitively an AP position is likely to provide a more comfortable patient position in which to undertake a radiographic image. If a PA position is to be undertaken then due consideration of any steps that could help minimise patient discomfort should be considered.

It must be acknowledged that differences in collimation field sizes and X-ray beam geometries between projections will have an impact on the radiation dose. Differences in the beam geometries were modelled using the PCXMC software and form a strength of this study. Differences in the beam geometries could also have image quality benefits when faced with pathology. Depending on the curvature of the spine it is possible, if tested on patients, that the visibility of the inter-vertebral disc spaces could be improved on a PA

projection when compared with AP. This feature could not have been tested when using a single rigid anthropomorphic phantom.

The effects of differences in collimation were not suited and as such form a limitation. Collimation will vary between radiographers and have some dependence on individual patient parameters e.g. size. The ability of a radiographer to correctly collimation may depend on the position. We would suggest that this may result from the availability of different anatomical landmarks and differences in the understanding of magnification.

Conclusion

Results obtained in this investigation demonstrate that the PA projection dramatically reduces the effective dose (up to 20%), and absorbed doses to the stomach (70.4%), colon (61.1%), remainder tissues (33.2%), ovaries (7.3%) and testes (15.9%), when compared to the AP projection. This may be at the expense of a minor reduction in image quality (not statistically significant). This may further be considered acceptable when balanced against the significant dose reduction and, therefore, despite this the PA projection may be considered as the preferred option when undertaking lumbar spine radiography. The optimum beam energy will depend on the projection, for AP projections a higher energy beam can provide a further means optimising lumbar spine imaging examinations.

LEGENDS FOR FIGURES/TABLES

Figure 1. Mean image quality scores for AP and PA projections across a range of tube potentials. E*rror bars demonstrate the standard deviation for the image quality scores.*

Figure 2. An illustration of the entrance surface dose (A) and effective dose (B), for each kVp increment, across both AP and PA projections. *Error bars denote the standard error for each measurement.*

Figure 3. An illustration of the absorbed doses for the stomach (A), colon (B) and remainder tissues (B), for each kVp increment, across both AP and PA projections. *Error bars denote the standard error for each measurement.*

Figure 4. An illustration of the absorbed doses for the testes (A) and ovaries (B), for each kVp increment, across both AP and PA projections. *Error bars denote the standard error for each measurement.*

Figure 4. An illustration of the percentage change in absorbed dose for each organ, for each kVp increment, across both AP and PA projections.

Table 1. Image Quality Criteria used in the VGA (Adapted from CEC guidelines, 2006).

Table 2. Likert scale questions used to compare acquired images.

Table 3. Image Quality Score for the AP and PA projections.

Table 4. Demonstrates the percentage ED and absorbed dose reductions achieved through the implementation of the PA projection.

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Table 1. Image quality criteria used in the VGA (adapted from CEC guidelines, 1996)

Item	Anatomical image criteria	Weighting factor
1.	Visually sharp reproduction of the upper and lower vertebral endplates	2
2.	Visually sharp reproduction of the pedicles	2
3.	Reproduction of the intervertebral joints	3
4.	Reproduction of the spinous and transverse processes	3
5.	Visually sharp reproduction of the cortex and trabecular structures	3
6.	Reproduction of the adjacent soft tissues, particularly the psoas shadows	1
7.	Reproduction of the sacro-iliac joints	2

Table 2. Image quality criteria used to compare acquired images

Score	Image quality options
1	Significantly less than reference image
2	Slightly less than reference image
3	Equal to reference image
4	Slightly better than reference image
5	Significantly better than reference image

Table 3. Image quality score for the AP and PA projections.

kVp	AP Projection			PA Projection		
	Mean	**SD**	**% change from reference image**	**Mean**	**SD**	**% change from reference image**
75				41.6	1.1	-13.3
80	58.2	5.8	+21.3	45.4	5.8	-5.4
85	52.4	7.7	+9.2	40.2	3.5	-16.3
90	51.0	5.7	+6.3	38.2	5.0	-20.4
95	46.0	4.3	-4.2	37.2	0.8	-22.5
100	42.2	5.9	-12.1	34.8	3.3	-27.5
105	33.2	0.8	-30.8	28.0	2.1	-41.7
110	28.2	3.1	-41.3	25.4	2.6	-47.1

SD, standard deviation. A score of 48 is equivocal to the reference image (shaded area).

Table 4. Demonstrates the percentage ED and absorbed dose reductions achieved through the implementation of the PA projection.

kVp increment	ED	Stomach	Colon	Remainder tissues	Ovaries	Testes
70	22.8%	72.2%	68.3%	34.4%	22.8%	24.7%
75	21.3%	74.0%	64.6%	36.0%	8.7%	14.9%
80	20.6%	72.6%	63.1%	35.0%	6.6%	8.7%
85	20.1%	71.5%	61.7%	34.1%	5.6%	11.2%
90	19.6%	70.4%	60.5%	33.3%	5.2%	14.4%
95	19.2%	69.5%	59.3%	32.6%	4.8%	16.7%
100	18.7%	68.6%	58.3%	32.1%	4.4%	17.8%
105	18.3%	67.7%	57.4%	31.6%	3.9%	17.9%
110	17.9%	66.9%	56.6%	29.3%	3.7%	16.6%
Overall (mean)	**19.8%**	**70.4%**	**61.1%**	**33.2%**	**7.3%**	**15.9%**

Figures are quoted in percentages. ED, effective dose. Remainder tissues include adrenals, extrathoracic region, gallbladder, heart, kidneys, lymphatic bodes, muscle, oral mucosa, pancreas, small intestine, spleen, thymus and either prostate(♂) or uterus(♀).

FIGURE 1

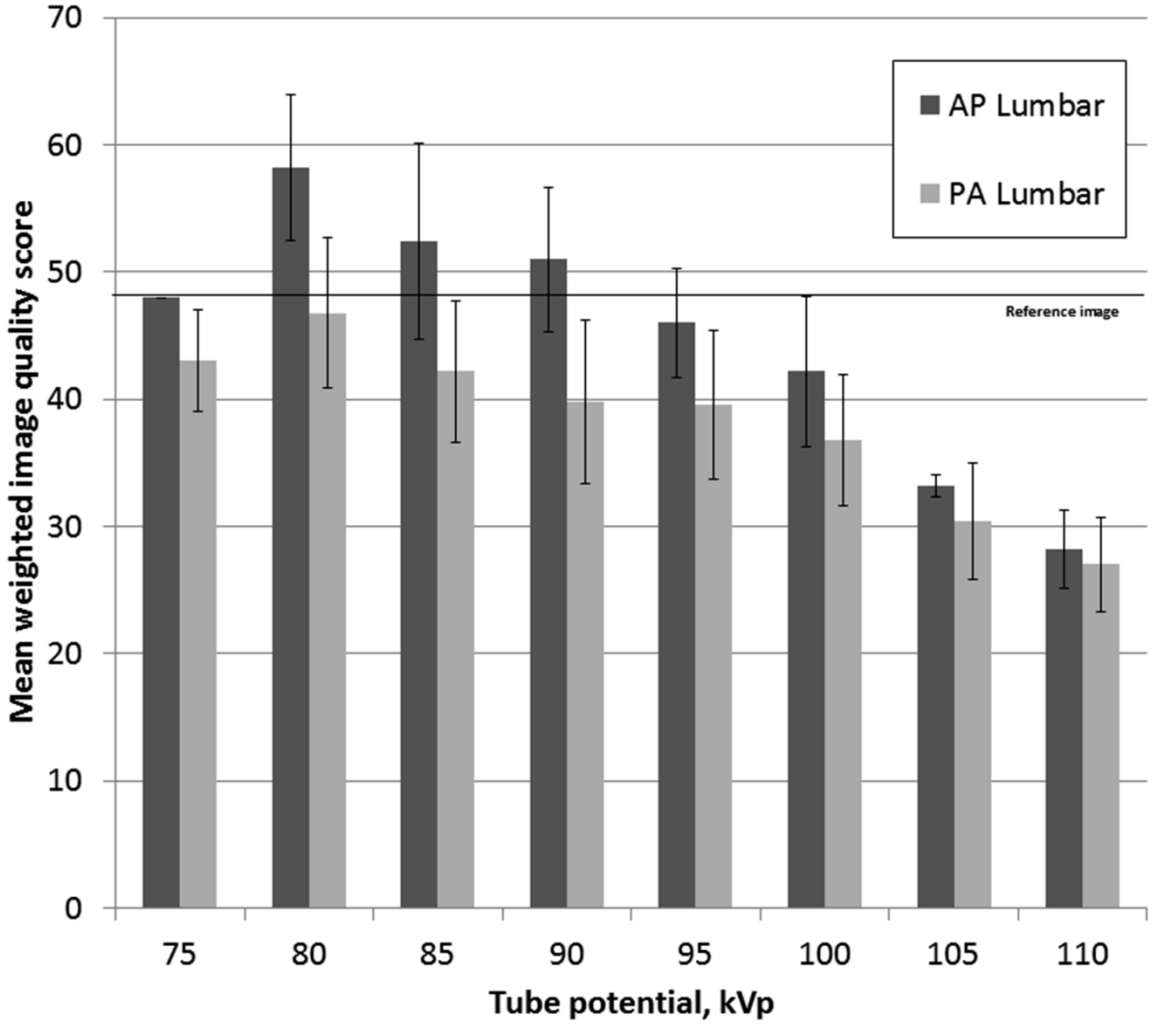
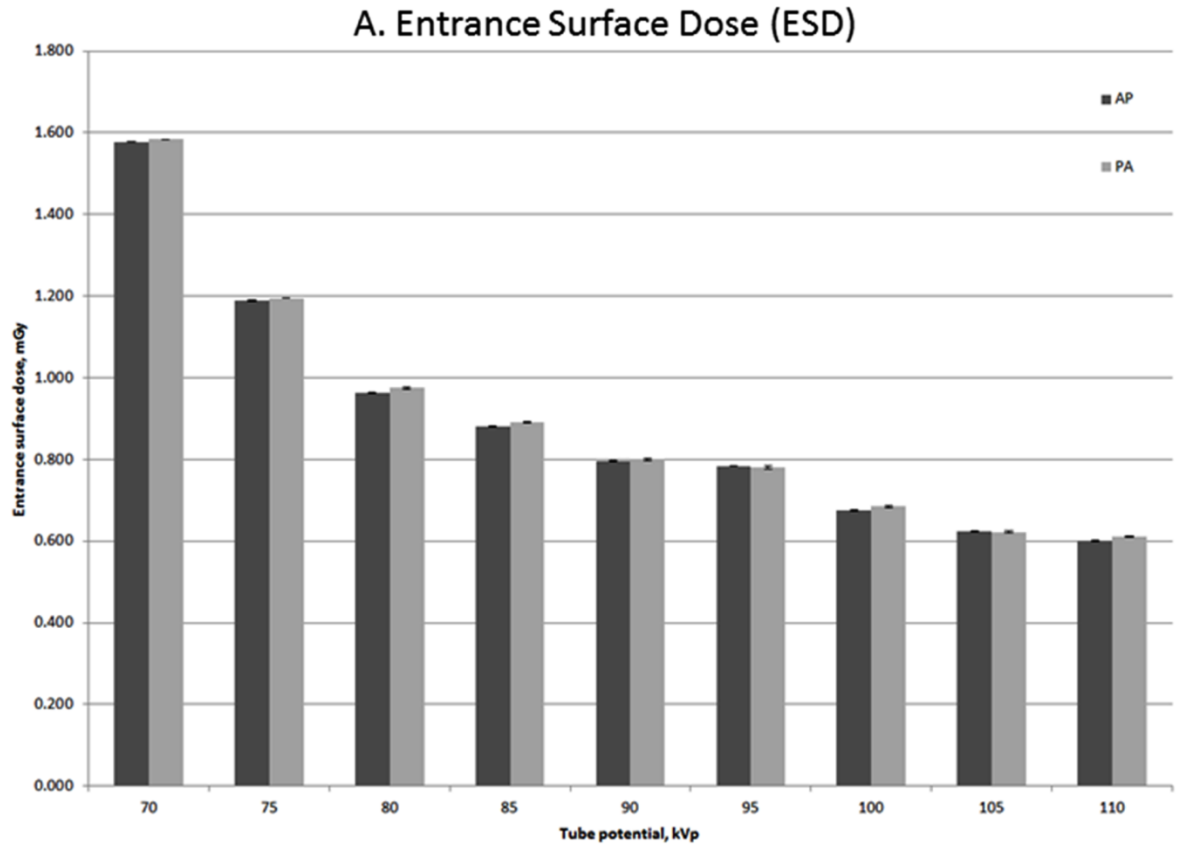

70
60
50
40
30
20
10
0
Mean weighted image quality score
AP Lumbar
PA Lumbar
Reference image
75
80
85
90
95
100
105
110
Tube potential, kVp

FIGURE 2


A. Entrance Surface Dose (ESD)
Entrance surface dose, mGy
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
AP
PA
70
75
80
85
90
95
100
105
110
Tube potential, kVp

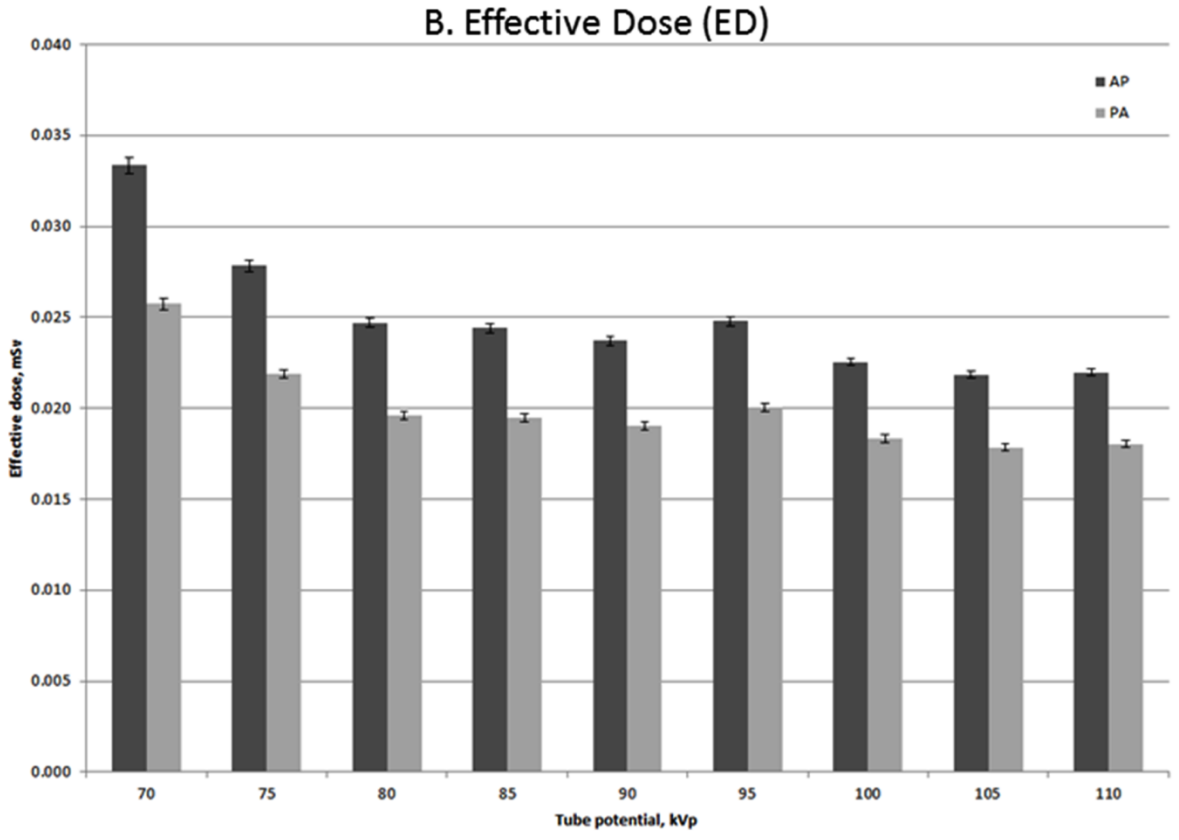
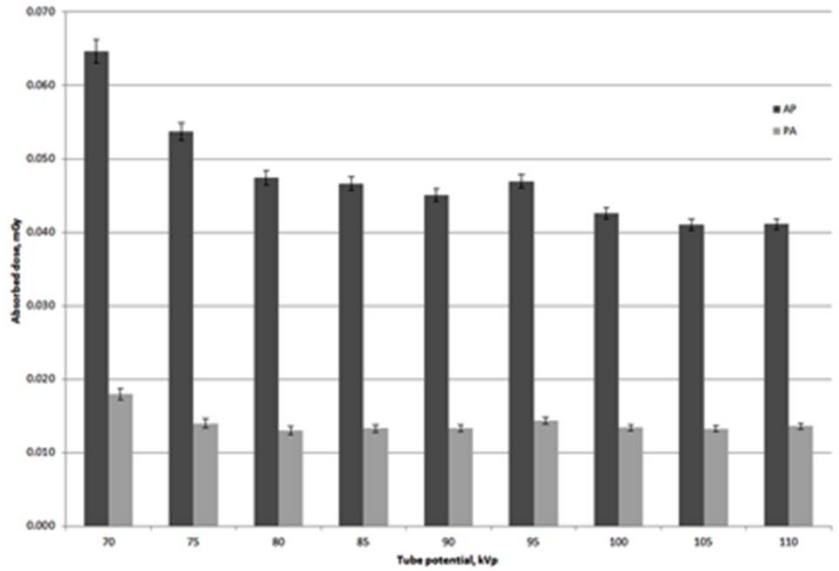
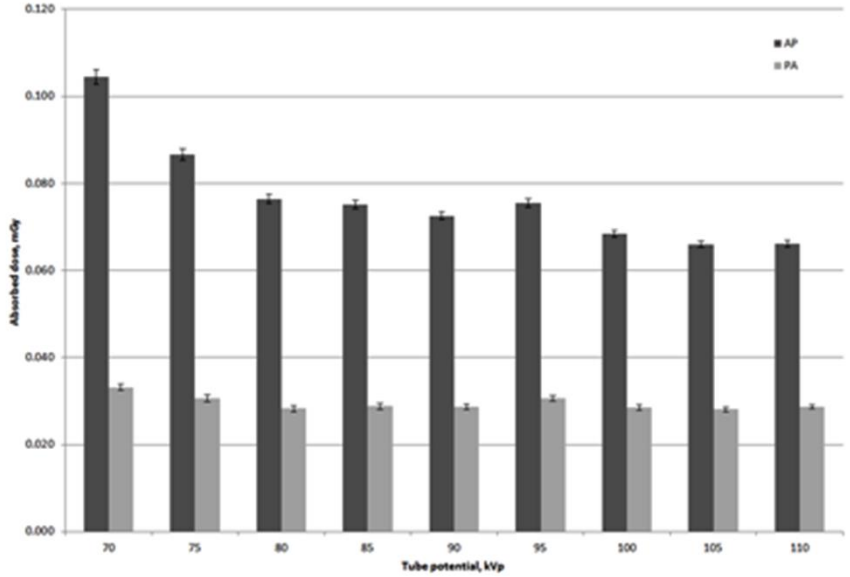

B. Effective Dose (ED)
Effective dose, mSv
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
AP
PA
70
75
80
85
90
95
100
105
110
Tube potential, kVp

FIGURE 3

A. Stomach



B. Colon



C. Remainder Tissues

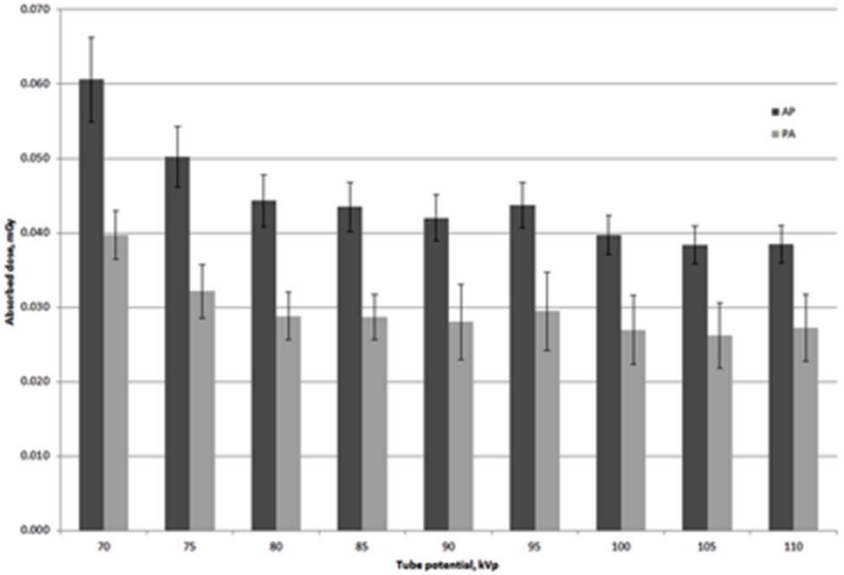
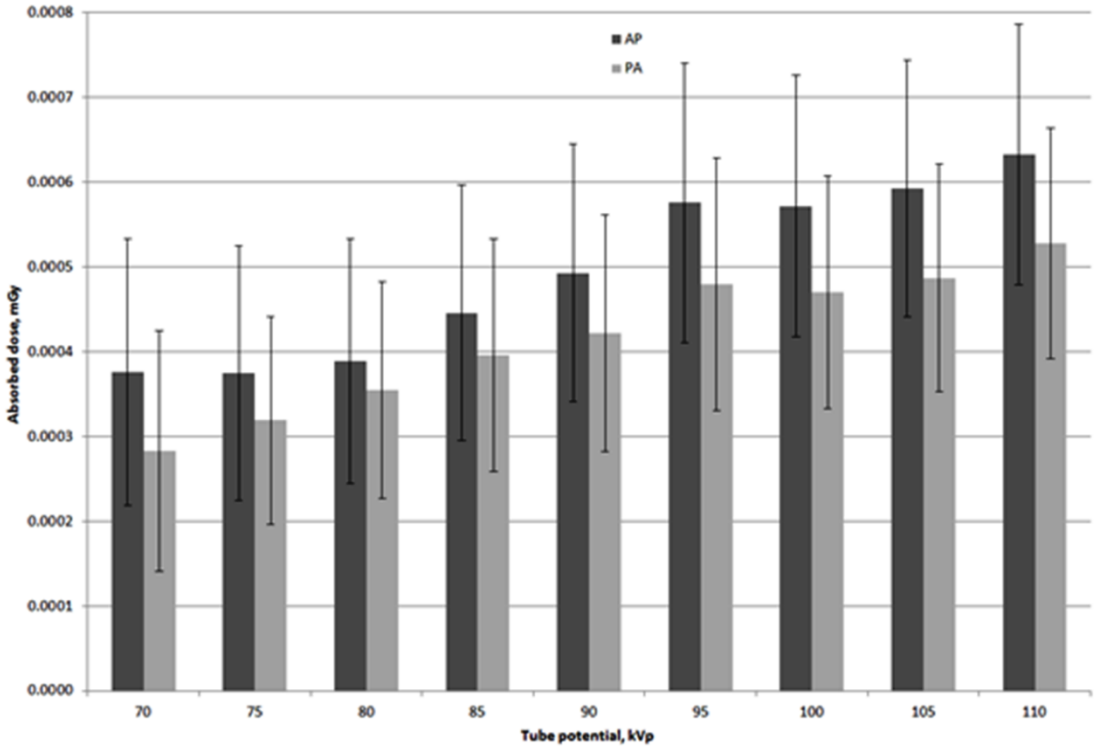


FIGURE 4

A. Testes



B. Ovaries

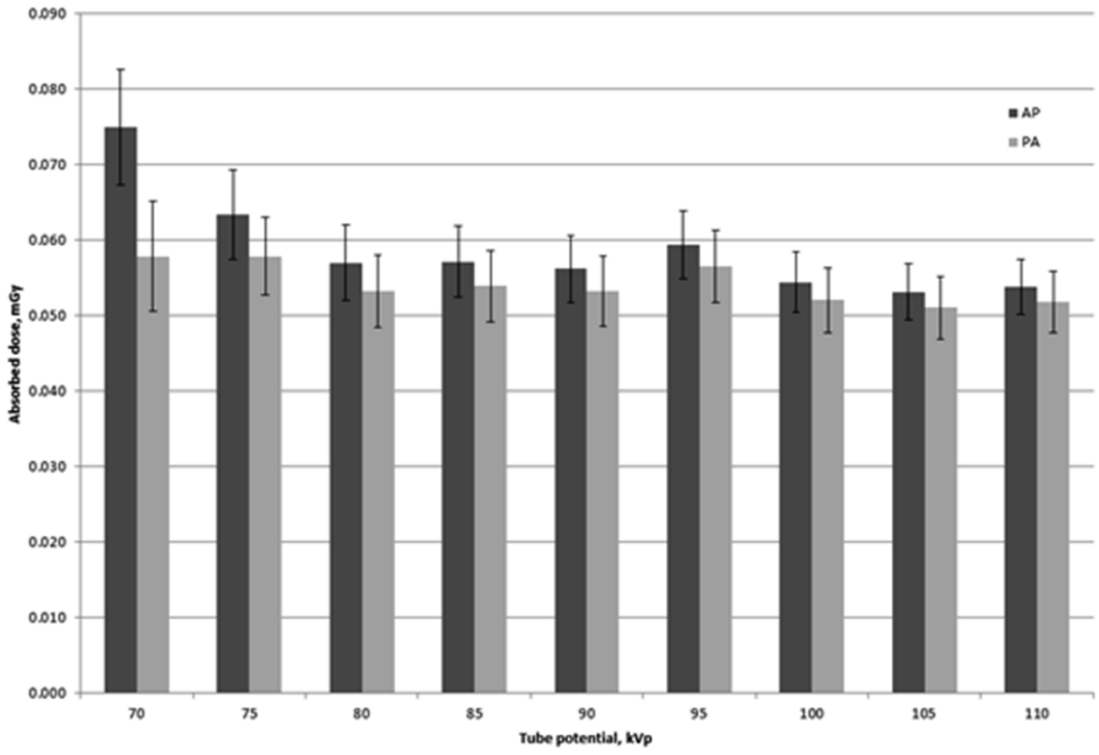
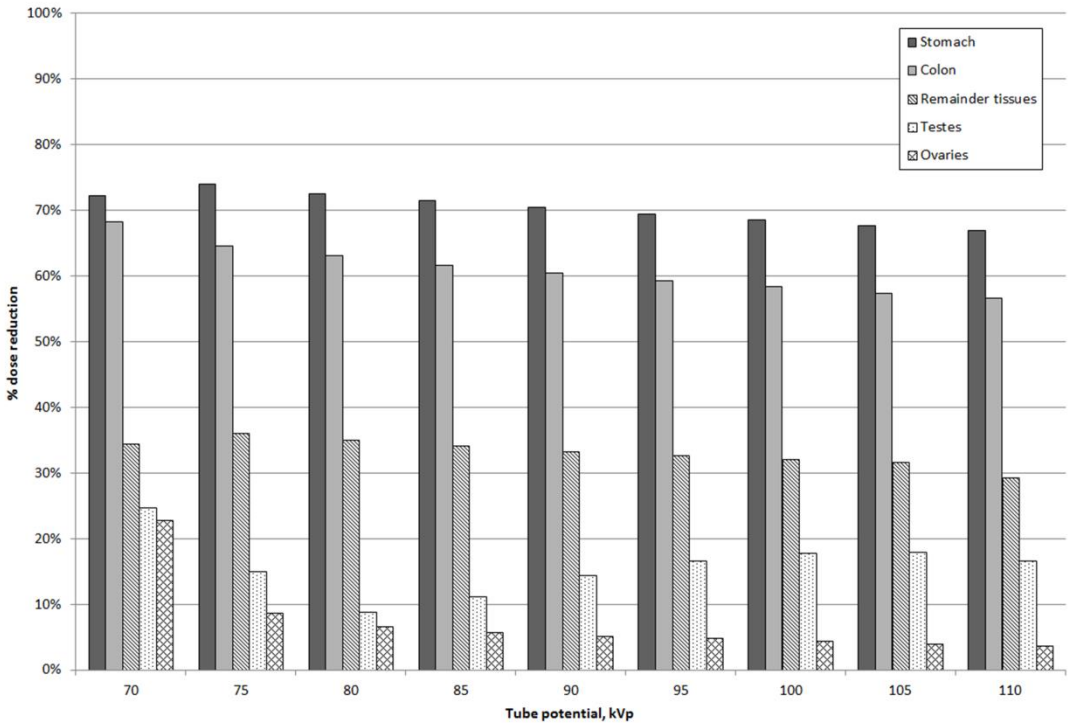


FIGURE 5


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% dose reduction
70
75
80
85
90
95
100
105
110
Tube potential, kVp
Stomach
Colon
Remainder tissues
Testes
Ovaries