STUDENT NAME: Gina Nirula

PROJECT TITLE:
Assessing Digital Tomosynthesis for Paediatric Sacroiliac Joint Imaging

STUDENT'S NAME: Gina Nirula **SUPERVISOR'S NAME:** Dr. Idris Elbakri

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SUMMARY:

Objective: To assess the use of digital tomosynthesis (DT) as an alternative imaging modality to radiography for the imaging of paediatric sacroiliac (SI) joints.
Methods: Three anthropomorphic pelvis phantoms were imaged using DT at three dose levels: equivalent to the dose incurred in radiography (tube current-time product of 0.32 mAs), almost double the dose incurred in radiography (0.63 mAs) and the default dose setting of the DT system (1.6 mAs). Radiographs of the phantoms were also acquired for comparison. Six radiologists were asked to compare DT images to radiographs and rate DT as either better, the same or worse than radiography.
Results: An exact Chi-square test was performed on the data and showed no significant difference in preference for DT between the three phantoms (exact p-value = 0.3389). There was a significant difference in preference for DT between radiologists as well as between the three dose settings (exact p-value = 0.0095 and 0.0001, respectively). At a mAs of 0.32 there is no clear preference for DT, however as mAs increases so does preference for DT.
Conclusions: DT shows promise as a possible imaging alternative to radiography, although at dose levels higher than radiography. DT may prove advantageous in SI joints imaging if it reduces the need for subsequent computed tomography imaging which is typically used when radiography yields equivocal results.

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Student's Signature **Supervisor's Signature**

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1. Introduction

There is increasing concern as to the adverse effects of the ionizing radiation used in diagnostic imaging. In particular, research has been focused on determining the risk of radiation-induced cancers by using data gathered from Japanese atomic bomb survivors [1-3]. These studies have demonstrated a greater incidence of leukemia and various solid cancers. The above mentioned data has also been extrapolated and results suggest risk is present at the lower radiation doses used in medical imaging [1, 4]. The ionizing radiation used in diagnostic imaging carries a risk of causing tissue damage which may lead to both stochastic and deterministic effects like cancer and cataracts. These potential harmful effects are especially worrisome regarding the paediatric population as they are at higher risk due to their longer life expectancy at the time of exposure and the fact that their immature, differentiating cells are more vulnerable to the effects of radiation than adult cells [1, 5].

Diagnostic imaging studies such as computed tomography (CT) and digital radiography (DR) are cornerstones in modern patient care. CT accounts for a large portion of the medical imaging radiation dose. Of all radiological examinations 9% are CT, yet it is responsible for 47% of the medical imaging dose [6]. Both CT dose and CT use continue to increase [1, 3, 5] and patients may be subjected to several scans throughout the progression of their care.

Alternative methods of imaging are one way to reduce patient dose. Recently digital tomosynthesis (DT) has been introduced and explored for a variety of applications, such as angiographic, dental, breast, chest and orthopaedic imaging. [7-9]. At our institution DT has also been investigated for its use in imaging paediatric facial bones [10]. DT uses standard x-ray equipment to take a series of low dose projection images as the x-ray tube moves over a designated path. Section images are reconstructed using software into images with depth resolution. Although DT does not produce images of as high quality depth resolution as CT, its in-slice resolution can be better because of the high resolution detectors used [7]. Moreover, the sectional imaging provided by DT is acquired at much lower dose than CT. For example, the effective dose associated with DT for an adult chest examination is roughly 0.124 millisieverts (mSv) which is less than two percent of the dose associated with a thoracic CT exam. [9]

In DT, dose and image quality can be altered by varying parameters such as the tube potential (referred to as kilovoltage, or kV) and tube current-time product (in milliampere seconds, or mAs). The kV is the electrical potential applied to the x-ray tube, an increase in kV results in an increase in the penetration of the photons through the patient, which may reduce the radiation dose. However, an increase in kV also decreases the contrast of the image thus reducing image quality. The mAs is linearly related to dose and increasing it produces more photons, less noisy images, and thus better image quality at the cost of a higher dose.

Imaging studies of the sacroiliac (SI) joint (Figure 1) are used to diagnose infection or trauma in paediatric patients. At our institution (Health Sciences Centre) standard protocol dictates that patients receive a series of radiographs with three different views: posteroanterior (PA), an oblique view of the right SI joint and an oblique view of the left SI joint (Figure 2). The difficulty with this protocol is proper positioning of the patient for the oblique views as the anatomy of the SI joint differs from patient to patient. Thus it is challenging to position the patient optimally in order to achieve a complete view of each joint (Figure 3). Another factor interfering with the quality of the radiographs is the presence of overlying bowel gas and fecal material (Figure 4). If the radiologist is not confident in the radiographs because of poor positioning, overlying material or lack of information, the patient is imaged using other modalities such as bone scintigraphy, magnetic resonance imaging or CT - which carries with it a relatively high radiation dose of ten to twenty mSv [11]. The purpose of this project is to assess the use of DT for paediatric SI joint imaging. DT is promising for SI joint imaging for several reasons. Oblique views are not necessary with the depth resolution obtained with a single PA view. Clutter from overlying materials is also reduced. The dose from DT may be comparable to radiography and lower than CT. We hypothesize that DT will provide images of the SI joint that are preferred over conventional radiography at dose levels comparable to those obtained with radiography.

This report summarizes the methods and results of two studies. In 2011 we carried out a limited pilot study to investigate the feasibility of DT for SI joint imaging. We imaged one pelvis phantom. The data was too limited to carry out a thorough analysis. In 2012, we carried out a more comprehensive phantom-based investigation involving several imaging phantoms and image readers.

2. Materials and Methods

2.1 Pilot Study 2011

In order to determine the use of DT for the imaging of SI joints an anthropomorphic pelvis phantom was imaged while varying kV and mAS.

The anthropomorphic pelvis phantom used resembles a sixteen to eighteen year old adolescent and is bone encased in acrylic which has similar attenuation and scatter properties to human tissue (Figure 5). The DT images were acquired using the Definium^{TM} 8000 x-ray system (GE Healthcare, Waukesha, WI) with DT capabilities commercially known as VolumeRad^{TM} (Figure 6). Posteroanterior images of the pelvis phantom were taken at the default setting of 76 kV, 1.6 mAs, as well as with altered parameters (kV and mAs). We varied kV from 76 to 90 while letting the automatic exposure control (AEC) system set the mAs. The AEC system sets mAs according to the thickness of the patient; a higher mAs and thus higher dose is used for larger patients and vice versa for smaller patients. At higher kV, a net reduction in dose is expected because the x-ray beam is more penetrating. PCXMC 2.0 Monte Carlo software was then used to calculate the effective dose associated with each kV setting. In our study mAs was varied from 0.63 to 2.5, with 1.6 being the default setting.

Once all the images were acquired, they were shown in no particular order with no identifying information to three paediatric radiologists (with experience ranging from eight to thirty-nine years) and two radiology residents who rated each of them according to a specific scale (Figure 7). The rating scale involved assessment of the visibility of the articular margins of the joint in the anterior-superior, middle and posterior-inferior sections of the SI joint. The scale was based on the fact that the articular margins must be seen in all three parts of the joint for the imaging to be considered diagnostic.

2.2 Main Study 2012

The pilot study was limited because it was conducted with one imaging object. During the second term of this project, we acquired three anthropomorphic pelvis phantoms. The phantoms resembled a sixteen to eighteen year old adolescent and were made of bone encased in acrylic. The phantoms were of similar size, shape and weight and had no notable differences.

Based on the parameters varied in the pilot study we decided to only alter mAs. This is because kV has a fairly small effect on effective dose and the images at high kV were not well received. Thus we decided to focus on varying mAs as it has a larger effect on effective dose and the images acquired at mAs values below default were fairly well received in the pilot study.

In order to determine if DT is an acceptable alternative to standard protocol radiographs we first determined the effective dose associated with said radiographs. Each phantom was imaged using the Definium^{TM} 8000 x-ray system (GE Healthcare, Waukesha, WI) with the standard three views (PA, right and left obliques). A solid-state detector (Unfors RaySafe, Billdal, Sweden) was also placed on the surface of each phantom to measure the entrance exposure in milliRoentgen (mR). The effective dose associated with each view for each phantom was calculated using PCXMC 2.0 Monte Carlo software and the entrance exposure values obtained with the solid-state detector. The cumulative effective dose for each phantom was calculated by summing the effective dose associated with the three views and the three resulting cumulative doses were averaged to arrive at an average effective dose in mSv of 0.148 ± 1.10 (Table 1). The phantoms were then imaged at the default 76 kV at mAs values which would yield the same effective dose as radiography (0.32 mAs) and at approximately double (0.63 mAs) in addition to the default value of 1.6 mAs. Standard protocol radiographs with PA, right and left oblique views were also obtained of each phantom for comparison purposes. Four paediatric radiologists (with experience ranging from less than one year to forty years) and two radiology residents were recruited to compare radiographs of each phantom to DT of the same phantom done at the mAs settings stated above. After viewing both the radiographs and corresponding DT images the readers were asked to rate DT as either better, the same or worse (for diagnostic purposes) than the radiographs (Figure 8). Note that the images were presented to the radiologists in random order with no identifying information. The radiologists were given as much time as they needed to review the images and they were able to alter display and window levels if they so desired.

The data collected from the ratings completed by the radiologists were analyzed by the staff statistician at the Manitoba Institute of Cell Biology. An exact Chi-square test was performed to test for independence between the radiologists and preference for DT, phantoms and preference for DT and finally mAs and preference for DT.

3. Results and Discussion

3.1 Pilot Study 2011

In the kV series of images the effective dose decreased as kV was increased (Figure 9). Four of the five radiologists felt that the images were of diagnostic quality at kV values of 76 (default) and 90, which is 72% of the default effective dose (Table 2). It is also important to note that although the images at 90 kV were rated sufficient by four radiologists, two of those four commented that they did not like the image quality.

In the mAs series, the linear relationship between mAs and effective dose was demonstrated (Figure 10) and four of the five radiologists felt that the images with a mAs above the default of 1.6 (and thus at a higher effective dose) were acceptable. When judging images with a mAs below the default, four of the five radiologists rated the images with a mAs of 1.25 and 0.8 as sufficient, which is 78% and 50% of the default effective dose, respectively (Table 3).

Overall, there was some variability in the ratings amongst the five radiologists. In particular, one radiologist consistently stated that none of the images were of diagnostic quality because the iliac articular surfaces of the joint could not be seen. In general, the images at a higher kV were not as well received as those with a decreased mAs, this may be because increased kV has more of an effect on image quality than lower mAs settings. As kV is increased, image contrast is reduced thus making it difficult to distinguish subtle lesions.

This pilot study had some limitations. Only one phantom was available which resulted in a low number of images for radiologist review, we also had a limited number of radiologists and no statistical analysis was performed on the data.

3.2 Main Study 2012

The results of the ratings completed by the radiologists are summarized in Table 4. At 1.6 mAs the DT images rated “better” a total of fourteen times and “the same” a total of four times when compared to radiographs. At 0.63 mAs the DT images rated “better” a total of eleven times, “the same” a total of four times and “worse” a total of three times when compared to radiographs. At 0.32 mAs the DT images rated “better” a total of three times, “the same” a total of eight times and “worse” a total of seven times when compared to radiographs. Based on these results, it is evident that at a mAs of 0.32 there is no clear preference for DT, however as the mAs increases so does preference for DT.

Using an exact p-value of less than 0.05 as being considered significant, the exact Chi-square analysis showed a significant difference in preference for DT between radiologists as well as between the three mAs settings (exact p-value = 0.0095 and 0.0001, respectively). It was also illustrated that there is no significant difference in preference for DT between the three phantoms (exact p-value = 0.3389).

Figure 11 shows the difference in preferences for DT compared to radiography amongst the six radiologists. When comparing residents to the most experienced radiologists we find that their ratings are relatively similar which would indicate that years of experience do not play a factor in preference for DT. Other possible explanations for the variations in preference amongst radiologists include differences in amount of training received in DT and comfort level with interpreting DT images as it is rarely used clinically. There was also a significant difference in preference for DT between the three mAs settings. This is likely due to the decrease in image quality associated with the decrease in mAs (Figure 12). It is also important to note that there may be a somewhat artificial preference for radiographs as the phantoms did not have any overlying material to potentially obstruct the view of the joints and they were much easier to position for the oblique views as they are transparent.

The limitations associated with this study included a lack of overlying material to make the phantoms more realistic and a limited number of radiologists to review the images.

Regarding our initial hypothesis, the results of this study have shown that DT images of the SI joint are preferred over radiography, but only at dose levels higher than those comparable to radiography. Preference for DT may increase once clutter is introduced into the image objects. DT may have a further advantage if it reduces the need for CT. This is the subject of future investigations.

4. Conclusions

To conclude, dose reduction was achieved in the pilot study by increasing kV and decreasing mAs. Images with decreased mAs were fairly well received with the lowest being at a mAs of 0.8 which is 50% of the default effective dose. In the second half of the study DT has shown promise as a possible imaging alternative to radiography, albeit at mAs settings higher than what was determined to be dose equivalent. Thus the tradeoff between gain in diagnostic information and increase in dose needs to be investigated in order to determine the full potential of DT for the imaging of paediatric SI joints.

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[12] http://commons.wikimedia.org/wiki/File:Sacroiliac_joint.svg

[13] http://www.radswiki.net/main/index.php?title=File:Normal-pelvis-001.jpg

STUDENT NAME: Gina Nirula

Appendix

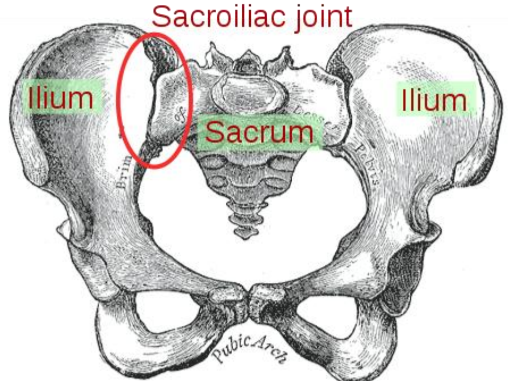
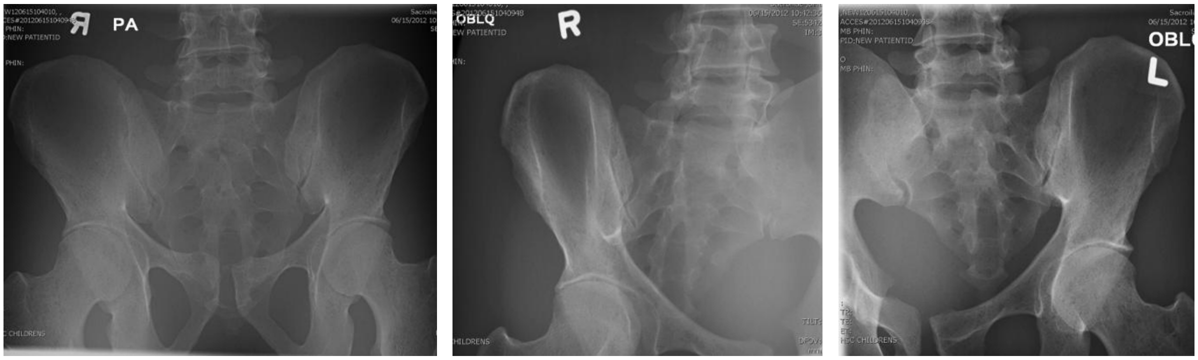


Figure 1. Anatomy of the SI joint [12]



(a) (b) (c)

Figure 2. Standard protocol radiographs of an anthropomorphic pelvis phantom (a) PA view, (b) oblique view of the right SI joint, (c) oblique view of the left SI joint

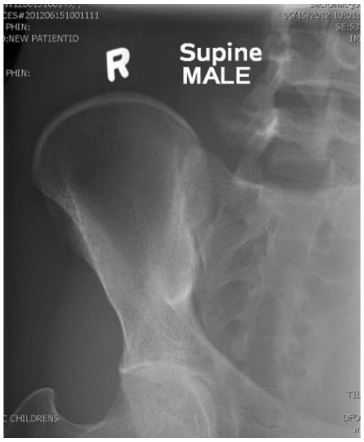


Figure 3. Oblique radiograph of an anthropomorphic pelvis phantom showing the right SI joint. In this case the phantom has been over rotated and the view of the joint is incomplete.

Figure 4. PA radiograph of the pelvis with overlying material [13]

Figure 5. Anthropomorphic pelvis phantom

Figure 6. Definium^{TM} 8000 x-ray system

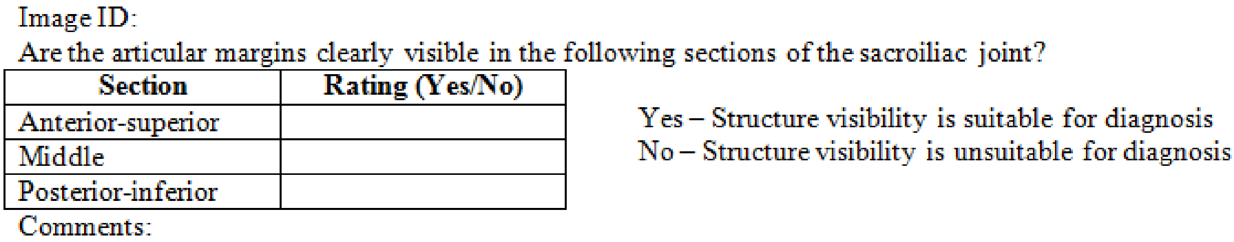


Image ID:

Are the articular margins clearly visible in the following sections of the sacroiliac joint?

Section	Rating (Yes/No)
Anterior-superior	
Middle	
Posterior-inferior	

Yes – Structure visibility is suitable for diagnosis

No – Structure visibility is unsuitable for diagnosis

Comments:

Figure 7. Rating scale used by radiologists in pilot study

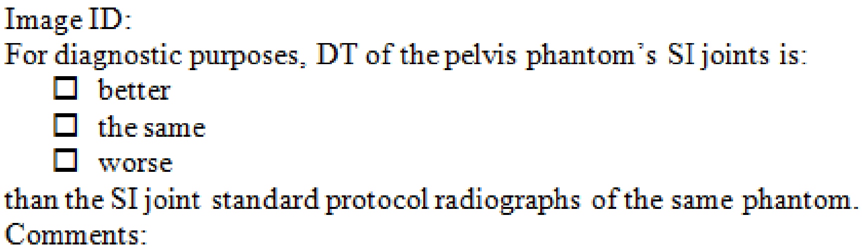


Image ID:

For diagnostic purposes, DT of the pelvis phantom's SI joints is:

- ☐ better
- ☐ the same
- ☐ worse

than the SI joint standard protocol radiographs of the same phantom.

Comments:

Figure 8. Rating scale used by radiologists in main study

STUDENT NAME: Gina Nirula

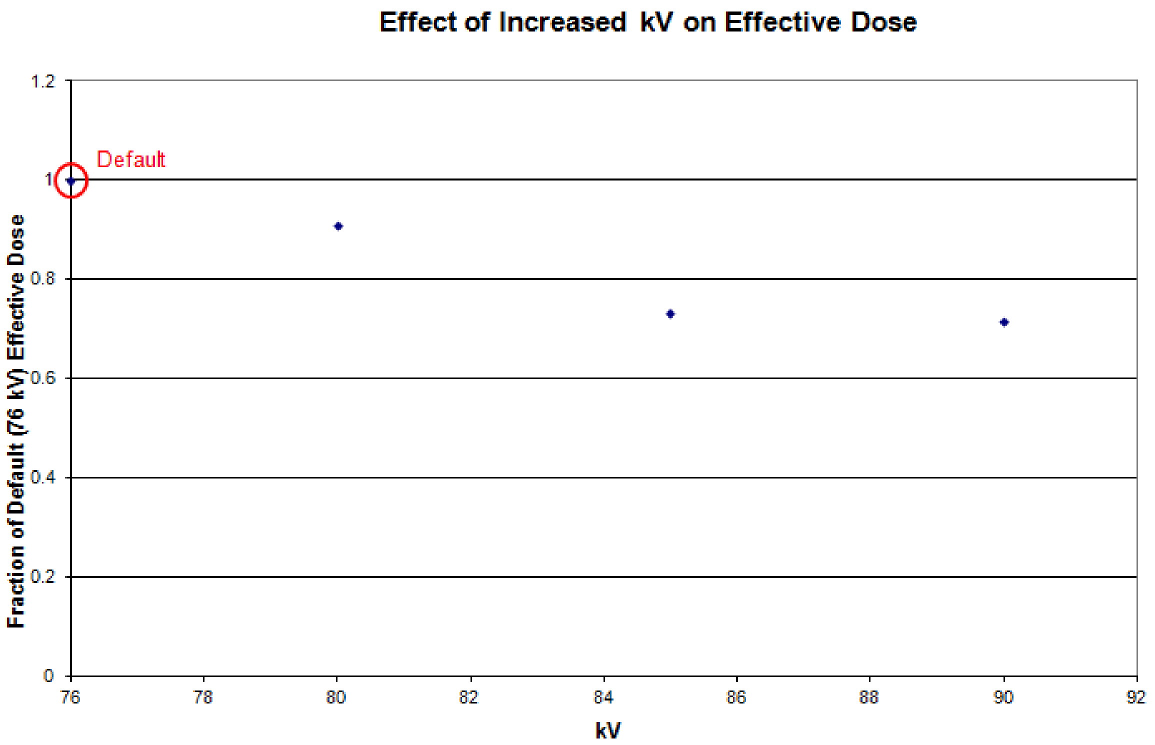


Figure 9. Effective dose as a function of increased kV

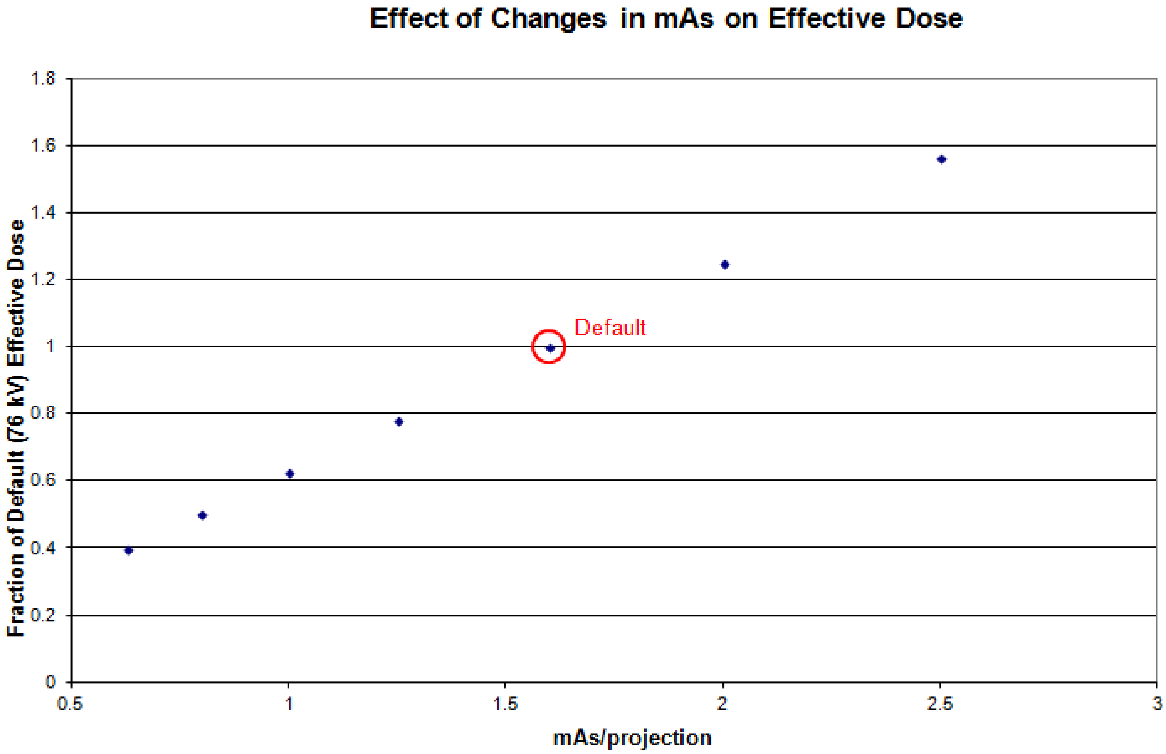


Figure 10. Effective dose as a function of variations in mAs

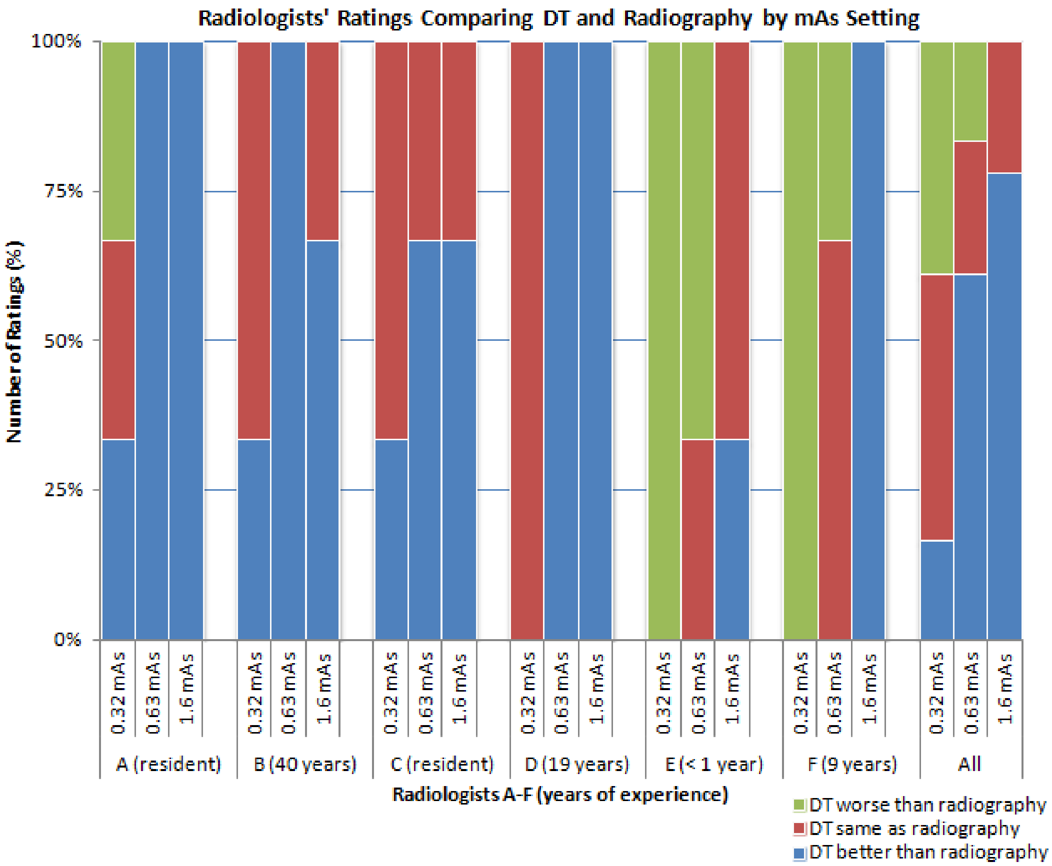


Figure 11. Graph showing radiologists' responses when comparing DT to radiographs

(a) (b) (c)

Figure 12. DT slices of phantom 3 done at (a) 1.6 mAs, (b) 0.63 mAs, (c) 0.32 mAs

STUDENT NAME: Gina Nirula

Phantom 1		
View	PCXMC Effective Dose (mSv)	PCXMC Error (%)
PA	0.054	0.6
Right SI joint	0.039	0.6
Left SI joint	0.051	0.6
Total	0.145	1.04
Phantom 2		
View	PCXMC Effective Dose (mSv)	PCXMC Error (%)
PA	0.047	0.7
Right SI joint	0.033	0.7
Left SI joint	0.045	0.7
Total	0.126	1.21
Phantom 3		
View	PCXMC Effective Dose (mSv)	PCXMC Error (%)
PA	0.048	0.6
Right SI joint	0.064	0.6
Left SI joint	0.062	0.6
Total	0.174	1.04
Average Effective Dose (mSv)	0.148	
Average Error (%)	1.10	

Table 1. Effective doses for standard protocol radiographs of each phantom

kV	mAs/ projection	Effective Dose (mSv)	Fraction of Default Effective Dose	No. of radiologists who rated "yes" for all 3 sections/Total no. of radiologists
76 (Default)	1.6	0.737 ± 0.0006	1	4/5
80	1.25	0.669 ± 0.0005	0.91	3/5
85	0.8	0.540 ± 0.0004	0.73	2/5
90	0.63	0.528 ± 0.0004	0.72	4/5

Table 2. Rating results of images in the kV series

mAs	Fraction of Effective Dose	No. of radiologists who rated "yes" for all 3 sections/Total no. of radiologists
2.5	1.56	4/5
2	1.25	4/5
1.6 (Default)	1	4/5
1.25	0.78	4/5
1	0.63	3/5
0.8	0.5	4/5
0.63	0.39	3/5

*Note: all of the above images were acquired at 76 kV

Table 3. Rating results of images in the mAs series

Phantom and mAs Setting	For diagnostic purposes, compared to standard protocol radiographs of phantoms, the DT of phantoms is:		
	Better	The Same	Worse
Phantom 1 (1.6 mAs)	6	0	0
Phantom 2 (1.6 mAs)	5	1	0
Phantom 3 (1.6 mAs)	3	3	0
Total	14	4	0
Phantom 1 (0.63 mAs)	4	2	0
Phantom 2 (0.63 mAs)	4	1	1
Phantom 3 (0.63 mAs)	3	1	2
Total	11	4	3
Phantom 1 (0.32 mAs)	2	2	2
Phantom 2 (0.32 mAs)	1	2	3
Phantom 3 (0.32 mAs)	0	4	2
Total	3	8	7

Table 4. Rating results of main study