Comparison of CT Number between Conventional CT and ImaSim Software

BY

MUHAMMAD FIRDAUS BIN BAHARUDIN

SCHOOL OF HEALTH SCIENCES

UNIVERSITI SAINS MALAYSIA

2015

CERTIFICATE

This is to certify that the dissertation entitled

Comparison of CT Number between Conventional CT and ImaSim Software

is the bona fide record of research work done by

MUHAMMAD FIRDAUS BIN BAHARUDIN

during the period of February 2015

to June 2015

under our supervision

Supervisor	Co-Supervisor
En. Mohd Fahmi Bin Mohd Yusof	En. Mohd Hasni Bin Muhammad Hanafi
Lecturer,	Radiologist,
School of Health Science	School of Health Science
University Sains Malaysia	University Sains Malaysia
16150 Kubang Kerian,	16150 Kubang Kerian,
Kelantan, Malaysia.	Kelantan, Malaysia.
Date:	Date:

ACKNOWLEDGEMENTS

First, I am thankful to Allah SWT by His permission for me to complete this project successfully in order to fulfill the requirement for bachelor degree in Medical Radiation.

I would like to thank to School of Health Sciences, USM for giving me opportunity to complete my project entitled COMPARISON OF CT NUMBER BETWEEN CONVENTIONAL CT AND IMASIM SOFTWARE.

I would also like to thank to my supervisor Mr Mohd Fahmi Bin Mohd Yusof as my supervisor for his guidance and support upon completion of this study.

Nevertheless, thanks to Mr Mohd Hasni Bin Muhammad Hanafi spending a lot of time to help me in my study and handling the machines. I am very much appreciating his guidance along the process of the study.

I am also greatly appreciated the help and supports from my fellow coursemates upon completing this project. Finally and most importantly, I dedicate this project to my dad Baharudin Bin Sulaiman, my mom Noraini Binti Bahri, and my only sister Nurhana Binti Baharudin.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LISTS OF SYMBOLS

HU	Hounsfield unit
kV	Kilovoltage
MV	Megavoltage
kVp	Kilovoltage Peak
mAs	Tube current-time product
°	degree
cm	centimeter
μ/ρ	Mass attenuation coefficient
μ	Linear attenuation coefficient
g	gram
σ	Standard deviation
mGy	milligray

ABSTRAK

Tujuan kajian ini adalah untuk menentukan kesesuaian perisian simulasi Tomografi Berkomputer (TB), ImaSim digunakan untuk pengimbasan gambar. Gambar TB daripada pelbagai tisu diperolehi dengan menggunakan TB konvensional dan perisian simulasi TB. Nilai jumlah TB pelbagai tisu yang mewakili ketumpatan tisu telah dibandingkan di antara kaedah TB konvensional dan perisian ImaSim. Untuk mendapatkan imej TB konvensional, "CIRS 062 Electron Density CT Phantom" telah digunakan dan 5 fantom plak digunakan iaitu udara, paru-paru menghembus nafas, adipos, air dan tulang padat (1000 mg / cc HA). Tisu jenis yang sama digunakan untuk mensimulasi dalam simulasi TB perisian ImaSim dan semua nombor TB telah direkodkan. Kedua-dua kaedah konvensional dan simulasi menggunakan mAs yang sama iaitu 260 mAs di tiga tenaga yang berbeza iaitu 80 kVp, 120 dan 140 kVp kVp. Nilai jumlah TB diperolehi bagi TB konvensional dan ImaSim perisian adalah di dalam julat yang boleh diterima bagi nombor TB untuk setiap tisu. Ujian khi-kuasa dua dikira memberikan nilai yang rendah untuk udara, lemak dan air iaitu kurang daripada 2.98. Nilai khi-kuasa dua untuk paru-paru dan tulang memberikan nilai tinggi iaitu sehingga 200. Oleh itu, ketepatan jumlah TB diperolehi daripada perisian ImaSim khusus untuk paru-paru dan tulang dipersoalkan sebagai nilai yang menyimpang dari nilai taraf dan nombor TB yang diperolehi secara konvensional.

ABSTRACT

This study determines the suitability of ImaSim CT simulation software, as CT Image generation and analysis. CT images of various tissues are obtained by using conventional CT and the CT simulation software. The value of CT number of various tissues which represents the tissue's density is compared between conventional CT method and ImaSim software. To obtain the CT image conventionally, CIRS 062 Electron Density CT Phantom was used and 5 plug phantoms were used which are air, lung exhale, adipose, water and dense bone (1000 mg/cc HA). The same types of tissues were used to simulate in the CT simulation software ImaSim and all the CT numbers were recorded. Both conventional and simulation method uses fixed tube current-time product at 260 mAs at three different energy which are 80 kVp, 120 kVp and 140 kVp. The value of CT number obtained for conventional CT and ImaSim software is in the acceptable range of CT numbers of each specific tissues. The chi-square calculated gives low value for air, fat and water which is less than 2.98. Chi-square value for lung and bone gives high value which is up to 200. Therefore the accuracy of CT number obtained from ImaSim software specifically for lung and bone is questionable as the value is deviated from the standard value and the CT number obtained conventionally.

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Computed tomography is an x-ray procedure that combines many x-ray images and is generated into cross-sectional view and also 3D images. The fundamental limitations of conventional radiograph is superposition and conspicuity due to overlapping structures. A strong reason for developers to led the development of conventional radiography (Hsieh, J., 2009). The clarity and accuracy of images produced by CT scanners have enabled CT to become one of the most widespread modalities for diagnostic imaging. Total cases of 26.3 million CT procedures were performed in United States from November 1998 to October 1999 (Harris, C.H, 2001).

CT imaging is an important part of medicine and plays a crucial role in radiotherapy. Education in this field is mostly limited to textbook teaching due to equipment restrictions limiting the amount of time students can spend experimenting with principles learned in the classroom and their effects on image quality. ImaSim software is highly interactive and its utilization via a graphical user interface (GUI) is intuitive. ImaSim containing a simulation environment for teaching and self-learning the fundamentals of medical x-ray imaging. The image creation with the main x-ray based imaging modalities found in radiology or radiotherapy departments can be virtually explored (Landry,G, 2013).

Phelps *et al.* (1975) developed the correlation of CT numbers with electron density, physical density, and effective atomic number for an EMI scanner operated at 120 kVp. The results showed an excellent correlation between CT numbers and electron density, indicating the major role of Compton interactions in CT imaging. Their study also demonstrated the very good correlation that exists between CT numbers and physical density (g/cm^3). (Mull, Richard T, 1984)

The most important parameters with respect to CT image quality are image noise, CT-numbers, uniformity, spatial resolution and low contrast resolution. Low contrast resolution is the ability to differentiate objects with slight density differences. The potential to resolve an object depends on the level of contrast in the object and its size, reconstruction algorithm, image noise and window settings used to display the image. Spatial resolution is the ability to differentiate small objects with high contrast compared to the background. The uniformity describes the homogeneity of the scanned material. The uniformity measurements are important to ensure that cupping and beam hardening artifacts can be avoided. CT images are generated by measurement of attenuation of x-rays through the tissue of interest. Attenuation is described by CT-numbers or Hounsfield units (HU). Each pixel in the image corresponds to a specific HU (Gulliksrud,K, 2013)

$$\text{CT number} = \frac{\mu material - \mu water}{\mu water} X\ 1000 \qquad (1.1)$$

With $\mu_{material}$ and μ_{water} is the linear attenuation coefficient of material being scanned and water respectively.

1.2 Objectives of Study

General Objectives:

The general objective of the study is to determine the suitability of simulation CT ImaSim software for CT image generation and analysis.

Specific Objectives:

1. To obtain CT image of various tissue using conventional CT and simulation CT
2. To compare CT number obtained from conventional with simulation at different CT energies

1.3 Research Questions

1. How CT images are obtained between conventional and ImaSim simulation methods?
2. Are there any differences on image information of various tissue on CT of CT machine and ImaSim software?
3. Is there any significant difference of the value of CT number between conventional CT and ImaSim software at different energies?

1.4 Research Hypothesis

H_0 : There is no significant difference of image producing between conventional CT and simulation CT.

H_A : There is significant difference of image producing between conventional CT and simulation CT.

H_0 : There is no significant difference of the value of CT number between conventional CT and simulation CT.

H_A : There is significant difference of the value of CT number between conventional CT and simulation CT.

CHAPTER 2

LITERATURE REVIEW

2.1 ImaSim image simulation

ImaSim software covers the planar kV imaging, planar MV imaging, CT imaging and CBCT imaging. It is very suitable for virtual demonstrations of imaging phenomena as well as used as virtual experimentation purposes. The effects of varying imaging parameters on the quality of the final image can be demonstrated and studied. To obtain a virtual image, there are five parameters the user of this software needs to go through which are x-ray production, object creation, geometrical setup, detector selection and modality dependent image processing. (Landry,G, 2013).

ImaSim is a modular program where the user first defines the radiation source (which can be based on SpekCalc in the case of a kilovoltage X-ray source), then the object to be imaged, followed by the set-up geometry. Finally, a choice among several imaging detectors must be made. With the whole setup complete, the user then can start the image simulation process, and watch the X-ray image being created in front of their eyes. In the case of a CT scan, for example, the sinogram is created in real time. Once finalized, images can be analysed. (Verhaegen,F, 2013).

2.2 CT number

An X-ray computed tomography scanner (Somatom Sensation Open, Siemens) was used to investigate the density distribution inside the samples. The maximum voltage and current of machine setting were 120kVp and 33mA, respectively. The target used for X-ray was tungsten. X-ray CT provides an image pixel value in CT scans, called CT number. The CT number is represented as the Hounsfield unit (HU), which is related to the density. Water and air corresponding to HU values of 0 and -1000, respectively.

The linear relationship between attenuation and density was established by Davis and Wells in 1992 which then the CT numbers can be explained as density values. This relation was further developed by Lindgren in 1991. On the other hand, the CT numbers of the same tissue have being different among scanners from different manufacturers. Therefore, this relationship could not be applied directly to another experiment. Calibration curve is needed by scanning reference test samples with known densities. From the calibration curve, the relationship between the CT number and the density can be obtained experimentally (Marashdeh et al., 2012).

2.3 CT image

A study was conducted by Francis Zarb *et al.*, (2010) on development of optimized CT scan protocols specifically concerning on potential radiation risks on patients. By scanning a Catphan 600 CT QA phantom, the image quality was assessed by 2 expert observers. The parameters assessed includes contrast resolution, spatial resolution and noise. The result shows optimization was effected through the establishment of the limits at which the image quality is reduced by dose reduction. The tube current, tube voltage and pitch changes necessary to achieve the optimization thresholds.

A study by Kristine Gulliksrud *et al.*, (2013) shows the variations in CT numbers, uniformity and low contrast resolution for a CT quality assurance phantom affects the CT image quality. The study was to analyze the characteristics of the most commonly used QA phantom in CT: Catphan 500/504/600. Nine different phantoms were scanned on the same day on one CT scanner with the same parameter settings. Variations in CT numbers, uniformity and low contrast resolution were evaluated for all the phantoms. The result shows some variations were observed in low contrast resolution and the CT number modules of the phantom. The variations in CT numbers can be interpreted as substantial depending on the chosen regulatory framework.

CHAPTER 3

MATERIALS AND METHODS

3.1 Materials

3.1.1 ImaSim Software Light Version

ImaSim software light version was used for this project. ImaSim is highly interactive and its utilization through a graphical user interface (GUI) is intuitive. The software package covers the main x-ray based modalities consists of planar kilovoltage (kV), planar (portal) megavoltage (MV), fan beam CT, and CBCT imaging. This study focuses on CT imaging part. The main components need to be setup in this project were source selection, object selection, setup selection and detector selection.

Source selection for kV sources in ImaSim was handled by SpeckCalc, a kilovoltage spectrum creation tool which is based on a verified model. With SpeckCalc, accelerating potentials of up to 300 kV with a tungsten anode can be modeled. Object selection enable user to create custom composite objects using an editor. A composite object consists of a combination of such building blocks. Blocks can be translated, rotated and resized. Each block has an assigned material, chosen from a total of 124 different tissue/tissue-substitute compositions. Set up editor was for scanning set up that provides user ability to position the photon source, composite object and detector in a coordinate system. Detector selection was for detector types that can be chose.

There were three types of detector for kilovoltage which were ideal integrator, Cesium Iodide (CsI), and gadolinium oxysulfide (Gd_2O_2S).

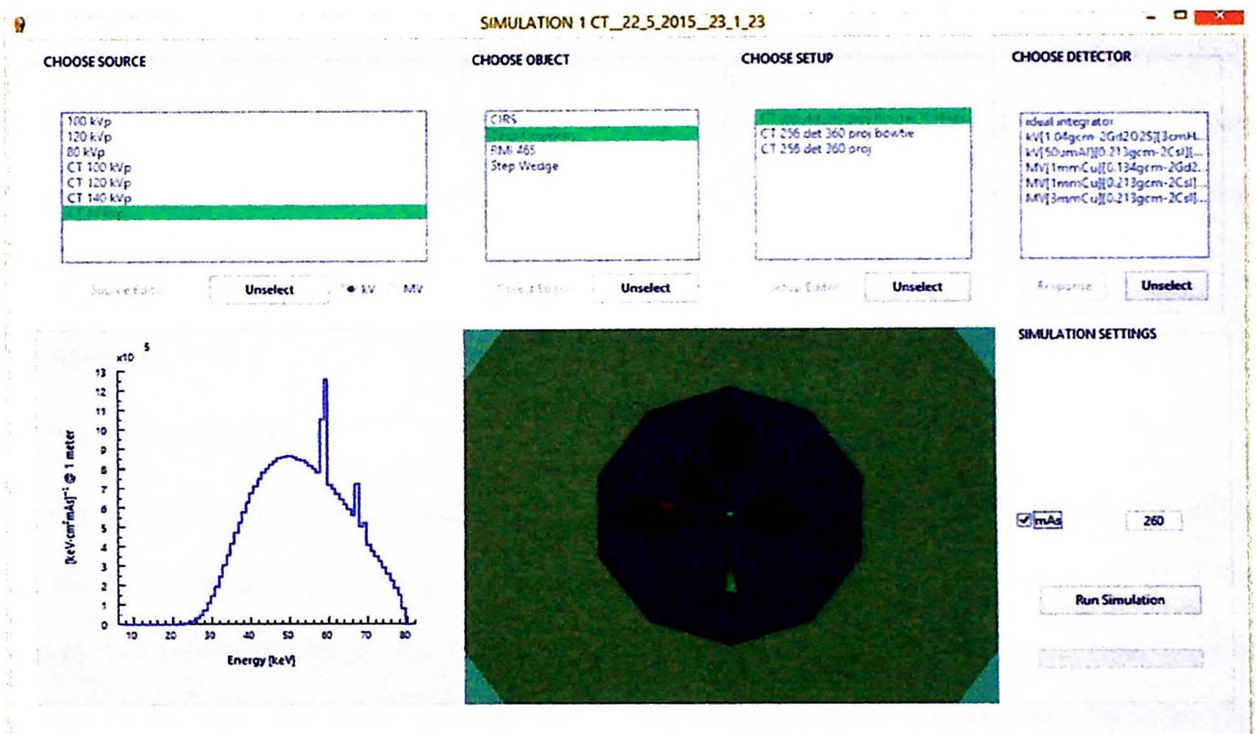

Figure 3.1: Imasim software for the whole parameter

3.1.2 CIRS 062 Electron Density CT Phantom

The CIRS 062 Electron Density CT Phantom can be used to calibrate the CT unit by establishing the relationship between the electron density of various tissues and their corresponding CT number (in Hounsfield Units, HU). The Model 062 consists of two nested disks made from Plastic Water® -LR. They can represent both head and abdomen configurations. Nine different tissue equivalent electron density plugs can be positioned at 17 different locations within the scan field.

3.1.3 Siemens Somatom CT Scan Machine

Somatom Definition AS is one of the CT scanner built by Siemens. This specific type is available at the Radiology Department of Hospital Universiti Sains Malaysia. Dual source CT gives double temporal resolution, double speed and twice the power while lowering the dose even further. The x-ray tube's kilo voltage (kV) determines the average energy level of the x-ray beam. Changing the kV setting results in an alteration of photon energy and a corresponding attenuation modification of the materials scanned.

3.2 Methods

3.2.1 ImaSim Procedure

Source selection was the first parameter to be set. It consists of size of energy bin, anode angle, filtration and energy that is going to be used. The energy bin used was 1 that the value of the energy bin recommended by the creator of ImaSim software. Anode angle used was 7°. The greater anode angle the larger coverage field. The tube potentials selected were 80 kVp, 120 kVp and 140 kVp which is the standard range. The filtration used was 12 mm Aluminum thickness, 0.8 mm Beryllium thickness and 1000mm air thickness. All of these parameters were key-in in this session.

Tube potential that was used	80, 120 and 140 kVp
Size of energy bin (target)	1
Anode angle	7°
Filtration	12 mm Aluminum 0.8 mm Beryllium 1000 mm Air

Table 3.1: Source selection parameter

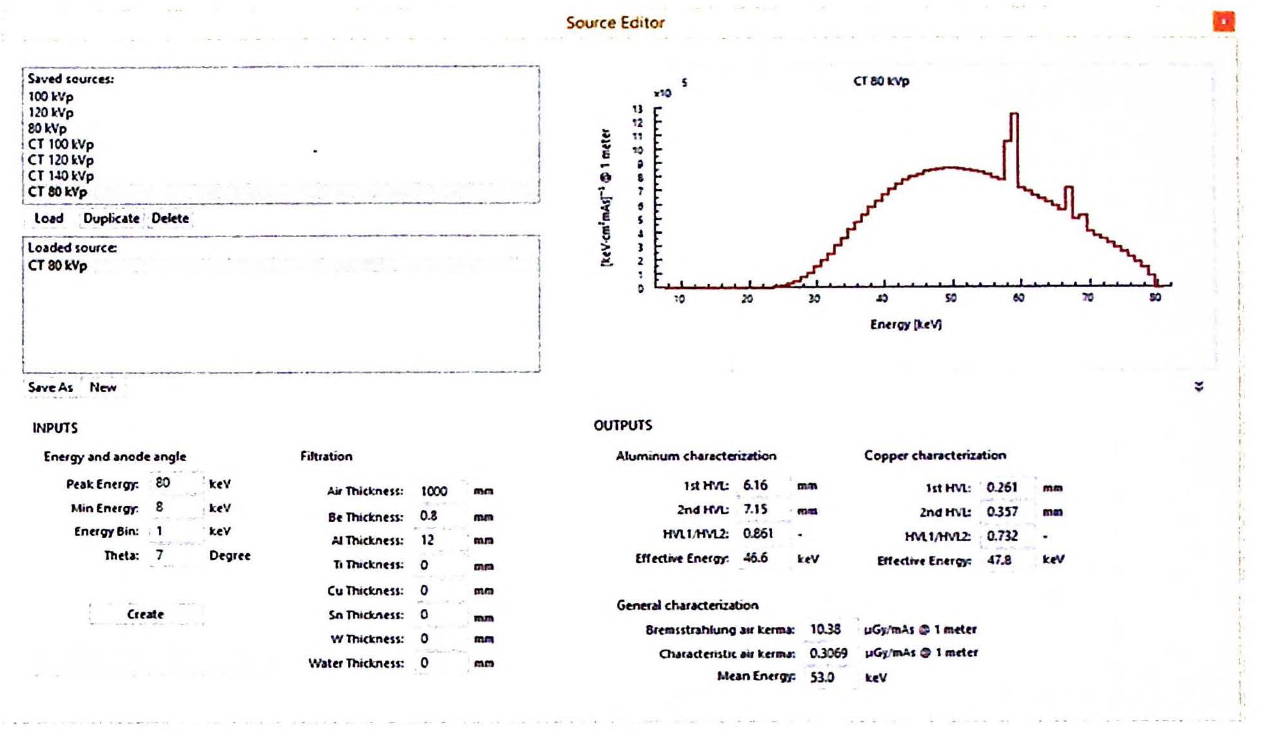

Figure 3.2: Source selection part in Imasim software

Second parameter to be set is the object selection. The phantom to be simulated was built in form of elliptical cylinder shape. It is important to build the phantom as close as possible to the CIRS electron density phantom that was scanned using the CT scan machine. The bulk from CIRS plastic water was chose as the background material. 5 types of different plug phantom was choosen which are adipose tissue, lung tissue, air, bone tissue and water. These plug phantom was inserted into the background solid water material.

Components	Materials	Specification
Plastic water phantom	CIRS plastic water	Shape: elliptical cylinder Diameter: 8 cm Width: 10 cm Coordinate: (X: 0, Y: 0, Z: 0)
Adipose	CIRS Adipose	Shape: elliptical cylinder Diameter: 1.25 cm Width: 10 cm Coordinate: (X: 0, Y: 0, Z: -2.5)
Lung	CIRS Lung	Shape: elliptical cylinder Diameter: 1.25 cm Width: 10 cm Coordinate: (X: 0, Y: 0, Z: 5)
Air	Air	Shape: elliptical cylinder Diameter: 1.25 cm Width: 10 cm Coordinate: (X: 0, Y: 5, Z: 0)
Bone	CIRS Bone	Shape: elliptical cylinder Diameter: 0.4 cm Width: 10 cm Coordinate: (X: 0, Y: -5, Z: 0)
Water	Water	Shape: elliptical cylinder Diameter: 1.25 cm Width: 10 cm Coordinate: (X: 0, Y: 2, Z: 2)

Table 3.2: Object selection parameters for each material in phantom

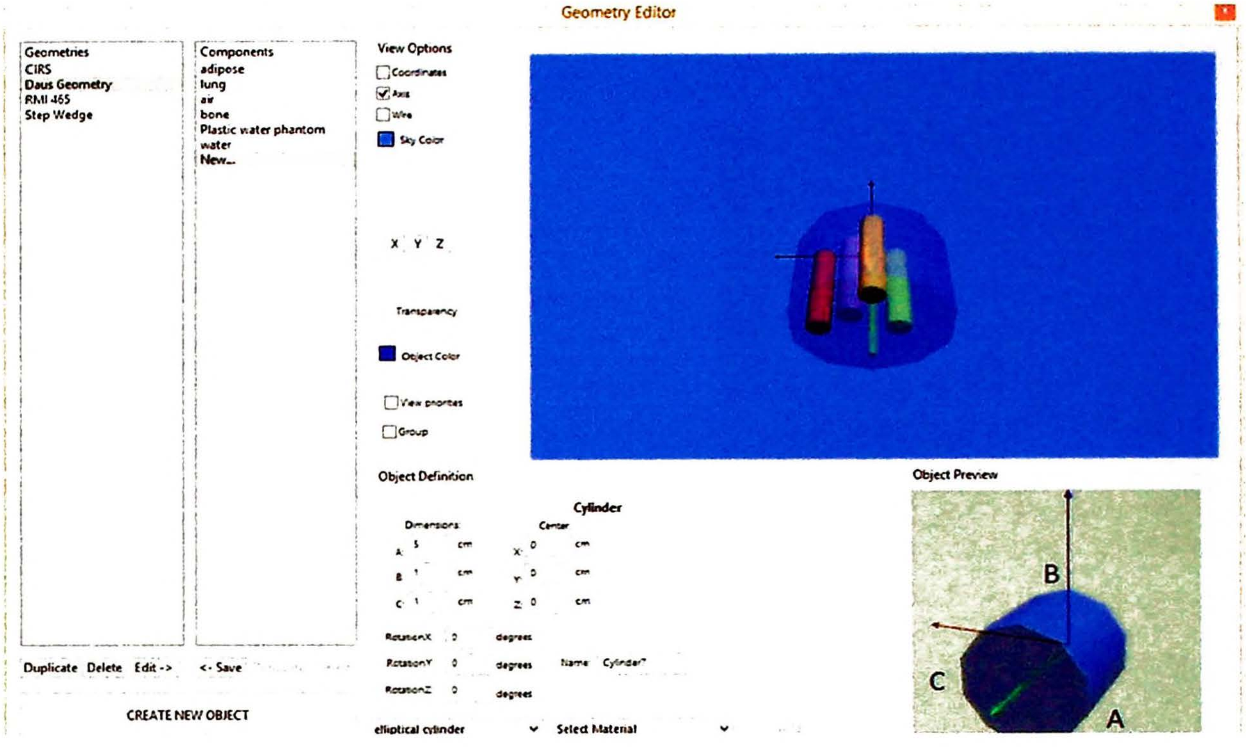

Figure 3.3: Object selection part in ImaSim software

The third parameters need to be adjusted is the scanning setup selection. It consists of source to detector distance, source detector rotation, origin position and detector width and thickness. Source to detector distance gives the distance between focal spot to the coordinate system's origin while the detector to origin distance gives the distance between the detector's centers to the coordinate system's origin. The scan length is 15 mm, the slice thickness is 1 mm and fan angle is 35^0.

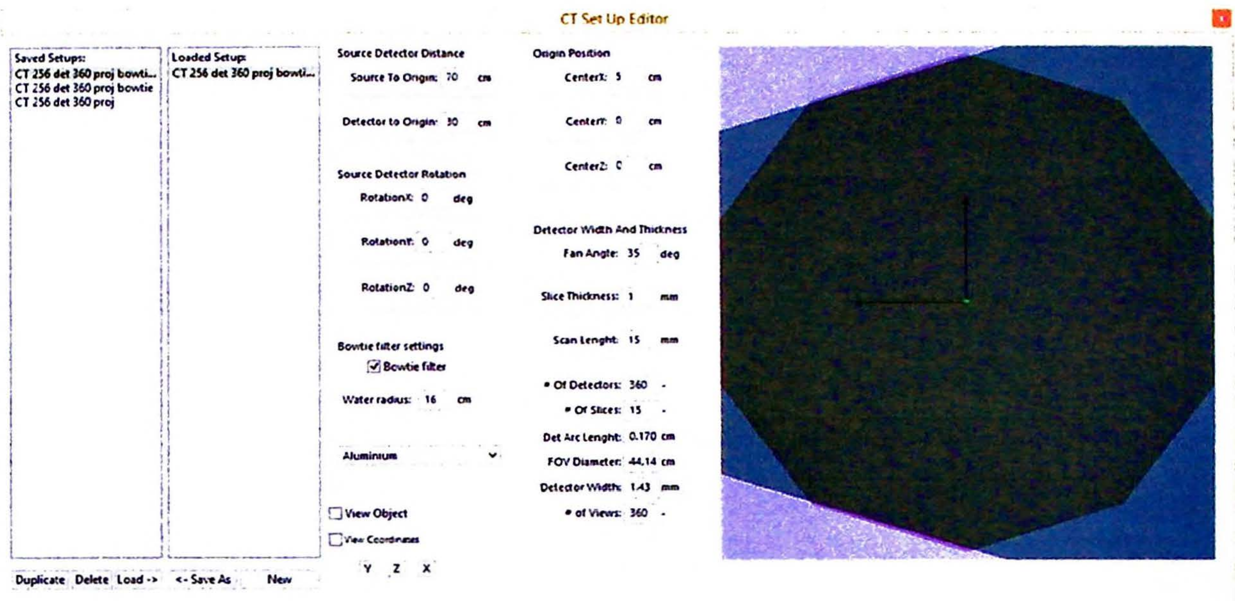

Figure 3.4: Object selection parameter in Imasim software

Source detector distance	Source to origin: 70 cm Detector to origin: 30 cm
Origin position	Center X: 5 cm, Y:0 cm, Z:0 cm
Detector width and thickness	Fan angles: 35° Scan length: 15 mm Slice thickness: 1 mm Number of detector: 360 Number of slice: 15 Number of views: 360

Table 3.3: Scanning set up parameter

The last parameter is the simulator settings which gives the value of tube current-time to be used in the simulation. The tube current-time value used is 260 mAs for all the energies. After all the parameters are completed, it is then can be simulated and the simulation window displays the fan sonogram. Then, the convert to parallel button was pressed to convert from the fan sonogram to parallel sonogram. Ram-Lak filter was chosen for filter back-projection process because it is good in spatial resolution although quite sensitive to noise (Lee, S.W. et al., 2011). The back-projection button was then clicked to obtain the image. The image then was saved in ImaSim software. The procedure is repeated for three different energy 80, 120 and 140 kVp with a fixed tube current-time which is 260 mAs.

3.2.2 Image tool by ImaSim software for image analyzing

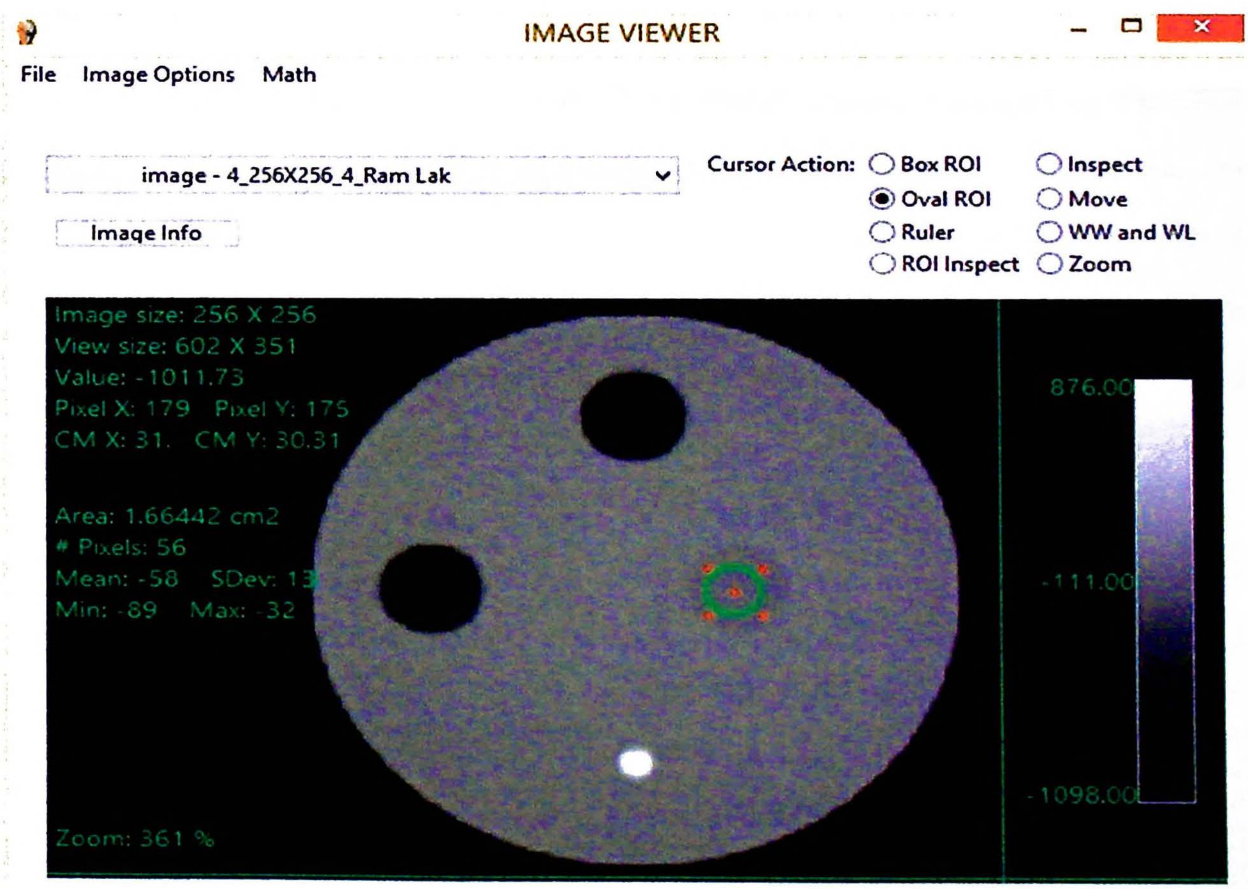

Figure 3.5: Analyzing CT scan image of 100 kVp, 260 mAs by ImaSim image tool

All the images created in the simulation are then opened in the image viewer section where we can acquire the important values. A region of interest (ROI) of oval shape is made inside every tissue phantom. The values of mean CT number, standard deviation, minimum and maximum were recorded.

3.2.3 Siemens Somatom CT scan procedure

Using the CIRS 062 Electron Density CT Phantom, five different plug phantom tissues were selected to be placed inside the main phantom. The tissues plug phantom chosen are air (0 g/cc), adipose (0.97 g/cc), lung exhale (0.5 g/cc), Solid dense bone (1000 mg/cc HA) (1.66 g/cc) and water, H_20 equivalent insert (0 g/cc). After all the tissue phantom is plugged in, the CIRS phantom is placed on the CT scan table, positioned to the center of the phantom and it is ready to be scanned. The scan is repeated for three different energy 80, 120 and 140 kVp with a fixed tube current-time 260 mAs. After the scan is completed, the values of CT number maximum, minimum, average and standard deviation of each tissues were recorded. The following table and figure shows the positions of different density plugs.

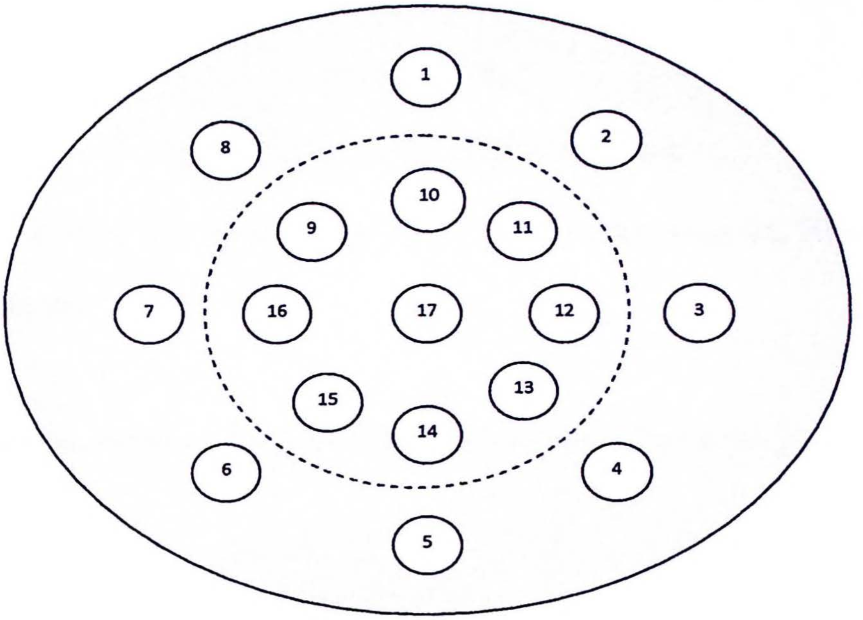

Figure 3.6: Tissue phantom positions

Number	Plug Phantom	Density (g/cc)
1	Air	0.000
2	Adipose	0.970
3	Lung (exhale)	0.500
4	Lung (inhale)	0.200
5	Trabecular bone (200 mg/cc HA)	1.16
6	Solid dense bone (1000 mg/cc HA)	1.66
7	Water, H_2O equivalent insert	1.004
8	-	-
9	Air	0.000
10	Adipose	0.970
11	Lung (exhale)	0.500
12	Lung (inhale)	0.200
13	Trabecular bone (200 mg/cc HA)	1.16
14	Solid dense bone (1000 mg/cc HA)	1.66
15	Water, H_2O equivalent insert	0.00
16	-	-
17	-	-

Table 3.4: Tissue phantom positions

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Graph tabulated by all values of 5 tissues CT numbers by standard, Siemens Somatom and ImaSim software

4.1.1 CT number for standard, Siemens Somatom and ImaSim at 80 kVp

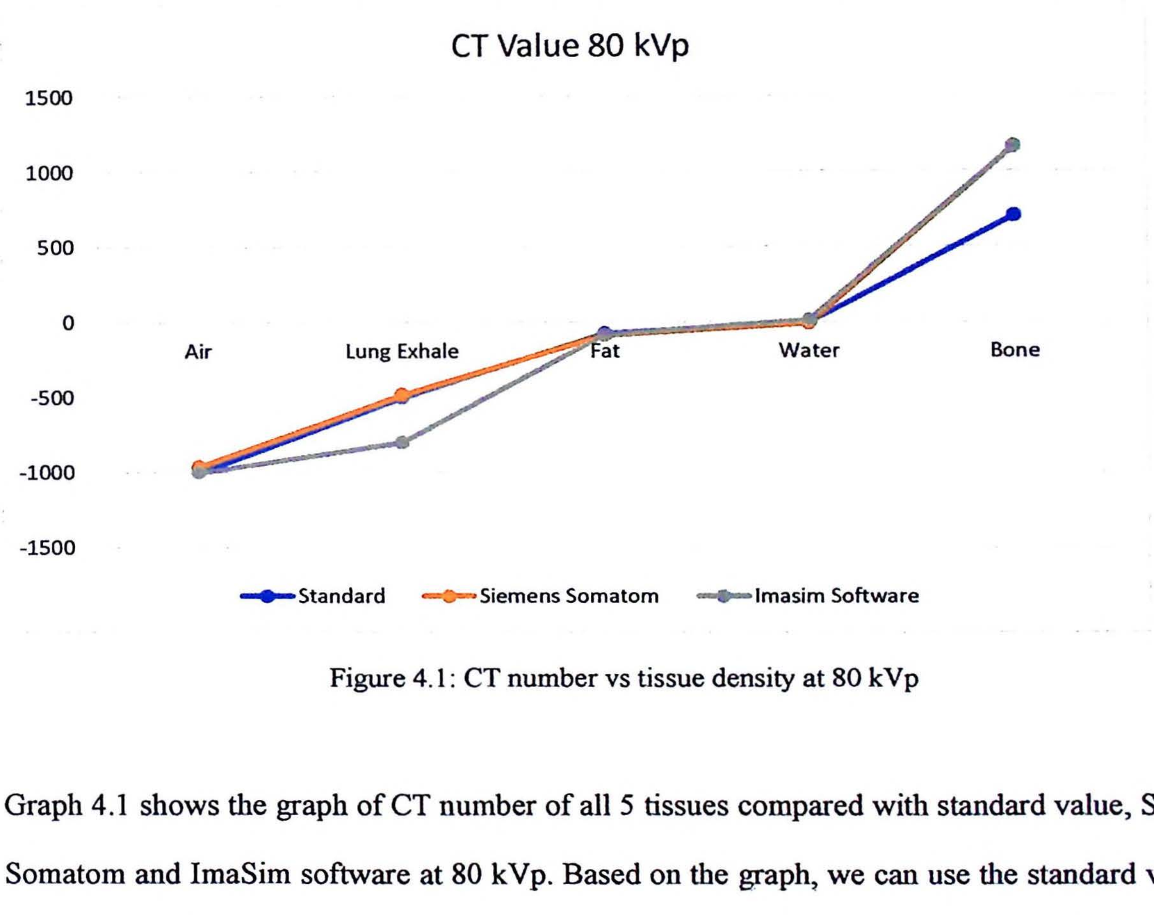

Figure 4.1: CT number vs tissue density at 80 kVp

Graph 4.1 shows the graph of CT number of all 5 tissues compared with standard value, Siemens Somatom and ImaSim software at 80 kVp. Based on the graph, we can use the standard value as the reference for both Somatom and ImaSim. When compared to the tissues' density from air to bone, the CT number will increase and the graph plotted will increase. What can we see from the graph there are 2 points at which the graph of Siemens and ImaSim deviated from the standard value. At lung exhale tissue, ImaSim software gives lower value of CT number compared to standard and Siemens while at bone tissue both Somatom and ImaSim gives higher CT number compared to standard value.

4.1.2 CT number for standard, Siemens Somatom and ImaSim at 120 kVp

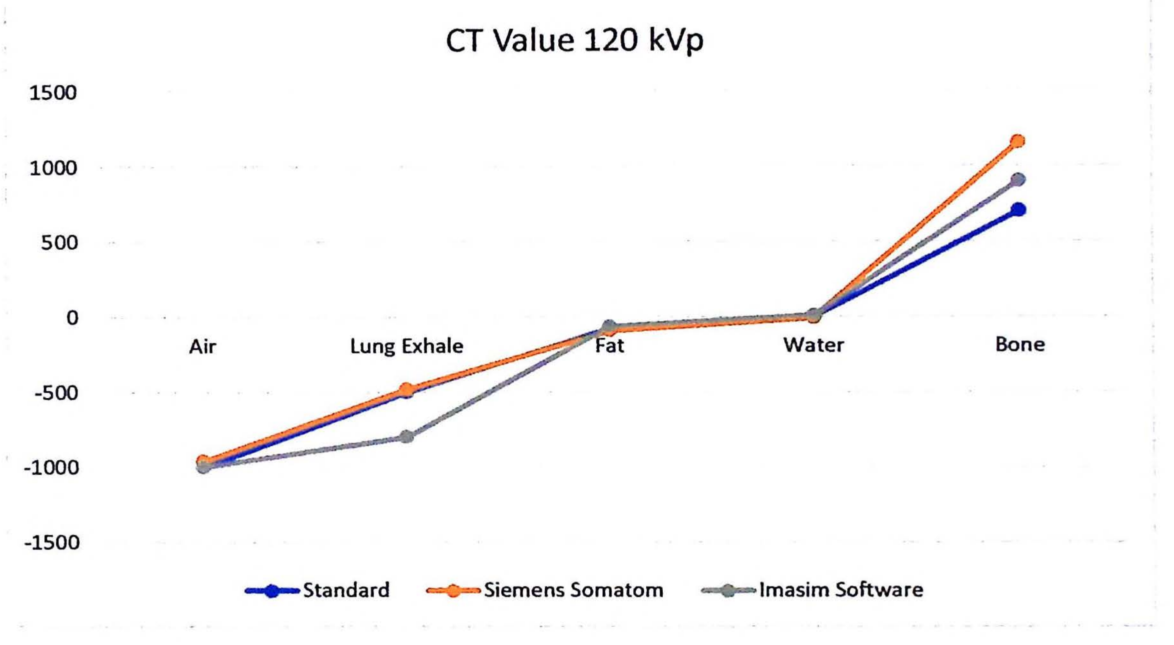

Figure 4.2: CT number vs tissue density at 120 kVp

Graph 4.2 shows the graph of CT number of all 5 tissues compared with standard value, Siemens Somatom and ImaSim software at 120 kVp. Based on the graph there are 2 points at which the graph of Siemens and ImaSim deviated from the standard value. At lung exhale tissue, ImaSim software gives lower value of CT number compared to standard and Siemens while at bone tissue Somatom gives higher value of CT number while ImaSim gives CT number slightly higher than standard.

4.1.3 CT number for standard, Siemens Somatom and ImaSim at 140 kVp

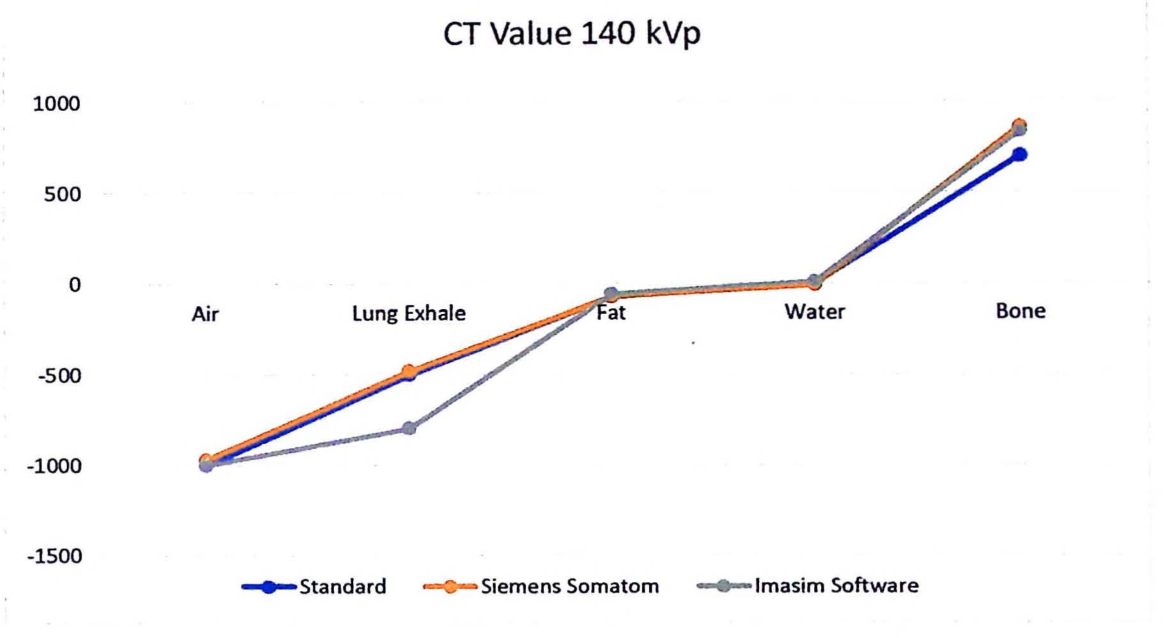

Figure 4.3: CT number vs tissue density at 140 kVp

Graph 4.3 shows the graph of CT number of all 5 tissues compared with standard value, Siemens Somatom and ImaSim software at 140 kVp. Based on the graph there are 2 points at which the graph of Siemens and ImaSim deviated from the standard value. At lung exhale tissue, ImaSim software gives lower value of CT number compared to standard and Siemens while at bone tissue both Somatom and ImaSim gives CT number slightly higher than standard.

4.2 Calculation of χ^2 of Chi-square test

4.2.1 Comparison between Somatom & ImaSim

Type of tissues	Energy (kVp)	CT Number		$y_i - x_i$	$(y_i - x_i)^2$	$\sigma_{(CT)}$	$\sigma_{(CT)}^2$	$\frac{(y_i - x_i)^2}{\sigma_{(CT)}^2}$
		Somatom (y_i)	ImaSim (x_i)					
Air	80	-961.09	-999.27	38.18	1457.71	40.30	1624.09	0.90
	120	-959.84	-997.67	37.83	1431.11	21.90	479.61	2.98
	140	-968.95	-997.07	28.13	790.73	20.07	402.80	1.96
Lung	80	-483.10	-798.73	305.63	93409.70	45.87	2104.06	44.40
	120	-481.21	-798.00	316.79	100355.90	25.40	645.16	155.55
	140	-478.43	-796.47	318.04	101149.44	20.80	432.64	233.80
Fat	80	-87.18	-83.20	-3.98	15.84	48.80	2381.44	0.0067
	120	-92.34	-64.40	-27.94	780.64	28.47	810.54	0.96
	140	-72.28	-58.53	-13.75	189.06	25.87	669.26	0.28
Water	80	-8.51	12.87	-21.38	457.10	56.07	3143.84	0.15
	120	-5.80	9.53	-15.33	235.01	39.80	1584.04	0.15
	140	-8.75	9.13	-17.88	319.69	11.40	129.96	2.46
Bone	80	1161.55	1158.07	3.48	12.11	36.47	1330.06	0.0091
	120	1154.54	898.73	255.81	65438.76	14.80	219.04	298.75
	140	860.63	835.60	25.03	626.50	11.40	129.96	4.82

Table 4.1: Chi-square calculated compared between Siemens Somatom and ImaSim

Table 4.1 shows the comparison of chi-square test between Somatom and ImaSim for all 5 tissues and all 3 energies. As we can see from the table, mostly the value of chi-square is small except for lung and bone. The value of chi-square for lung is 44.4, 155.55 and 233.80 for 80, 120 and 140 kVp respectively. The value of chi-square for bone that gives high value of chi-square is at 120 kVp which is 298.15.

4.2.2 Summarized table of Chi-square values

Sample	X^2 values								
	Somatom Vs ImaSim			Standard Vs Somatom			Standard Vs ImaSim		
	80 kVp	120 kVp	140 kVp	80 kVp	120 kVp	140 kVp	80 kVp	120 kVp	140 kVp
Air	0.90	2.98	1.96	0.322	0.375	1.142	0.33×10^{-3}	0.011	0.021
Lung	44.40	155.55	233.80	0.055	0.046	0.150	42.413	137.646	203.158
Fat	0.0067	0.96	0.28	0.017	0.031	0.002	0.028	0.139	0.405
Water	0.15	0.15	2.46	0.010	0.003	0.053	0.053	0.057	0.641
Bone	0.0091	298.75	4.82	12.608	8.934	2.547	157.758	180.303	141.485
Total X^2	45.47	458.39	243.32	13.01	9.39	3.89	200.25	318.16	345.71

Table 4.2: Values of Chi-square for all tissues at 3 different energies

Table 4.2 shows the summarized of all chi-square calculations for all 5 tissues at 3 energies. It is compared between standard values, Siemens Somatom and ImaSim software. As we can compare, the values obtained for air, fat and water gives a consistent value of less than 2.98. When we compared the value of lung, the value at Somatom vs. ImaSim and Standard vs. ImaSim gives high value whereas at standard vs. Somatom gives the value less than 0.1. At bone tissue, the highest chi-square value calculated is at standard vs. ImaSim which up to more than 140. On the other hand at Somatom vs. ImaSim and standard vs. Somatom the values obtained is a little bit fluctuated. For example at Somatom vs. ImaSim at energy 80 kVp it gives low value, then it rises up to 200 at 120 kVp and then decreased to 4.82 at 140 kVp.

4.3 Discussion

In general, most of the value of CT number of the tissues generated from ImaSim agree with those measured at the scanner. Based on graph 4.1, 4.2 and 4.3 mostly the CT number values are similar except at 2 points which are lung exhale and bone. Based on the chi-square calculation it can be seen that the value of error is high especially at lung exhale and bone, indicating that we did not properly simulate this insert. Based in the previous research, the cause for discrepancy is not obvious but a potential explanation would be a mismatch between the composition used in the simulation and that of the actual insert (Landry, G., *et al.*, 2011).

According to Frank Verhaegen *et al.*, (2005), low CT number tend to increase with kVp, whereas high CT number tend to decrease with kVp. For example like bone, if we scan with 140 kVp the CT number obtained will be less than when we scan with 80 kVp. By referring to the table of CT value obtained in the appendix, the data is a little bit fluctuated given that some tissue gives increasing reading of CT values with increased tube voltage while some other gives decreasing reading of CT values with increased tube voltage. For example air and lung exhale gives a steady increasing CT value when the tube voltage increased. On the other hand, bone gives a steady decreasing CT value when the tube voltage increased. While the other 2 which is fat and water gives fluctuated reading as in the CT value increased at 120 kVp and then decreased at 140 kVp. According to J.T. Bushberg *et al* (2003) reducing tube voltage will reduce radiation dose, increase signal contrast for some tissues with high atomic number due to photoelectric effect increased and significantly increase beam hardening artifact if the beam energy gets too low.

In 1975 at Hospital of the University of Pennsylvania, Phelps *et al* showed an excellent correlation exists between CT numbers and electron density, indicating the major role of Compton interactions in CT imaging. Physical properties of each type of material influence the Compton scatter. It is important to have the value of linear attenuation coefficients, μ for individual interaction like photoelectric effect interaction, Rayleigh scattering, coherent scattering and Compton scattering. Values of μ were strongly dependent on incident x-ray energy on the physical density of the interacting medium (Seibert, J.A. *et al.*, 2005). As we can see from the table of CT numbers in appendix, air has lowest atomic number, electron density and density. Therefore the CT number will be lower than others which has higher atomic number.