COMPARISON OF CT NUMBER BETWEEN CONVENTIONAL CBCT AND IMASIM SOFTWARE

BY

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbols/ Abbreviations	Definition
CBCT	Cone Beam Computed Tomography
CIRS	Centre for Interactive Research on Sustainability
CT	Computed Tomography
DICOM	Digital Imaging and Communications in Medicine
DVT	Digital Volume Tomography
FDK algorithm	Feldkamp, Davis and Kress (FDK) algorithm
FOV	Field of View
g/cm^3	gram per centimeter cube
HU	Hounsfield Unit
kV	kilovoltage
kVp	peak kilovaltage
mAs	milliampere-second
max	maximum
MDCT	Multidetector Computed Tomography

min	minimum
mm	millimeter
MV	Mega Voltage
ROI	Region of Interest
TIFF	Tagged Image File Format
χ^2	Chi-square Test
2D	2 Dimensional
3D	3 Dimensional
σ	Expected error of measurement

ABSTRACT

The aim of this study was to compare the CT number between the conventional Cone Beam Computed Tomography (CBCT) and ImaSim simulation software. The CT numbers in CBCT were performed by using CIRS 062 M electron density phantoms with four types of tissue equivalent plug density phantoms ranging from 0 g/cm^3 to 1.61 g/cm^3 based on the common tissues in the oral cavity. The CT numbers of tissue equivalent density plugs were of air, adipose, water and bone were compared between CBCT and ImaSim software at 80 kVp and 10 mAs. 15 slices of CBCT images with slice thickness of approximately 1.0 mm are obtained from central axis of phantom were selected to measure the average CT number by drawing a region of interest (ROI) on every slice. The images of ImaSim were obtained by simulation of CBCT at similar phantom set up and CBCT exposure factors. The measurement of chi-square 'goodness of fit' was used to determine the closeness of CT numbers among theoretical, Planmeca Romexis CBCT and ImaSim. The results showed that the x^2 values of CT numbers of theoretical value against Planmeca Romexis CBCT were between 0.651 and 5.206 while the x^2 values of theoretical value against Imasim CBCT was between 3.738 and 42.201. However, the range of x^2 for Planmeca Romexis CBCT vs ImaSim CBCT was between 1.877 and 58.887. In conclusion, the high density tissues such as bone gave the highest degree of closeness of CT numbers between Planmeca Romexis CBCT and ImaSim. Therefore, low density tissues are best applied in ImaSim CBCT simulation.

ABSTRAK

Tujuan kajian ini adalah untuk membandingkan nombor CT antara pancaran kon tomografi berkomputer konvensional (CBCT) dan perisian ImaSim. Nombor tomografi berkomputer (CT) pancaran kon tomografi berkomputer (CBCT) telah dijalankan dengan menggunakan fantom ketumpatan elektron CIRS 062M dengan empat jenis fantom ketumpatan palam bersamaan tisu antara 0 g/cm^3 sehingga 1.61 g/cm^3 berdasarkan pada tisu biasa di dalam rongga mulut. Nombor CT ketumpatan palam bersamaan tisu adalah udara, adipos, air dan tulang telah dibandingkan antara CBCT dan perisian ImaSim pada 80 kVp dan 10 mAs. 15 hirisan daripada imej CBCT dengan ketebalan hirisan kira-kira 1.0 mm yang diperolehi dari paksi tengah fantom telah dipilih untuk mengukur purata nombor tomografi berkomputer (CT) dengan melukis sebuah kawasan yang penting (ROI) pada setiap hirisan. Imej ImaSim diperoleh daripada simulasi CBCT pada persediaan fantom dan faktor pendedahan CBCT yang sama. Pengukuran "chi-square", x^2 'kebagusan yang wajar' digunakan untuk menentukan kedekatan nombor CT antara teori "Planmeca Romexis CBCT" dan ImaSim. Keputusan menunjukkan bahawa nilai x^2 nombor CT daripada nilai teori terhadap "Planmeca Romexis CBCT" adalah di antara 0.651 dan 5.206 manakala nilai x^2 daripada nilai teori terhadap ImaSim CBCT adalah di antara 3.738 dan 42.201. Walau bagaimanapun, julat x^2 untuk "Planmeca Romexis CBCT" terhadap ImaSim CBCT adalah di antara 1.877 dan 58.887. Kesimpulannya, ketumpatan tisu yang tinggi seperti tulang memberikan tahap tertinggi kedekatan nombor CT antara "Planmeca

Romexis CBCT” terhadap ImaSim. Oleh itu, ketumpatan tisu yang rendah adalah yang terbaik untuk digunakan di dalam simulasi ImaSim CBCT.

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Cone-beam computed tomography (CBCT) is a relatively new diagnostic tool to dentistry that has revolutionized diagnosis and treatment planning. In the late 1990s, a new tomographic scanner known as cone beam computed tomography (CBCT) or digital volume tomography (DVT) was developed specifically for maxillofacial and dental use by Italian and Japanese groups (Arai et al., 2011). CBCT is competent by using rotating gantry to which an X-ray source and detector is fixed. The beam of X-ray is cone-beam shape and captured a cylindrical or spherical volume of data, described as field of view (FOV). The divergent pyramidal or cone beam shape of x-ray beam is directed through the middle of interest onto X-ray detector on the opposite side of patient. The X-ray detector is rotate around a fixed fulcrum within the region of interest (Scarfe, Levin, Gane & Farman, 2009)

The dimension of FOV is primarily dependent on the detector size and shape, beam projection geometry and the ability to collimate the beam. In general, the smaller the field of view (FOV), the higher the spatial resolutions of image (Scarfe, Levin, Gane & Farman, 2009). CBCT imaging provides 3-dimensional (3D) diagnostic information with better spatial resolution and less distortion than panoramic radiography machines (Prins *et al.,* 2011). CBCT is used to design different of two-dimensional (2D) tomographic slices and projection image as well as 3D volume and surface reconstructions.

The image of the CBCT gained from the detector that able to record x-ray photons, read off and send the signal to computer and be ready for the next acquisition many hundreds of times within a single rotation. The rotation is commonly produced within times equivalent to, or less than, panoramic radiography about 10 to 30 seconds, which necessitates frame rate image acquisition times of milliseconds (Scarfe & Farman, 2008)

ImaSim is a new software package for simulating X-ray imaging procedures and serve as a useful educational tool for medical x-ray imaging. ImaSim is mostly planned as an educational tool for teaching or self-learning the basics of the X-ray imaging process according to its creator which is Frank Verhaegen and Guillaume Landry of Maastro Clinic and Francois Deblois of the Jewish Hospital in Montreal. However, this software is used in research purposes in several recent scientific papers. The software gives beneficial to student to understanding of the imaging process by a hands-on approach coupled to classroom teaching (Landry, deBlois & Verhaegen, 2013).

The software package covers the main X-ray based modalities: planar kV, planar (portal) MV, fan-beam CT and CBCT imaging. The program ignores photon scatter and follows a ray tracing approach, besides to make calculation times reduced. Furthermore, ImaSim software consisting teaching software based on simulation environment.

CT number is in volumetric (3D) digital radiology, the radiographic density in each voxel of the volume of interest that expressed by number which air has density – 1000, water is 0, and compact bone +1000. CT number is expressed in Hounsfield Unit. For interpreting CT scans, a CT number scaleis widely used,

$$CT_{Number} = \frac{\mu Material - \mu Water}{\mu Water} \times 1000 \qquad (1.1)$$

Where the CT_{Number} (computed tomography number) is expressed in Hounsfield Units (HU) and μ is the attenuation coefficient for X-ray beam (Bryant, Drage & Richmond, 2012). The beam hardening, reconstruction artifacts, scattered radiation, or object orientation and inhomogeneities which might cause considerable intra and inter-scanner variability of the measured CT numbers are the factors that influenced the CT numbers (Groell et al., 2000).

Derivation of tissue properties from the CT equation:

$$\mu_{material} = \mu_{water} (CT_{no.} + 1) \qquad (1.2)$$

μ_{is} the attenuation coefficient for x-ray beam. Its mean that vacuum has a value of -1000 HU and water has 0 HU, thus providing two energy independent calibrations point. The energy dependence of the attenuation coefficients of other substances are different from that of water and often markedly (Bryant, Drage & Richmond, 2012).

1.2 Objective of the Study

1.2.1 Aim

To compare the CT number between CBCT and ImaSim software.

1.2.2 Objectives:

The objectives of this study are:

- To obtain image of Cone Beam Computed Tomography (CBCT) by using CBCT machine and ImaSim simulation.
- To calculate the deviation of CT number of various tissue substitutes between CBCT and ImaSim software.

1.3 Research Questions

1. How CBCT images are obtained between conventional and simulation methods?
2. Are there any differences on image information of various tissues on CBCT of CBCT machine and ImaSim software?
3. Which tissues are best simulated using the ImaSim?

1.4 Significance of Study

The results of this study contribute towards the Computed Tomography (CT) number between two different method which are using conventional and simulation method. ImaSim software is as a tool of for basic education of medical x-ray imaging. This software is an alternative to determine the CT number without use the real medical x-ray machine. Through this research, we could compare the CT number between conventional CBCT and Imasim software. The kVp used in this study is 80 kVp with 10 mAs.

CHAPTER 2

LITERATURE REVIEW

According to Bryant, Drage & Richmond (2012), CT number is expressed in Hounsfield Units (HU) and μ is the attenuation coefficient for x-ray beam. By definition vacuum has value of -1000 HU and water has 0 HU, thus providing two-energy independent calibration points. However, the energy dependence on attenuation coefficient of other substances are different from that of water and often markedly so. This means the substances other than water have energy-dependence CT numbers. Sarkis *et al.* (2007) state that Hounsfiled number maps are reproducible for a given configuration, but there is large variation in the values when measuring the tissue densities on low volume scans even the type of tissue is same. However, the CT numbers are not reliable and vary between machines. Besides that, Yamashina *et al.* (2008) state that "CBCT values were quite different compared the Hounsfield units from typical Multi detector Computed Tomography (MDCT) system" and give numerical examples with differences of hundreds of unit.

Mah, Reeves & McDavid (2010) conducted a study to investigate the relationship between grey scales in dental cone beam CT (CBCT) and HU in CBCT scanners. The manufacturers of dental CBCT systems have not used a standard system for scaling the grey scales or to compare the values with different machines. From the other of literature review, there are found that the weakness exists with CBCT systems, the display of HU is do not correct. Based on linear regression equation of the reference materials, attenuation coefficients were obtained for each materials and CT number in HU were derived by using the standard equation. In previous study by Katsumata et al, the authors found that calculated density (HU) on CBCT scan varied widely from a range of -1500 to over +3000 for different type of bone. The ability to assess the density or quality of bone is limited and in region of soft tissue it clearly shows that HU vary greatly and provide little and no significant data.

There are several factors that influence the CT numbers in CBCT for example beam hardening, artifacts from metallic restorations and scattered radiation that stated by Olivera *et al.* (2013). Of particular relevance to CBCT, the amount of scattered radiation varies with the FOV, with x-ray beam parameters and also with the anatomical location. Generally as the FOV decrease, the radiation dose decreases. The CBCT is significantly lower of radiation dose with decrease the FOV.

A study by Landry, deBlois & Verhaegen (2013) stated that ImaSim is a software tool for basic education of medical x-ray imaging in radiotherapy and radiology. This software include the main x-ray based on modalities which are planar kilovoltage(kV), planar (portal) megavoltage (MV), fan beam CT and CBCT imaging. The users can choose the photon source; object to be image and imaging set up with three-dimensional editors. This software ignores the photon scatter in order to reduce time. CBCT reconstruction was based on FDK algorithm with the same filter implementation as in CT. In this software, the authors not implemented the imaging of three-dimensional voxelized geometries.

CHAPTER 3

MATERIALS AND METHOD

3.1 CIRS 062 Electron Density Phantom

The Model 062M Electron density phantom enables precise correlation of CT data to electron density of various tissues and their CT number in Hounsfield units (HU). The phantom is manufactured from CIRS Tissue Equivalent Materials. The Model 062M consists of two nested disks made from Plastic Water® -LR. They can represent both head and abdomen configurations with the size 180 mm x 50 mm for electron density head insert and 330 mm x 270 mm x 50 mm for electron density abdomen. This phantom has nine different tissue equivalent electron density plugs that can be positioned at 17 different locations within the scan field. The size for each density plug is 30 mm x 50 mm. Table 3.1 shows the summarized the properties of the head, and density plug phantoms of CIRS 062M electron density phantom (Cirsinc.com, 2015).

Figure 3.1 CIRS 062 electron density phantom

Table 3.1 Table of summarization of Electron Density Plug Phantom

Phantom Part	Physical Density, g/cm^3	Relative Electron Density, x 10^{23} electrons/cc
Electron Density Head Insert	1.029	3.333
Lung (Inhale) Equivalent Electron Density Plug	0.20	0.634
Lung (Exhale) Equivalent Electron Density Plug	0.50	1.632
Breast (50%) Gland/ 50% Adipose) Equivalent Electron Density Plug	0.99	3.261
Solid Trabecular Bone (200 mg/cc HA) Electron Density Plug	1.16	3.730
Liver Equivalent Electron Density Plug	1.07	3.516
Muscle Equivalent Electron Density Plug	1.06	3.483
Adipose Equivalent Electron Density Plug	0.96	3.171
Solid Dense Bone (800 mg/cc HA) Equivalent Electron Density Plug	1.53	4.862
Solid Dense Bone (1250 mg/cc HA) Equivalent Electron Density Plug	1.82	5.663
Water Equivalent Material Surrounding Removal ϕ 1 "Vial for Real Water Electron Density Plug	1.00	3.340

Only three types of electron density plug had used in this research which is adipose equivalent, water and dense bone (800 mg/cc HA). Optional distance marker plugs enable quick assessment of the CT scanners distance measurement accuracy. The 062M is just one of three configurations available as a part of the Cone Beam CT Electron Density & Image Quality Phantom.

3.2 Cone Beam Computed Tomography Machine (CBCT)

The Planmeca ProMax® 3D Max was used in dental x-ray room in Hospital Universiti Sains Malaysia. The control panel and tube series number of Planmeca ProMax® 3D Max are TPK 355382 and TPP 101403. This machine is a 3D imaging device that produces all required volume sizes for diagnostic imaging on the maxillofacial region – from the smallest specialized cases to images of the entire skull. Scan volume (field of view) depends on detector size and shape, beam projection geometry and the ability to collimate the beam. The ProMax 3D is incorporating a small 3D sensor to ProMax digital panoramic line.

In general, the smaller the field of volume (FOV), the higher the spatial resolution of the image. With a maximum field of view (FOV) of Ø23 x 26 cm, it offers entirely new possibilities for diagnostics. There are various selection in kilovoltage and mAs which at range between 62 and 90 kvp for kilovoltage and 1 to 14 mAs. Planmeca ProMax 3D Max complies with a multitude of diagnostic requirements: those of endodontics, periodontics, orthodontics, implantology, dental and maxillofacial surgery, and temporomandibular Join Disorders (TMJ) analysis.

Figure 3.2 Planmeca ProMax 3D, CBCT machine

3.3 ImaSim Software

ImaSim was developed by Guillaume Landry, François deBlois and Frank Verhaegen at McGill University (Montreal, Canada) and Maastro Clinic (Maastricht, the Netherlands). This software is heavily inspired by the use of x-ray imaging in medicine, but can also be used for simulating industrial and other applications. ImaSim works in a modular approach; one assembles the x-ray source (using SpekCalc, co-developed by the same group), the subject to be imaged and the imaging panel, and then one defines the overall geometry. Image formation can then be simulated and various parameters can be changed based on available tissue equivalent materials in the ImaSim database.

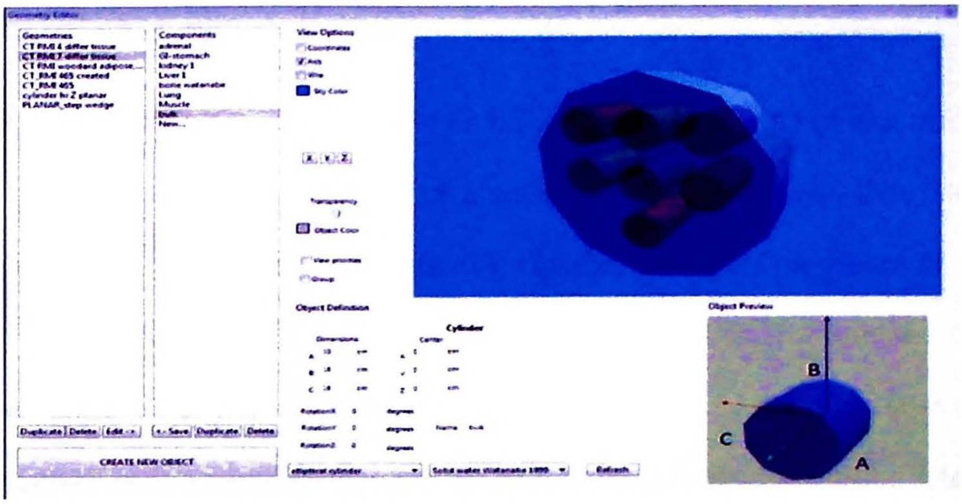

Figure 3.3 Lay out of ImaSim Software

3.4 Image Acquisition

CT number varies at the function of density of sample. Different types of plug density phantoms ranging from 0.00 to 1.61 g/cm^3 based on common tissue exist in oral cavity region.

CBCT images are obtained by scanning head phantom of electron density phantom. The images by simulation method are obtained by simulation of CBT using ImaSim software. The CT number of tissues are taken from different type of densities (air, adipose, water and bone) is compared between CBCT and simulation method. The differences between two methods were done using goodness of fit test calculation. CT numbers are taken at 80 kVp with 10 mAs.

3.4.1 CBCT Image Acquisition

The adipose equivalent, water and dense bone (800 mg/cc HA) of electron density plug was inserted into head section of electron density phantom. One slot of the phantom was left vacant to measure CT number of air. The head of electron density phantom was position on a box to scan by using CBCT machine in order to fit into the imaging position refer figure 3.4. In this research, phantom was scanned by using CBCT machine with exposure factor of 80 kVp and 10 mAs. The mAs is 121 and time of exposure is 12 second. The detector is rotate 180 degree. The image was send direct to Digital Imaging and Communications in Medicine (DICOM). The CT number was determining by using Planmeca Romixes software.

Figure 3.4 Set up of electron density phantom

3.4.2 ImaSim Image Acquisition

Imasim software package covers the main x-ray based medical modalities: planar kilovoltage (kV), planar (portal) megavoltage (MV), fan beam computed tomography (CT) and cone beam CT (CBCT). In this research, cone beam CT (CBCT) modality was selected. The 80 kvp of energy and cirs object was choosing. In the object editor, there are many components and the size of plug phantom that can be that can be selected. The ideal integrator was used to run the simulation. Before running the simulation, the value of mAs was pre-determined. The simulation was run in 180 degree based on CBCT machine, the Ram Lak filter was chosen because the spatial resolution of Ram Lak was increased. The Ram Lak filter gave the image noise level highest because the Ram Lak emphasizes high frequencies that affect it sensitive to noise (Seung-Wan *et al.*, 2011). The Image quality was improved by higher spatial resolution. Lastly, the raw images were reconstructed to obtain axis image. Figure 3.5 shows the flow of ImaSim image simulation process.

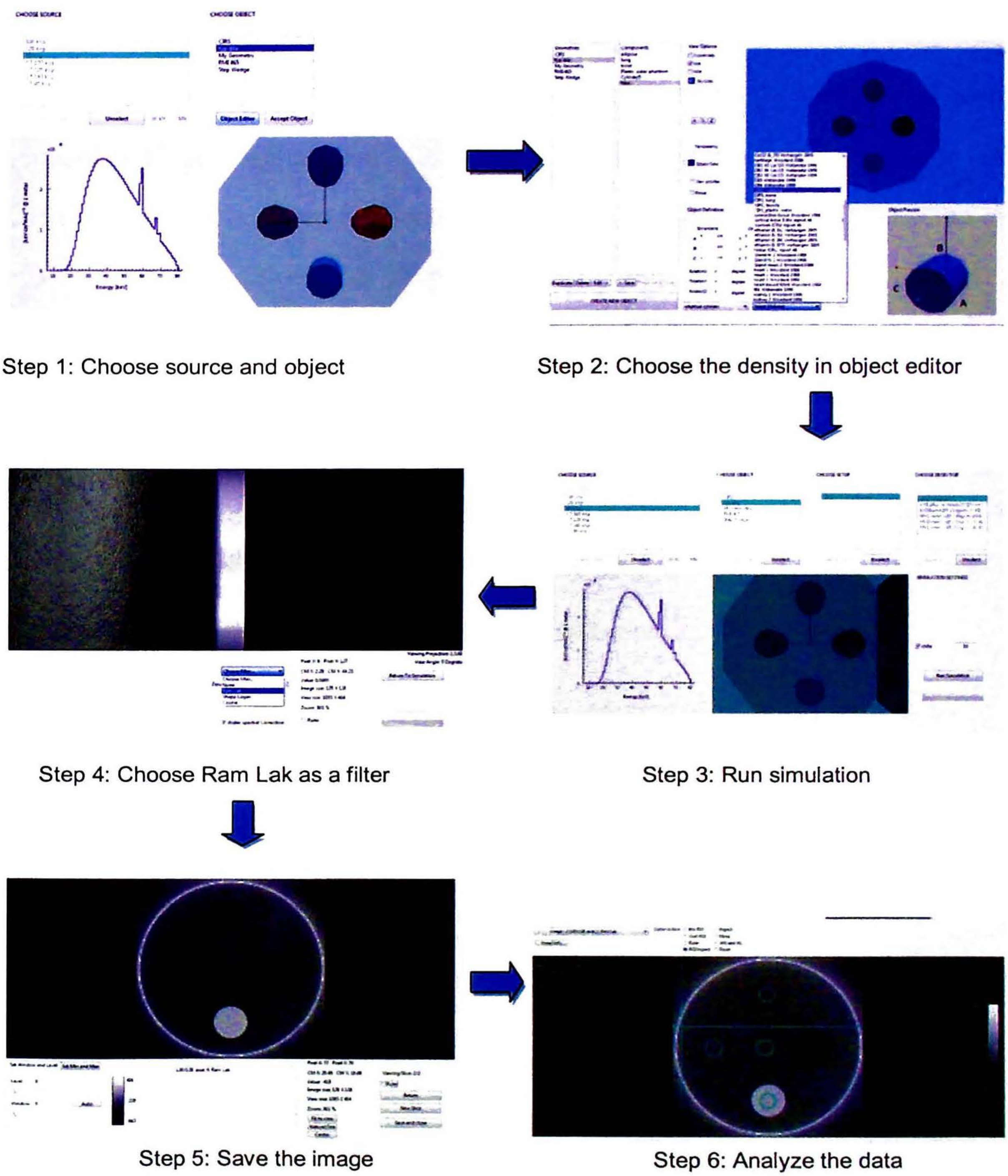

Figure 3.5 The flow of ImaSim simulation process

3.5 Data Analysis

The analysis procedures was used to determine CT number between conventional and simulation. 15 slices of images with slice thickness of approximately 1.0 mm are obtained from central axis of phantom are selected to measure average CT number. Then region of interest (ROI) is drawn to obtain average CT number for every slices. For direct image analysis using ImaSim software, CT images are converted into Digital Imaging and Communications in Medicine (DICOM) or Tagged Image File Format (TIFF) image format to be read by Imasim software. While for CBCT the image is directly convert into DICOM and analyzed using Planmeca software. Similar ROI is drawn on CT images to obtain average CT number using CBCT and Imasim software.

CT number analysis, measurement of 'goodness of fit' to determine the degree of closeness of CT numbers between conventional CBCT and ImaSim using chi-square equation of:

$$x^2 = \sum_{i=1}^{N} \left[\frac{y_i - f\ (x_i)}{\sigma_{i\ CT}}\right]^2$$

Where, y_i : observed value

x_i : theoritical prediction

σ_i : expected error of measurement (3.1)

(Marashdeh et al., 2012)

Error, σ can be calculated using equation:

$$\sigma = \frac{\max - min}{2}$$

where, max: maximum value

min: minimum value (3.2)

3.6 Measurement of Variables

- Independent variable is the type of tissue densities which are air, adipose tissue, water and bone.
- Dependent variable is the CT number between CBCT and ImaSim methods.

CHAPTER 4

RESULTS AND DISCUSSION

The graph of CT numbers for theoretical, Planmeca Romixes CBCT and ImaSim CBCT is plotted in Figure 4.1. The figure illustrated that the Planmeca Romixes CBCT and ImaSim CBCT are in agreement with the standard CT numbers where CT number increased with increased density of tissue equivalence density plug phantoms.

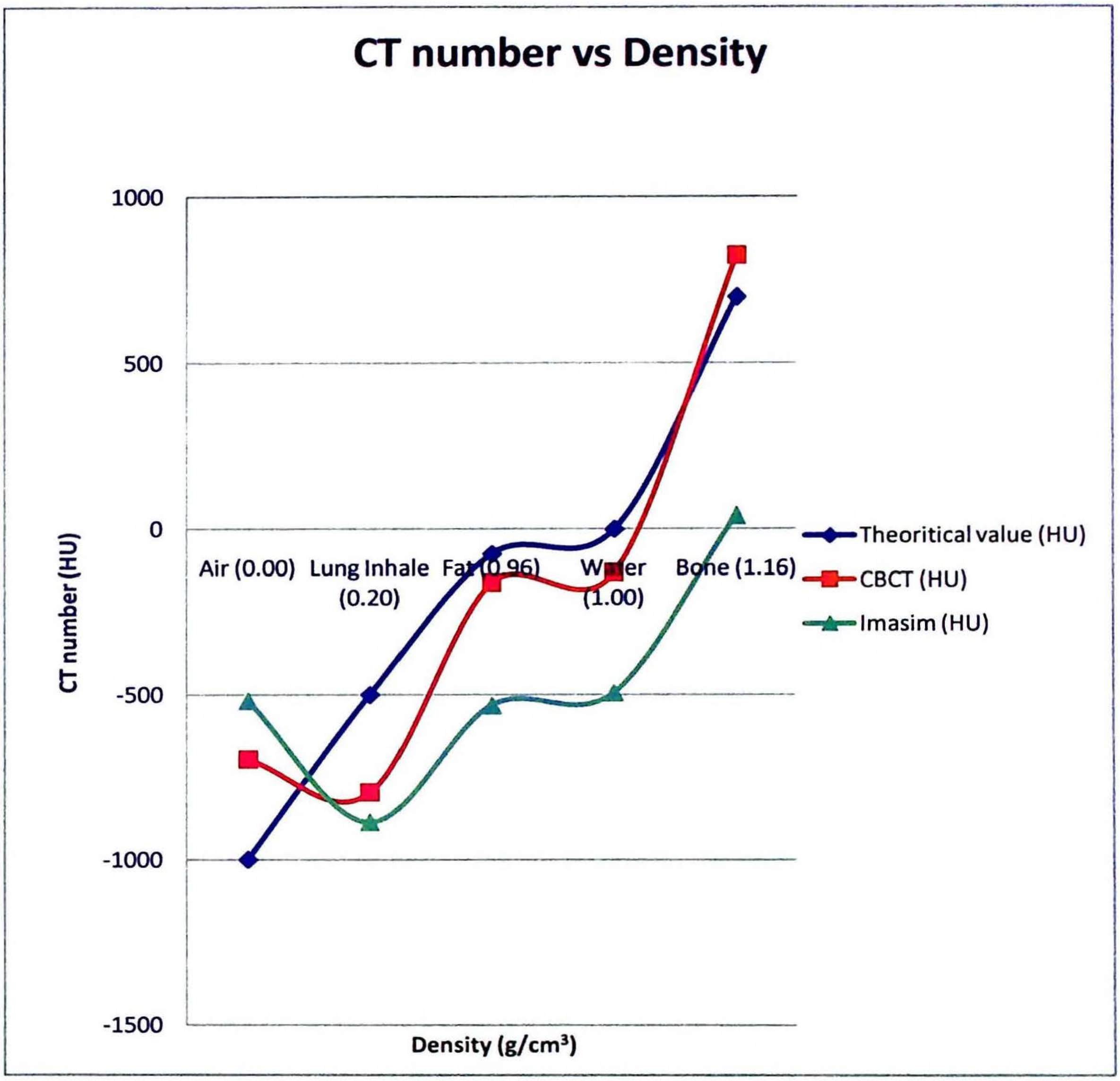

Figure 4.1 The graph of CT numbers for theoretical, Planmeca Romixes CBCT and ImaSim CBCT for various tissue equivalent plug density phantoms.

Table 4.1 and 4.2 show the average, maximum, minimum, and standard deviation of CT number (HU) between Planmeca Romixes software (CBCT) and ImaSim software respectively on CBCT x-ray energy of 80 kVp and 10 mAs at various tissue equivalence density plug phantoms. The comparison of CT numbers for theoretical value, Romixes CBCT and ImaSim CBCT for various tissue equivalence plug phantoms is presented in Table 4.3. It is shown that the theoretical value of CT number of for adipose tissue and water is higher than CBCT and ImaSim software. The CT number for air in ImaSim CBCT is higher than Planmeca Romixes CBCT and theoretical value. However for bone, the CT number of bone in Planmeca Romixes CBCT is higher than theoretical value and ImaSim CBCT.

Table 4.1 CT numbers of Planmeca Romixes CBCT for various tissue equivalent plug density phantoms.

Plug Phantom	Density (g/cm^3)	Mean CT Number (HU)			Standard Deviation
		Average	**Maximum**	**Minimum**	
Air	0.00	-695.330	-657.267	-924.33	45.461
Adipose Tissue	0.97	-161.600	-20.417	-301.080	47.163
Water	1.00	-130.170	5.850	-258.030	45.143
Dense Bone (800 mg/cc HA)	1.61	823.831	967.667	677.400	47.639

Table 4.2 CT numbers of ImaSim CBCT for various tissue equivalent plug density phantoms.

Plug Phantom	Density (g/cm^3)	Mean CT Number (HU)			Standard Deviation
		Average	Maximum	Minimum	
Air	0.00	-516.670	-366.333	-627.133	55.000
Adipose Tissue	0.97	-531.470	-471.133	-603.130	29.533
Water	1.00	-492.07	-359.333	-563.400	32.400
Dense Bone (800 mg/cc HA)	1.61	41.867	150.27	-53.533	42.400

Table 4.3 Comparison of CT numbers between Planmeca Romixes and ImaSim CBCT for various tissue equivalent plug density phantoms.

Density (g/cm^3)	CT numbers (HU)		
	Theoretical value	Planmeca Romixes CBCT	ImaSim CBCT
Air (0.00)	-1000	-695.33	-516.67
Adipose (0.97)	-75	-161.6	-531.47
Water (1.00)	0	-130.17	-492.07
Bone (1.61)	700	823.83	41.97

The goodness of fit Chie-square test, x^2 between Planmeca Romixes CBCT and ImaSim CBCT to the theoretical values is shown in Table 4.4. The goodness of fit calculation between Planmeca Romixes CBCT and ImaSIm CBCT is also presented in the table. The table showed that the CT numbers Planmeca Romexis CBCT is near to the theoretical values shown by the total x^2 values compared to ImaSim CBCT. The CT numbers of ImaSim CBCT is also significantly differs to that in Planmeca Romixes CBCT. It is also understand that the CT numbers of ImaSim CBCT is close to the theoretical and Planmeca Romixes CBCT at lower density tissues. The detailed calculation of can be refered in Appendice (Table 7.9, 7.10, 7.11).

Table 4.4 The x^2 values forPlanmeca Romixes CBCT and ImaSim CBCT to the Theoretical values.

Sample	χ^2 values		
	Theoretical value vs Planmeca Romixes	Theoretical value Vs ImaSim	Planmeca Romixes vs ImaSim
Air	5.206	13.738	1.877
Adipose	0.651	42.201	27.707
Water	0.973	23.273	12.589
Bone	0.728	41.714	58.887
Total x^2	7.558	120.926	101.043

The values of standard deviation (SD) of CT numbers at various densities were also shown in Table 4.1 and Table 4.2, where SD indicated uniformity of density of the tissue equivalence plug phantoms. The small the standard deviation show the high the uniformity (Sakamoto, Bulgarevich & Miki, 2014). ImaSim CBCT provided better density uniformity indicated by the SD of CT numbers. ImaSim CBCT provided lower SD of CT numbers between 29.533 and 42.400 at various tissue densitites compared to Planmeca Romixes CBCT between 45.143 and 47.639. The density uniformity of air in ImaSim CBCT however showed higher SD value of 55.00 compared to 45.461 by Planmeca Romixes CBCT.

Figure 4.1 showed the linearity of CT number at function of density, ρ. The CT number (HU) of air is slightly difference between theoretical value, Planmeca Romexis (CBCT) and ImaSim software with CT numbers of -1000, -695.33 and -516.67 respectively. The CT number of fat and water between theoretical value and CBCT is closer while the CT number of ImaSim is greater. The CT number of bone for ImaSim CBCT software shows significant different to theoretical value and Planmeca Romexis CBCT. The value CT number of bone for ImaSim, theoretical value and Planmeca Romexis is 41.97, 700 and 823.83 respectively.

The CT numbers of fat, water and bone for Planmeca Romexis CBCT were in good agreement with theoretical value of CT number compared to ImaSim CBCT. The CT number is in volumetric (3D) digital radiology, the radiographic density contributed by the x-ray attenuation with tissues in each voxel of the volume of interest that expressed in number (Molteni, 2015). Based on varies tissue density of CT number (HU) in this study, the influence by voxel might be caused the deviation of CT numbers by ImaSim CBCT. This is because the ImaSim CBCT does not equip with voxel algorithms. The imaging of three-dimensional voxelized geometries is currently not applied in ImaSim software (Landry, deBlois & Verhaegen, 2013).

Table 4.4 shows the chi square test for theoretical value vs Planmeca Romexis (CBCT), theoretical value vs ImaSim and Planmeca Romexis (CBCT) vs ImaSim software. The chi square calculation is a method to determine the closeness or goodness of fit of between observed value and the expected value. The chi square test, x^2 for theoretical value vs Planmeca Romixes CBCT is relatively smaller than that between theoretical and ImaSim CBCT. The range of x^2 between Planmeca Romixes CBCT and theoretical values were between 0.651 and 5.206 compared to x^2 between ImaSim CBCT and theoretical values between 13.738 and 42.201. The result shows that the degree of closeness between theoretical vs CBCT is better than theoretical value vs ImaSim software. The factors that influence the CT number include beam hardening, artifacts from metallic restorations and scattered radiation (Oliveira et al., 2013).

The goodness of fit of air, adipose tissue, water and bone in Planmeca Romexis CBCT and ImaSim CBCT was between 1.877 and 58.887. The value of X^2 for bone is higher than others tissue. Based on the chi square result, the best applied for ImaSim software is at lower density such as air (-1000 g/cm^3) and water (0 g/cm^3).