EVALUATION OF IMAGE ENHANCEMENT USING DIFFERENT PROTOCOLS FOR ROUTINE THORAX COMPUTED TOMOGRAPHY EXAMINATION ON 16-SLICE SCANNERS IN TWO TERTIARY HOSPITALS

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2021

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by

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Thesis submitted in fulfilment of the requirements for the degree of Master of Science

May 2021

ACKNOWLEDGEMENT

All praises to Allah

I wish to express my sincere gratitude and appreciation to my supervisor Dr. Noor Khairiah A. Karim, whom convincingly guided and encouraged me to get things done and making sure that I am on the right track, even when the road got tough. Without her persistent help, the objectives of this study would not have been realized. Many thanks to my co-supervisor, Dr. Noor Diyana Osman who willingly taken time out of her hectic schedule to guide me and telling me what should I do when I am in the dark, and Professor Ibrahim Lutfi Shuaib, whom inspire me to always think outside of the box and also his generous guidance to the young learners like me. I am forever indebted to the staff from Imaging Unit of IPPT, USM and Radiology department, HPP for their kindness and help for this study. I wish to acknowledge the support and great love of my family, parents and my nine siblings, my superior at work, HH Kuan for his understanding, colleagues from EFCOF and EHS department, and everyone whom anonymously lend their hand in this work.

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LIST OF ABBREVIATIONS

3D	3 Dimensional
AA	Ascending aorta
ABT	Automatic bolus tracking
ALARA	As low as reasonably achievable
ATCM	Automatic tube current modulation
CM	Contrast medium
CNR	Contrast to noise
CT	Computed tomography
FTD	Fixed time delay
FV	Fixed volume
HPP	Hospital Pulau Pinang
HU	Hounsfield unit
IPPT	Institut Perubatan dan Pergigian Termaju
IV	Intravenous
kV	kilovoltage
mAs	milliampere-second
MDCT	Multidetector computed tomography
MoH	Ministry of Health
PT	Pulmonary trunk

PV	Pulmonary vein
ROI	Region of interest
SD	Standard deviation
SNR	Signal to noise
SVC	Superior vena cava
USM	Universiti Sains Malaysia
WBV	Weight based volume
Z	Atomic number

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PENILAIAN PENINGKATAN IMEJ MENGGUNAKAN PROTOKOL BERBEZA UNTUK PEMERIKSAAN TOMOGRAFI BERKOMPUTER TORAKS RUTIN PADA PENGIMBAS *16-SLICE* DI DUA BUAH HOSPITAL TERTIER

ABSTRAK

Tujuan kajian ini dijalankan adalah untuk membandingkan dan menilai peningkatan kontras dan kualiti imej untuk tomografi berkomputer toraks rutin pada pengimbas 16-slice di dua buah hospital yang menggunakan protokol yang berbeza. Dua protokol tersebut adalah; 1) teknik *automatic bolus tracking,* (ABT) yang mana isipadu kontras media yang diberi kepada pesakit adalah berpandukan berat badan pesakit tersebut, yang dikenali sebagai, *weight based volume* (WBV), dan; 2) teknik *fixed time delay* (FTD), menggunakan waktu menunggu yang sama untuk semua pesakit dan semua pesakit diberi nilai isipadu kontras media yang sama, *fixed volume* (FV) tanpa mengira berat badan pesakit. Data 140 pesakit telah dikumpul secara retrospektif daripada dua hospital; 70 orang pesakit telah melalui prosedur tomografi berkomputer di Institut Perubatan dan Pergigian Termaju, Universiti Sains Malaysia (IPPT, USM), menggunakan teknik ABT dengan WBV. Baki 70 orang pesakit adalah daripada Hospital Pulau Pinang, Kementerian Kesihatan Malaysia (HPP, KKM), dan mereka telah melalui prosedur yang sama menggunakan teknik FTD dengan FV. Pesakit IPPT terdiri daripada 19 lelaki dan 51 wanita; min umur ± SD 53.6 ± 11.2 tahun; min berat ± SD 54.04 ±13.77 kg. Manakala pesakit HPP terdiri daripada 24 lelaki dan 46 wanita; min umur ± SD 54.5 ± 13.2 tahun. Darjah peningkatan kontras pada *region of interest* (ROI) telah diukur dalam nilai Hounsfield unit (HU) untuk tujuan analisa secara kuantitatif. Untuk penilaian kualitatif, imej CT telah digred pada skala 1-5; *1= very poor, 2 = poor, 3 = fair, 4 = good, and 5 = excellent.* Nilai min peningkatan kontras untuk pesakit HPP adalah lebih besar daripda nilai min peningkatan kontras untuk pesakit IPPT ($p<0.001$). Perbandingan min untuk skor kualiti pada skala 1-5 menunjukkan tiada perbezaan statistik yang ketara, ($p = 0.185$). Jumlah isipadu kontras media dan nilai HU adalah berhubungan secara positif, namun lemah, $r = 0.1619$. Secara tuntas, protokol FTD dengan FV telah menghasilkan darjah peningkatan kontras yang lebih tinggi. Penilaian kualitatif menunjukkan tiada perbezaan statistik yang ketara antara protokol walaupun para penilai menilai imej CT yang diambil menggunakan teknik ABT dengan WBV lebih tinggi. Telah banyak kajian yang cenderung memilih ABT dengan WBV kerana protokol ini menghasilkan imej yang lebih baik dari segi kontras dan kualiti imej. Kesimpulannya, teknik imbasan dan administrasi kontras yang optimum untuk *16-slice* toraks rutin adalah ABT dengan WBV. Ini kerana teknik ini boleh ditentukan mengikut keperluan individu dan boleh menghasilkan imej yang memuaskan. Adalah penting untuk mengambil kira faktor yang saling berkait yang boleh mempengaruhi darjah peningkatan kontras dan kualiti imej. Setiap teknik administrasi kontras media dan keboleh pakaian dalam praktis klinikal perlu dikaji lebih dalam.

EVALUATION OF IMAGE ENHANCEMENT USING DIFFERENT PROTOCOLS FOR ROUTINE THORAX COMPUTED TOMOGRAPHY EXAMINATION ON 16-SLICE SCANNERS IN TWO TERTIARY HOSPITALS

ABSTRACT

The purposes of this study were to evaluate and compare the degree of contrast enhancement and image quality of routine thorax computed tomography (CT) examination on 16-slice scanner in two hospitals using two different protocols. The two protocols named as; 1) automatic bolus tracking (ABT), which volume of contrast media (CM) administered were tailored to the patient weight, known as weight-based volume, (WBV); 2) fixed time delay (FTD) technique, using the same delay for every patient and the patients were administered with fixed volume of contrast media (FV) regardless of their individual variations. Data of 140 patients were collected retrospectively from two centers; 70 patients were examined at Institut Perubatan dan Pergigian Termaju, Universiti Sains Malaysia (IPPT,USM), using ABT with WBV technique, and another 70 patients were examined at Hospital Pulau Pinang, Ministry of Health Malaysia (HPP, MoH) using FTD with FV technique. Patients from IPPT comprises of 19 males and 51 females; mean age ± standard deviation (SD) 53.6 ± 11.2 years; mean weight ± SD 54.04 ± 13.77kg. Patient from HPP comprises of 24 males and 46 females; mean age ± SD 54.5 ± 13.2 years. The degree of contrast enhancement in region of interest (ROI), were measured in Hounsfield unit (HU) values, for quantitative assessment. As for qualitative assessment, CT image were graded on 5 –point scale; 1= very poor, 2 = poor, 3 = fair, 4 = good, and 5 = excellent. The mean enhancement values for patient from HPP were found to be greater than the mean of enhancement values for patient from IPPT ($p<0.001$). Mean comparison of qualitative scores on a 5-point scale showed no statistical significant difference ($p = 0.185$). Total contrast media volume and HU values were found to correlate positively, but weak, ($r = 0.1619$). Overall, FTD with FV protocol yields higher degree of contrast enhancement for routine thorax CT examination. Qualitative assessment showed no statistical significant difference between protocols although CT images taken in ABT with WBV technique were graded higher by assessors than FTD with FV technique. A lot of previous studies preferred ABT with WBV as it produce better result in terms contrast enhancement and improve subjective image quality. To conclude, the optimal scanning technique and CM administration contrast for 16-slice routine thorax CT is ABT with WBV as it can be individualised in order to achieve comparable and satisfactory image enhancement and image quality. It is important to take into account of multiple inter related factors that affect the degree of contrast enhancement and image quality. Each CM administration technique and their validity in clinical practice should be studied further.

CHAPTER 1: INTRODUCTION

1.1 Background

Multi detector computed tomography (CT) has evolved in its ability to image faster, accurately capture rapidly moving structures and improve resolution. Contrast enhancement is a key component in CT imaging which helps to distinguish abnormal body structure from other structures. With rapid and short scanning times, it is essential to optimise the contrast medium (CM) administration and image acquisition in achieving maximal contrast (Saade et al., 2016). Contrast enhancement is needed in determination of image quality and it is dependent on numerous interacting factors. Significant factors that may influence contrast transit time are inter individual variation such as patient's body weight and height, heart rate, circulation time, and cardiac impairment (Bae, 2006). However, many important variables that help to determine image quality are controllable by the operator.

Most common selections for CT protocols are fixed time delay (FTD), timing bolus and automatic bolus tracking (ABT). FTD technique uses administration of CM as a trigger to start CT scanning. This delay will be determined based on historical data and operator's understanding, which individual variations were usually ignored. Although this technique has promised a good result, particularly in patients with no underlying cardiovascular disorder, scan delay should be tailored to each individual. As for timing bolus technique, CM is injected in small volume (of 15 to 20 ml) and followed by repetitive low dose CT scanning. Enhancement-time relationship's graph is plotted to determine time to peak enhancement, and subsequently, scan delay. Pitfall that remains for timing bolus technique is that although the amount of contrast use was high, there was no obvious improvement in contrast enhancement degree. ABT technique uses multiple low dose scan, which will be initiated after an entire bolus of

CM administered, and arterial enhancement at the anatomic ROI reaches a certain threshold. This technique helps to conserve CM, and is effective, but scan can fail to initiate if the ROI is placed incorrectly, if the patient moves, or if there is venous inflow problem.

During portal phase scan, tailoring the CM volume to patient's body weight can help to reduce inter patient variability. This weight-based volume (WBV) technique seems to be superior to fixed volume (FV) technique. Contrast administration using FV of 70 to 80 ml for thorax CT, is a common practice.

1.2 Problem statement

Bolus-tracking technique has previously been proposed as an effective tool for better synchronising scanning with contrast enhancement, however there were still no consensus achieved on which technique results optimum vascular attenuation (Bae, 2006; Como et al., 2011; Erkonen & Smith, 2010; Johnson & Fishman, 2006; Purysko et al., 2016; Rawson & Pelletier, 2013).

1.3 Objectives

General objective

To compare the degree of contrast enhancement and image quality of thorax CT examinations on 16-slice scanner in two hospitals using different scanning techniques (automatic bolus tracking in portal-venous phase imaging vs fixed time-delay examinations), and CM volume (fixed vs weight-based contrast volumes).

Specific objectives

1. To assess and compare the degree of contrast enhancement and image quality for each thorax CT examination by quantitative and qualitative measurement.
2. To propose the optimal scanning technique and contrast media administration method to achieve satisfactory image quality for routine computed tomographic examinations.
3. To determine the relationship between HU values and CM volume.

1.4 Hypothesis statement

1) Null hypothesis, H_O

   H_O=There are no significant differences in contrast enhancement and image quality using different scanning techniques and CM administration protocols in both medical centres.

2) Alternative hypothesis, H_A

   H_A=There are significant differences in contrast enhancement and image quality using different scanning techniques and CM administration protocols in both medical

1.5 Thesis outline

In this writing, Chapter One is the introduction which describe about background of the study, statement of problem, lists of objectives, and thesis outline. It is a basic guideline to the research. Literature review and theories related to the study area was elaborated in Chapter Two and it is marked the past studies from various field and by number of scholars. In the theories, factors that affecting contrast enhancement in CT scan were briefly explained, which focusing on two common protocols, (ABT) with WBV CM and FTD with FV CM. As for Chapter Three, Materials and Method which describe about the study design, inclusion, exclusion criteria and methods used in data collection and analysis, which later helps in result and data analysis. In Chapter Four, results of patient demographics and analysis were presented in table for easy review and discussed in Chapter Five. Discussions were written based on findings and compared to previous studies. In Chapter 6, a conclusion and recommendation were written as to restate the main arguments and suggestion for future studies.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

In recent years, there is significant increment in contrast enhanced CT scan usage in emergency department including for thorax assessment. For many clinical conditions involving thorax, contrast enhanced CT plays a vital role as it helps to enhance lesions' conspicuity, and the need for contrast varies on case by case basis. Technological improvements of the multi-detector computed tomography (MDCT) in terms of its scanning speed has driven the need to match the CT image acquisition with CM delivery. MDCT is a medical instrument that has taken over plain x-ray protocols in clinical diagnostic because of the plain x-ray's inability to differentiate tissues of similar density (Bae et al., 2008). Tissue contrast is upgraded by using CT scanner and it combines series of X-ray images taken from 360 angles that allow for 3D visual reconstruction (Lusic & Grinstaff, 2013). Plain X-ray will display the entire anatomic structure and CT images allow us to visualise slices of a structure. Conventional CT scan produce only one tomographic slice image with each rotation, thus provide limitation. As CT scan evolved, it is equipped with continuous rows of detectors that yield multiple CT images with only one rotation. MDCT scan offers shorter time for scanning and it allows larger volume scanning (Erkonen & Smith, 2010; Herr, 2010). Pitfalls that remained for single slice CT is that it's incapability to cover a larger volume at one time inspection. It is suggested that larger volume coverage can be achieved by faster gantry rotation of a CT scanner (Johnson & Fishman, 2006). CT detectors of more rows leads to shorter examination time and better image quality. Image quality obtained from four generations of MDCT was compared in terms of image quality, and there was a significant difference that shows 64 row MDCT scored highest grade. CT scan become important in imaging procedure for clinical diagnostic, as it is able to distinguish, emphasise and enhance the image of inner body, thus helps in detecting any change within the body systems precisely (Bae et al., 2008). Since 1998, the progress of scanning speed and longitudinal resolution have contributed to increase performance for variety clinical protocols thus, to suit the speed it is required to adjust image acquisition protocols(Como et al., 2011; Johnson & Fishman, 2006). Intravenous injection of CM is required for most thorax examinations in order to enhance noticeable lesions, and this protocol still contributes challenges and technical issues associated in contrast enhancement and scan timing.

2.2 Computed Tomography and contrast media

Computed Tomography (CT) is based on X-rays discovered by Wilhelm Conrad Roentgen over 100 years ago. CT images are the result of analysis on beam of X-rays that passes through a media and experiencing insignificant scattering. This cross sectional medical imaging technology was introduced by Godfrey Hounsfield in 1972 (Alshipli & Kabir, 2017; Karna & Mats Lindholm, 2018).

Modern CT scanners with continued development in terms of spatial resolution, acquisition times and data reconstruction, has become recognised as part of tissue imaging procedure. CT is noninvasive diagnostic tool and it produces images by applying the same concept as traditional radiography, which allows for 3D visual reconstruction and segmentation of tissues of interest (Lindsay & Carstens, 2011; Lusic & Grinstaff, 2013; Waldman, 2009). The images are captured by rotating an X-ray source around an object, at small angular increments, for 360 degree rotation. Sequential slice-like image are obtained during the process using complex algorithms in order to create a 3D version of the scanned object (Lusic & Grinstaff, 2013). CT scan is preferable as it eliminates superimposition and demonstrates enhanced resolution, which helps to detect small changes in organ size, shape, margin and contour position compared to conventional radiography (Lindsay & Carstens, 2011). Radiology personnel have constantly studied and tried to acquire latest and better CT machines which later helps in faster acquisition and examination. However, side effects of latest technology in terms of image quality and radiation remain uncertain. It is proven that 64 rows MDCT have better image quality than 16 rows MDCT, but higher number of multiple slices can expose patients with higher radiation dose. Image quality of 64 rows MDCT is more than acceptable for diagnostic purpose, and there was a concern that current practice may lead to over exposure of radiation doses to the patients. 16 rows MDCT is conclude to produce least image quality, but acceptable for diagnostic purpose and also lowest in radiation dose.

In CT imaging, most of the body tissues are easily visualised, however it can be challenging process to image and identify the boundary between two adjacent tissues, such as liver and tumour, which their attenuation values can be quite similar. Hounsfield unit (HU) is a measurement on ability of the matter to attenuate X-ray. Zero (0) HU is given as a density value for water and -1000 HU is for air. Tissues attenuation values are likely to fall in range 30 to 100 HU, except for lung and bone, which the attenuation value is either up to or approximately -1000 HU and 1000 HU respectively. Typical approximated CT numbers are presented in Table 2.1.

Table 2.1 Approximated CT number for various materials for an X-ray beam in the range of 80-140 kVp (Kamalian et al., 2016).

Tissue	**CT number (HU)**
Air	-1000
Lung	-(550-950)
Fat	-(80-100)
Water	0
Muscle	10-40
Kidney	20-40
Blood	40-60
White matter	46
Gray matter	43
Spongious bone	50+
Dense bone	1000+

Absence of contrast media might cause wrong diagnosis as two adjacent body tissue may be considered as ROI because lack of contrast. The patient and contrast media factors are interrelated, which later plays role in distribution of contrast media within the body. With contrast media, there will be greater differences in CT attenuation, which helps in improving image quality (Bae, 2010b; Lusic & Grinstaff, 2013)

High levels of attenuation can be achieved with the incorporation of high atomic number (Z) elements into the contrast agent molecule. In CT imaging applications, iodine (Z=53) has been the chemical of choice and iodine content in contrast media is related to its radio opacity. Greater absorption and scattering of X-ray radiation is caused by iodine in the target organ or blood plasma, and this then will increase CT images contrast enhancement and better delineate vascular structure (Bae, 2010b; Thomas, 2015).

CM may be administered intravenously (IV) which then help in identification of vascular anatomy, and may also be administered orally for esophagus diseases assessment. If CM are to be administered through the vein, it is preferable for the IV catheter placed in the right antecubital vein as left arm may result in high attenuation "streak" artifacts (Han et al., 2001; Scholtz & Ghoshhajra, 2017).

2.3 Contrast enhancement

Contrast enhancement is needed in CT scan as it contributes to successful diagnosis of a particular patient and commonly applied to vascular disease assessment, which help in distinguishing vessel lumen. In this procedure, contrast agents are used to distinguish between organs and improve lesion recognition. Diagnostic yield can be optimised by using the correct type of contrast agent and selection of administration route (Rawson & Pelletier, 2013). However, not all CT protocols need for contrast, which mean that the need for contrast varies on case by case basis.

CM injection and CT scan play important part in allowing optimum contrast enhancement at specific time points. Several factors needed to take into account in determining the magnitude of contrast enhancement which can be grouped into; patient, injection of CM and CT scan. Patient and injection factors are highly interrelated, and the other factors may affect the magnitude of contrast enhancement while others may affect the timing of contrast enhancement (Figure 2.1) (Bae, 2006).

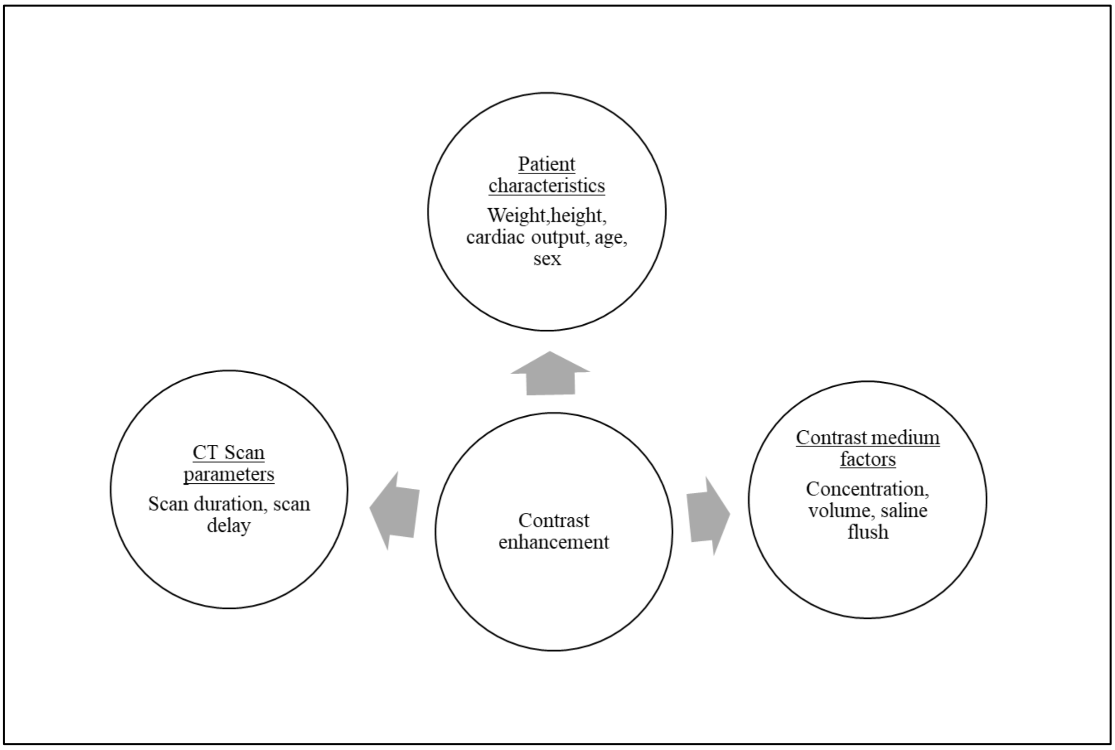

Figure 2.1 Overview of factors affecting contrast enhancement

2.4 Patient-related factors

Body weight of a patient is inversely proportional to the magnitude of contrast enhancement. Therefore, larger patients will exhibit lower magnitude of contrast enhancement. This effect can be associated with blood volume, the larger the patients, the larger the blood volume. Thus, in large blood volume, the administered CM dilutes more, reducing its concentration in the blood and the magnitude of the contrast enhancement will decrease (Bae, 2010b; Perrin et al., 2018; Saade et al., 2016). So it is suggested that amount of iodine should be adjusted according to patient's body weight. For large body weight's patient, it is recommended to use high volume and high concentration of CM, or to use faster injection rate (Bae et al., 2008; Erkonen & Smith, 2010).

Cardiac output is a significant patient -related factor which will determine the scan timing. It is directly proportional to the contrast bolus arrival time, and inversely proportional to vascular enhancement. Patient with large body weight has an effect on cardiac function. Reduce in cardiac function might leads to a longer circulation time and result in delayed peak enhancement as CM volume clears slowly. For patient with high cardiac output, contrast bolus settled faster at reduced enhancement (Lindsay & Carstens, 2011; Saade et al., 2016). Tailoring CM dose to patient's cardiac output is suggested using test bolus or tracking bolus method in order to eliminate variation between patients (Erkonen & Smith, 2010).

2.5 CT scanning related factors-scan delay

a) Bolus tracking

Based on a study, bolus tracking is a popular option for fast scanners. The scans will be so fast that without this technique, scanning would be impossible as it is easy to miss vascular phase. Bolus tracking technique is commonly applied in CT scanning which the contrast arrival in thoracic aorta will be monitored using a bolus tracking software, 8 second after CM injection, followed by multiple low radiation dose and images are acquired at fixed scanning level (Bae, 2010a). The first scan will be activated once the magnitude of contrast enhancement within the ROI with a desired HU is met (Cassel et al., 2013; Choi et al., 2016). Threshold for contrast enhancement is suggested in range of 50-150 HU as too low or too high threshold is not practical which will contribute difficulties in attenuation measurement and may result in long scan delay or erroneous diagnosis (Saade et al., 2016). Incorrect placement of ROI over a non-target structure is a common mistake when bolus tracking technique is used. ABT technique can be effective and save CM, but there are risks that if the ROI placed wrongly, patient is unable to lie still, or if there is problem with venous inflow, the scan would have problem to initiate correctly (Lindsay & Carstens, 2011). This technique was said to be better than test bolus technique and FTD, as scanning matches better with CM which produces stable enhancement, and as FTD was not always appropriate in minimising individual variability like ABT. For a population of children whom the rate of CM administration cannot be used to determine delay, Ruess and his co-workers (1998) used ABT method in their study.

b) Fixed time delay

In order to obtain a quality CT image, it is a must to set scan timing for the arrival of CM in targeted organ appropriately as scanning too early would result in sub peak enhancement whereas scanning too late would miss optimum enhancement (Bae, 2010a). For many routine CT acquisition, FTD is enough if maximum vessel opacification is not the main interest, and for patients with no underlying cardiovascular disorder (Gerber et al., 2007). FTD is one of the popular choices because of its simple procedure and it is easier to achieve good opacification (Fleischmann, 2006). Even though this technique has been employed successfully in pulmonary CT acquisition, it is not recommended in cardiac CT procedure (Scholtz & Ghoshhajra, 2017). This technique takes historical approach and the scan delay will be determined based on operator's experience and understanding on FTD mechanism, without taking into account on patient individual variations. The delay is predefined between CM injection and CT acquisition, without the need to monitor the attenuation level in the ROI. Optimal scan delay for the CM to reach ROI varies from patient to patient, which falls in range of 10s to 35s. As for children, it is advised for the delay to range from 10s to 15s interval due to their small size, thus scanning will end faster, compared to adult.

c) Test bolus

Test bolus is performed with a small amount of CM, usually 15-20% of the total dose and saline flush is injected to the patient and then followed by a repetitive low dose CT scan, also known as trial scans 8 to 15 seconds later, depending on the patient's pressured circulatory status. The scans are taken usually at 2 seconds interval and averaging for one slice is 20 to 30 seconds (Gerber et al., 2007; Saade et al., 2016). In the ROI, enhancement (measured in HU) over time will be recorded and the time to peak enhancement is calculated, which later will determine the scan delay. The delay is used to plan the actual diagnostic scan. In fast MDCT, if the contrast material arrival time is directly used as scan delay, this may result an early scan. Thus, sum of contrast material arrival time with additional delay is suggested so that diagnostic CT scan is adequately delayed and yield an optimum contrast enhancement. Test bolus technique is suggested when smaller vessels are in area of interest, and this overcome the variability of the bolus tracking technique. However, errors can still happen due to transient variations in cardiovascular physiology (Mai et al., 2013).

2.6 Contrast medium factors

Factors that are related to CM are injection duration, injection rate, CM volume, concentration and use of a saline flush. Injection duration is determined by the CM volume and injection rate, and it affects the magnitude of contrast enhancement and scan timing (Bae, 2010a; Cassel et al., 2013).

The duration of CM to be injected is depending on scanning conditions and clinical purpose of the examinations. As for large patient, the injection duration should be longer by adding up the CM volume and injection rate is fixed (Bae, 2010a). To achieve good enhancement throughout image acquisition, injection duration should be prolonged as too short duration will result in insufficient contrast enhancement (Hoshino et al., 2016).

Concentration of CM plays significant role in attaining satisfactory contrast enhancement. Iodine concentration is defined as number of iodine molecules detected in the desired vessel during CM administration. CM of a higher iodine concentration delivers more iodine mass per unit time and yields earlier and greater peak aortic enhancement. By using high concentration CM, volume can be reduced. For every 25% increment in concentration, it allows equivalent of 25% reduction of total volume administered. In several studies, concentration of 370 mg I/ml yielded significantly higher enhancement than 250 mg I/ml, and 300 mg I/ml was said to be the most adequate concentration (Behrendt et al., 2013; Furuta et al., 2004; Yagyu et al., 2005). If the CM being administered to patient has high concentration, it will cause beam hardening effects and will directly reduce the image quality (Abdul Razak et al., 2013). Contrast enhancement is directly proportional to CM concentration, which for per milligram iodine, contrast enhancement normally is normally in a range of 25-30 HU. It is suggested that to consider higher concentration of CM for heavier and larger patients as they yield less contrast enhancement (Bae, 2010a).

In optimising contrast bolus delivery, a saline flush pushes the tail of the injected contrast bolus into the central circulation and eventually allows better utilisation of contrast media and to make use of the remaining CM in the injection tubing and peripheral veins. This will contribute to optimum contrast enhancement. For a fixed volume of CM followed by a saline flush, the magnitude of the peak arterial enhancement is increased (Bae, 2010a).

2.7 Tube current (mA) and tube potential (kV)

There are a few scan parameters that can affect image quality, two of them are tube current and tube voltage.

Tube current-time product (mAs) is the product of the X-ray tube current (mA) and CT scanner exposure time per rotation (in seconds). Tube current is the most common scan parameters adjusted because of its linear relationship with radiation dose. When the tube current (mA) is increased, it will results in high radiation dose, as mAs is proportional to the radiation output. As an example, increasing tube current time product from 50 mAs to 100 mAs will also increase the radiation output two times, thus radiation exposure to patient will be increased (Lira et al., 2015). In order to reduce radiation dose exposure to patient, it is suggested that tube current should be adjusted to patient size, ROI and diagnostically required image quality (Schindera et al., 2008). Image noise, is inversely proportional to the square root of change in applied milliamperes (mA). For any decrease in image noise, image quality will be better (Maldijan & Goldman, 2013). In modern MDCT, it is equipped with automatic tube current modulation (ATCM) which helps proper patient exposure and allows tube current to be modulated during the scanning procedure. ATCM can help in saving dose as the scanner will produce less X-ray photon in lower attenuation region of the patient body and for region of higher attenuation, the tube will automatically modulate to higher values current. Reduction in radiation dose will result in increased image noise and decrease image quality (Scharf et al., 2017). Previous study has demonstrated that radiologists consistently gave higher image quality scores to images obtained with a higher tube current (Siva P. Raman Robert V. Blasko, Elliot K. Fishman, 2013). Image noise is easily measured by placing a ROI in an area of uniform density in the body. Image noise will be represented by standard deviation of the pixel values. Radiation dose and image noise can be modified by adjusting tube current, scan time and tube voltage. The radiation dose can also be linearly affected by scan time (Huda & Abrahams, 2015).

Tube voltage, measured in kilovoltage (kV), determines the energy of the photon emitted from X-ray tube. If tube voltage increases, photons bombarded are high in energy. Radiation dose is approximately proportional to the square of the percentage changes in kVp, if all other parameters being fixed. Radiation can be reduced up to 33% if tube voltage decreased from 120 kV to 100 kV provided that tube current is constant. Tube voltage will affect image noise and contrast enhancement of CT image, and at low voltage, CT image will have more noise (Seyal et al., 2015). In a study, the use of 120 kVp is decided as a standard number for all patients with normal body type as with this setting, it produces satisfactory image quality when compared to other tube voltage value (Kim et al., 2017). Increasing tube voltage will increase the output of the x-ray tube. If the tube current and scan time are not changed, decreasing the tube voltage will decrease the radiation dose to the patient. Changes in tube voltage also affect CT tissue attenuation values, which can change tissue contrast in a complex fashion. Tube voltage may be reduced when scanning smaller patient, especially if intravenous CM is administered. The lower tube current will increase the subject contrast provided by the contrast media and provide diagnostic scans of satisfactory image quality at reduced radiation dose (Mayo & Aldrich, 2006). It is noted that the radiation exposure delivered at a given tube voltage and current settings will vary greatly between CT scanners (Mayo & Aldrich, 2009).

CHAPTER 3: MATERIALS AND METHODS

3.0 Introduction

In order to evaluate the degree of contrast enhancement and image quality of thorax CT examinations on 16-slice scanner in two different centres, data of 70 patients were collected at Institut Perubatan dan Pergigian Termaju, (IPPT) and Hospital Pulau Pinang, (HPP) respectively.

3.1 Study design

This study was a retrospective cohort data collection study between Imaging Unit of IPPT, USM and Department of Diagnostic Imaging, HPP, MOH. Data collected were from patients whom their criteria met the inclusion criteria, and underwent a contrast-enhanced CT examination from July 2014 to December 2015.

3.2 Study duration

This study was conducted from 1st March 2016 to 28th February 2018 (24 months).

3.3 Study population

Population for this study was originated from all the patients' data whom underwent a contrast enhanced thorax CT examination using 16-slice scanner in each center.

3.4 Study sample

Data from a total of 70 consecutive adult patients who underwent a contrast-enhanced thorax CT examination during the period of July 2014 to December 2015 were collected from each centre (total 140 patients)**.** The determination of sample size was based on *Table N for Small Medium and Large ES at power = .80 for α = .01, .50, and .10* by Cohen (1992). Using t-test for the difference between two independent means, Alpha - 0.05, Power – 0.80, Standard deviation - 72 (based on highest value stated in related article), Detectable different- 36 (50% from standard deviation), it is calculated that sample size, N = 64. Assuming 10% drop out from each group, a total of 70 patients needed from each center (Figure 3.1).

Table 2
N for Small, Medium, and Large ES at Power = .80 for α = .01, .05, and .10

	α								
	.01			.05			.10		
Test	Sm	Med	Lg	Sm	Med	Lg	Sm	Med	Lg
1. Mean dif	586	95	38	393	64	26	310	50	20
2. Sig *r*	1,163	125	41	783	85	28	617	68	22
3. *r* dif	2,339	263	96	1,573	177	66	1,240	140	52
4. *P* = .5	1,165	127	44	783	85	30	616	67	23
5. *P* dif	584	93	36	392	63	25	309	49	19
6. χ^2									
1*df*	1,168	130	38	785	87	26	618	69	25
2*df*	1,388	154	56	964	107	39	771	86	31
3*df*	1,546	172	62	1,090	121	44	880	98	35
4*df*	1,675	186	67	1,194	133	48	968	108	39
5*df*	1,787	199	71	1,293	143	51	1,045	116	42
6*df*	1,887	210	75	1,362	151	54	1,113	124	45
7. ANOVA									
$2g^a$	586	95	38	393	64	26	310	50	20
$3g^a$	464	76	30	322	52	21	258	41	17
$4g^a$	388	63	25	274	45	18	221	36	15
$5g^a$	336	55	22	240	39	16	193	32	13
$6g^a$	299	49	20	215	35	14	174	28	12
$7g^a$	271	44	18	195	32	13	159	26	11
8. Mult *R*									
$2k^b$	698	97	45	481	67	30			
$3k^b$	780	108	50	547	76	34			
$4k^b$	841	118	55	599	84	38			
$5k^b$	901	126	59	645	91	42			
$6k^b$	953	134	63	686	97	45			
$7k^b$	998	141	66	726	102	48			
$8k^b$	1,039	147	69	757	107	50			

Note. ES = population effect size, Sm = small, Med = medium, Lg = large, diff = difference, ANOVA = analysis of variance. Tests numbered as in Table 1.
[a] Number of groups. [b] Number of independent variables.

Figure 3.1 Cohen's table of sample size. (Cohen,1992)

3.5 Inclusion and exclusion criteria

3.5.1 General inclusion and exclusion criteria

Data of patients who underwent a contrast-enhanced thorax CT examination, in the period of July 2014 to December 2015, were collected in this retrospective study. Inclusion criteria for patient's selection were those more than 18 years old and generally, patients with underlying shock, renal impairment and heart disease were excluded from this study.

3.5.2 Inclusion criteria for patients in IPPT

In IPPT, only patients who underwent contrast enhanced thorax CT examination using ABT technique, administered with WBV CM and of 350 mgI/ml in concentration were chosen. Total volume of CM injected to patients was tailored to their body weight and administered using a dual injector at a rate approximately 4.0 ml/s followed by saline flush at similar rate. The total iodine per kilogram body weight was kept constant at 400 mg/kg.

3.5.3 Inclusion criteria for patients in HPP

As in HPP, only patients who underwent contrast enhanced thorax CT examination using FTD technique, administered with fixed volume CM and 300 mgI/ml in concentration were chosen. CM of fixed volume, was administered using a dual injector at a rate approximately 1.5 to 2.0 ml/s followed by saline flush at similar rate.

3.6 Data collection method

For each patient, demographic data (age and gender), indication for CT of the thorax, and CT scan parameters (tube voltage, tube current, rotation time, slice thickness and pitch) were collected and documented (Table 3.1) (Appendix A,B,C and D).

Table 3.1 Details of scanning parameters in IPPT and HPP.

Scanning parameters	IPPT	HPP
Tube voltage (kVp)	120	120
Tube current (mAs)	98-395	300
Rotation time (sec)	0.6	0.5
Contrast scanning protocols	Automatic Bolus Tracking (ABT)	Fixed Time Delay (FTD)
Volume of CM	Weight based volume (WBV); 48-149 ml	Fixed volume (FV); 80 ml

3.7 Study variables

3.7.1 Dependent variables

a) Tube current

b) Tube voltage

c) Scanning protocols

d) Contrast volume

3.7.2 Independent variables

a) Age

b) Gender

c) Cardiac output

d) Body weight

3.8 Quantitative and qualitative analysis

Two radiologists from each centre (IPPT and HPP) with more than 3 years' experience conducted qualitative and quantitative analysis in independent and separate sessions. They were blinded to the scanning protocols and CM administration. For quantitative analysis, ROIs was placed manually, with diameter average of 8mm in the selected anatomy (main vessels) which were the ascending aorta (AA), main pulmonary trunk (PT) (before its bifurcation into the right and left pulmonary artery), superior vena cava (SVC), and pulmonary vein (PV). This was performed using OsiriX DICOM viewer (Bernex, Switzerland) and the attenuation readings in Hounsfield Unit (HU) were shown and recorded. During the ROI analysis, the vascular calcifications was avoided.

For qualitative analysis, to express overall image quality, all CT images were then scored in range of 1 to 5, based on five criteria as Table 3.2.

Table 3.2 Description criteria for image quality scoring.

Score	Criteria	Description
1	Very poor	-Blood vessel are undistinguished from surrounding -No/minimum vascular enhancement
2	Poor	-Some contrast between vessels and surrounding structure -Slight vascular enhancement
3	Fair	-Presence of contrast between vessels and surrounding structure -Presence of vascular enhancement -Images inadequate for evaluation
4	Good	-Presence of contrast between vessels and surrounding structure -Presence of vascular enhancement -Images allow proper evaluation but hard to evaluate
5	Excellent	-Strong contrast between vessels and surrounding structure -Clear vascular enhancement

3.9 Statistical analysis

Statistical analysis was conducted using commercially available software, IBM SPSS Statistics 24, and Microsoft Excel. All HU values and image quality score were then tabulate according to the protocols, and the mean for attenuation values and quality score were assessed and compared. In order to find the relationship between HU values and other parameters, Pearson's correlation coefficient (r) test was performed. Cohen's kappa coefficient (k) was conducted to find the inter assessor reliability. A p-value of less than 0.05 was considered statistically significant.

3.10 Ethical Issue

This non-interventional study has been approved by Jawatankuasa Etika Penyelidikan Manusia, Universiti Sains Malaysia (JEPeM-USM); USM/JEPeM/15090297, and The Ministry of Health Medical Research Ethics Committee (MREC); NMRR-15-2271-24987. The ethical committee deemed that patient written informed consent was not required due to the retrospective nature of the study. Official letters were obtained from IPPT, USM and HPP authorities before reviewing the data. The confidentiality and privacy of patients' data were actively protected. All data were assigned a unique identification number.

3.11 Conflict of Interest

There was no conflict of interest.

CHAPTER 4: RESULTS

4.1 Results

There was a total of 140 patients' data collected from both centres, 70 patients' data from each centre, IPPT and HPP respectively. These patients underwent contrast enhanced CT thorax examination using 16-slice scanner in time frame of July 2014 until December 2015.

4.1.1 Patients demographics

Demographic characteristics for patients involved in this study were presented as below (Table 4.1). Total of 70 patients' data were collected from each centre, making total of 140 patients.

From IPPT data were collected from a total of 51 female patients, and 19 male patients. Their age ranged from 29 to 77 years old with mean and standard deviation (SD) of 53.6±11.2 years old at the time when thorax CT examination was performed at the centre. Data from 46 female patients and 24 male patients were collected from HPP, with patients' age ranging from 20 to 80 years old. The mean age and SD was 54.5±13.2 years old (Figure 4.1).

Since IPPT used ABT with WBV technique, patient's weight were recorded. Their weight ranged from 32kg to 100 kg with mean ± SD of 54.04±13.77kg. As for HPP, protocol used was fixed-time delay (FTD) with fixed contrast volume (FV), so there was no weight recorded (Table 4.1).

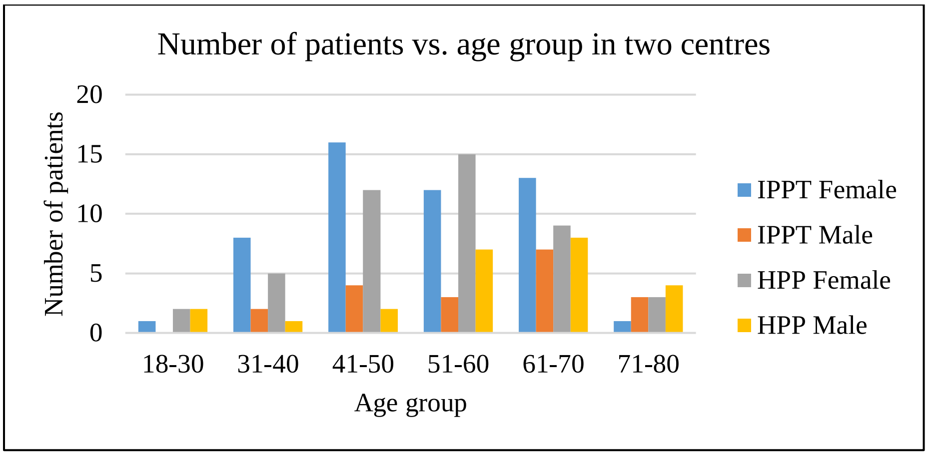

Figure 4.1 Number of male and female patients from IPPT and HPP grouped into age group

Table 4.1 Demographic characteristic of patients from both centers.

Center	**IPPT**		**HPP**	
Gender	**Female**	**Male**	**Female**	**Male**
Total number	51 (72.9%)	19 (27.1%)	46 (65.7%)	24 (34.3%)
Age (Mean ± SD)	53.6 ± 11.2 years old		54.5 ± 13.2 years old	
Weight (Mean ± SD)	54.04 ± 13.77kg		*NA	

*NA: Not Applicable

4.1.2 Mean of HU values in two centers

A complete data sets taken in the ROI of the ascending aorta (AA), superior vena cava (SVC), pulmonary trunk (PT) and pulmonary vein (PV) (Figure 4.2a, 4.2b) for both group (IPPT and HPP) provided in appendices.