COMPUTED TOMOGRAPHY DOSE INDEX FREE-IN-AIR AND SINGLE SCAN DOSE PROFILE ANALYSIS OF MULTI-SLICE SCANNERS

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Dedicated with love,

To the love of my life,

Luqman and Adam,

To the dearest in my heart,

Noor'Aini and Salehhon,

To the rainbows of my world,

'Izzaty, Mahfuz and Haziq.

Without you, my success would not be possible.

Thank you for loving me for who I am.

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ABSTRACT

The increasing use of computed tomography (CT) in clinical practice marks the needs to understand the dose descriptor and dose profile. The purpose of the current study is to determine the computed tomography dose index free-in-air ($CTDI_{air}$) and to evaluate the single scan dose profile (SSDP) in two types of multi-slice CT (MSCT) scanners. The MSCT scanners involved were 128-slice CT scanner Siemens SOMATOM Definition AS+ at Hospital Sultanah Aminah (HSA), Johor Bahru and 16-slice CT scanner Siemens SOMATOM Emotion 16 at Hospital Permai, Johor Bahru. Two types of dosimeters were used for the measurements which were thermoluminescence dosimeter (TLD-100) and optically stimulated luminescence dosimeter (nanoDot OSLD). For each CT scanner, all protocols were set based on the routine CT abdominal examinations for adult male. The scan time, slice thickness and nominal beam width were held on constant while the tube current and tube potential were modified. In total, there were seven protocols for 128-slice CT scanner and six protocols for 16-slice scanner. For both CT scanners, when the tube current or the tube potential was increased, the $CTDI_{air}$ was increased as well. For 128-slice CT scanner using TLD-100, when the tube current was constant at 100 mAs, the $CTDI_{air}$ ranged from 3.560 mGy (80 kV) to 13.585 mGy (140 kV). When the tube potential was constant at 120 kV, the $CTDI_{air}$ ranged from 8.825 mGy (100 mAs) to 21.528 mGy (250 mAs). From OSL dosimeter, when the tube current was constant at 100 mAs, the $CTDI_{air}$ ranged from 2.391 mGy (80 kV) to 7.751 mGy (140 kV). When the tube potential was constant at 120 kV, the $CTDI_{air}$ ranged from 6.084 mGy (100 mAs) to 14.604 mGy (250 mAs). For 16-slice CT scanner using TLD-100, when the tube current was constant at 100 mAs, the $CTDI_{air}$ ranged from 1.924 mGy (80 kV) to 4.624 mGy (130 kV). When the tube potential was constant at 110 kV, the $CTDI_{air}$ ranged from 2.456 mGy (50 mAs) to 6.493 mGy (200 mAs). From OSL dosimeter, when the tube current was constant at 100 mAs, the $CTDI_{air}$ ranged from 0.747 mGy (80 kV) to 1.649 mGy (130 kV). When the tube potential was constant at 110 kV, the $CTDI_{air}$ ranged from 1.058 mGy (50 mAs) to 3.833 mGy (200 mAs). For both MSCT scanners, the SSDP plotted using OriginPro 9.0 software showed that peaks in which the tube current was varied were higher and sharper than the SSDP peaks when the tube potential was changed. The full width at half maximum (FWHM) obtained from the SSDP presented the nominal beam width set for the MSCT scanner. For 128-slice CT scanner, the FWHM of OSLD was more reliable as it coincided with the nominal beam width which was 38.4 mm while for 16-slice CT scanner, the FWHM of TLD-100 was more reliable as it coincided with the nominal beam width which was 10.0 mm. The results showed good agreement between FWHM and nominal beam width. In conclusion, the X-ray tube output generated from the MSCT scanners was in line with the CT protocol setup.

ABSTRAK

Peningkatan penggunaan tomografi berkomputer (CT) dalam amalan klinikal menandakan perlunya pemahaman tentang pemerihal dos dan profil dos. Kajian ini bertujuan menentukan indeks dos tomografi berkomputer bebas-dalam-udara ($CTDI_{air}$) dan menilai profil dos imbasan tunggal (SSDP) pada dua jenis pengimbas tomografi berkomputer hiris berbilang (MSCT). Pengimbas MSCT yang terlibat ialah pengimbas CT 128-hiris Siemens SOMATOM Definition AS+ di Hospital Sultanah Aminah (HSA), Johor Bahru dan pengimbas CT 16-hiris Siemens SOMATOM Emotion 16 di Hospital Permai, Johor Bahru. Dua jenis dosimeter telah digunakan dalam pengukuran iaitu dosimeter luminesens terma (TLD-100) dan dosimeter luminesens optik terangsang (nanoDot OSLD). Bagi setiap pengimbas CT, semua protokol telah ditetapkan berdasarkan pada rutin pemeriksaan abdomen CT untuk lelaki dewasa. Masa imbasan, ketebalan hiris dan lebar alur nominal telah dimalarkan manakala arus tiub dan keupayaan tiub telah diubah suai. Keseluruhannya, terdapat tujuh protokol untuk pengimbas CT 128-hiris dan enam protokol untuk CT pengimbas 16-hiris. Bagi kedua-dua pengimbas CT, apabila arus tiub atau keupayaan tiub meningkat, $CTDI_{air}$ turut meningkat. Untuk pengimbas CT 128-hiris dengan menggunakan TLD-100, apabila arus tiub malar pada 100 mAs, $CTDI_{air}$ berjulat dari 3.560 mGy (80 kV) hingga 13.585 mGy (140 kV). Apabila keupayaan tiub malar pada 120 kV, $CTDI_{air}$ berjulat dari 8.825 mGy (100 mAs) hingga 21.528 mGy (250 mAs). Daripada dosimeter OSL, apabila arus tiub malar pada 100 mAs, $CTDI_{air}$ berjulat dari 2.391 mGy (80 kV) hingga 7.751 mGy (140 kV). Apabila keupayaan tiub malar pada 120 kV, $CTDI_{air}$ berjulat dari 6.084 mGy (100 mAs) hingga 14.604 mGy (250 mAs). Untuk pengimbas CT 16-hiris dengan menggunakan TLD-100, apabila arus tiub malar pada 100 mAs, $CTDI_{air}$ berjulat dari 1.924 mGy (80 kV) hingga 4.624 mGy (130 kV). Apabila keupayaan tiub malar pada 110 kV, $CTDI_{air}$ berjulat dari 2.456 mGy (50 mAs) hingga 6.493 mGy (200 mAs). Daripada dosimeter OSL, apabila arus tiub malar pada 100 mAs, $CTDI_{air}$ berjulat dari 0.747 mGy (80 kV) hingga 1.649 mGy (130 kV). Apabila keupayaan tiub malar pada 110 kV, $CTDI_{air}$ berjulat dari 1.058 mGy (50 mAs) hingga 3.833 mGy (200 mAs). Bagi kedua-dua pengimbas MSCT, SSDP yang diplot menggunakan perisian OriginPro 9.0 menunjukkan bahawa puncak SSDP yang mana arus tiubnya diubah adalah lebih tinggi dan lebih tajam berbanding puncak SSDP apabila keupayaan tiub diubah. Lebar penuh pada separuh maksimum (FWHM) yang didapati daripada SSDP menunjukkan lebar alur nominal yang ditetapkan pada pengimbas MSCT tersebut. Bagi pengimbas CT 128-hiris, FWHM daripada OSLD adalah lebih dipercayai memandangkan ia bertepatan dengan lebar alur nominal iaitu 38.4 mm manakala bagi pengimbas CT 16-hiris pula, FWHM daripada TLD-100 adalah lebih dipercayai kerana bertepatan dengan lebar alur nominal iaitu 10.0 mm. Dapatan menunjukkan terdapat persetujuan yang baik antara FWHM dan lebar alur nominal. Kesimpulannya, pengeluaran sinar-X yang dijana daripada tiub pengimbas MSCT adalah sejajar dengan tetapan protokol CT.

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LIST OF ABBREVIATIONS

CT	-	Computed tomography
CTDI	-	Computed tomography dose index
$CTDI_{air}$	-	Computed tomography dose index free in air
FWHM	-	Full width at half maximum
kV	-	kilovolt
kVp	-	peak kilovoltage
LiF	-	Lithium fluoride
mAs	-	milliampere second
MC	-	Monte Carlo
Mg	-	Magnesium
MOH	-	Ministry of Health Malaysia
MSCT	-	Multi-slice computed tomography
nC	-	nanocoulomb
OSLD	-	Optically Stimulated Luminescence Dosimeter
SSDP	-	Single slice dose profile
Ti	-	Titanium
TL	-	Thermoluminescence
TLD	-	Thermoluminescence dosimeter

LIST OF SYMBOLS

^{6}Li	-	Lithium-6
^{7}Li	-	Lithium-7

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The discovery of X-ray by Wilhelm Conrad Roentgen in his Wurzburg laboratory in 1895 marked the true start of imaging (Mikla, 2014). After the announcement, imaging techniques based on the discovery were almost immediately implemented all over the world. Roentgen's invention has been acknowledged as the predecessor of the modern era of medical imaging and he has been awarded the first Nobel Prize for physics in 1901 due to his discovery of this short-wave ray. The term "X-ray" is used until now because at that moment, he did not understand what the rays were and "X" was chosen since it is usually used to denote the unknown identity.

The use of X-ray has expanded to all kinds of practices including characterization analysis, industrial radiology, airport security and most importantly, medical imaging. The technology in medical imaging has been continuously improved and one of the development was the introduction of X-ray computed tomography (CT) to medicine in the early 1970s by Godfrey Newbold Hounsfield, which has broadened the use of slice imaging for the first time (Kalender, 2011). He is recognized as the inventor of CT and was awarded the Nobel Prize in 1979.

CT is a diagnostic procedure which uses special X-ray equipment to create cross-sectional pictures of human body (Mikla, 2014). CT was the first radiological imaging modality that exclusively provides computer digital images and offers images of single discrete slices (Kalender, 2011). The information acquired from CT examinations makes it one of the most widely used diagnostic tools (Oliveira et al., 1995). Unlike general X-ray examination, the capability of CT scanners to scan the whole body from image bone, soft tissue to blood vessels all at the same time has demonstrated the most valuable advantage of CT itself. Figure 1.1 showed the abdominal CT scan where a 3 cm nodal mass was at the level of the aortic bifurcation.

Figure 1.1 A cross sectional image of abdomen during abdominal CT imaging

Since the advent of CT, there were a lot of reports on the radiation exposure of CT systems (Shope et al., 1981). Those reports described various measurement methods to characterize the radiation delivered by CT and many of them were based on single scans measurements. The concept of the computed tomography dose index (CTDI) was introduced as a simple way to evaluate the CT dose descriptor. A long (100 mm) pencil ionization chamber is commonly used to make CTDI measurements which integrates the longitudinal single scan dose profile (SSDP) using a single axial scan (Jucius & Kambic, 1977). By far the most common method for measuring single scan dose profile (SSDP) is using thermoluminescence dosimeter (TLDs) due to its abundance of advantages, though several other methods have been described as well such as the use of a segmented ion chamber and radiographic film (Nakonechny et al., 2005).

As claimed by Shope et al. (1981), the dose description is to characterize the doses and according to Oliveira et al. (1995), the dose profile is such an important topic that attracts the interest of researchers. Therefore, the current study were to measure the CTDI free in air ($CTDI_{air}$) and SSDP using thermoluminescence dosimeter (TLD-100) and optically stimulated luminescence dosimeter (OSLD) in the multi-slice CT (MSCT) scanners at Johor Bahru hospitals. The measurements were taken free in air because $CTDI_{air}$ is an important element in the implementation of patient dosimetry (EUR, 1999). Those two dosimeters were chosen because they are feasible and give good outcomes (Nakonechny et al., 2005). The second national medical radiation exposure study commissioned by the Ministry of Health Malaysia which was conducted from 2005 until 2009 did not include the study on the SSDP (MOH Malaysia, 2009).

The concept of dose descriptor CTDI and dose profile SSDP provides a lot of information on the characterization and performance of MSCT. Besides, the effect of different tube current (mAs) and tube potential (kV) in measuring CT dose is worthy of special attention. In short, the current study intended to identify the most optimum dose profile and at the same time evaluate the performance of the MSCT scanners in Johor Bahru hospitals.

1.2 Problem Statement

The study of dose description and CTDI has started since the introduction of CT in the early 1970s (Shope et al., 1981). And since then, there were many comprehensive analyses and measurement of CT has been performed for scanners and operating conditions. The purpose of the present research is to investigate the descriptions of CT dose including the CTDI free in air and dose description which later known as single slice dose profile (SSDP).

However, in Malaysia, there was no recent report on the SSDP although there was a second national medical radiation exposure study conducted by Ministry of Health Malaysia from 2005 to 2009 (MOH Malaysia, 2009). The inadequate of the SSDP reports on multi-slice CT (MSCT) scanners in Malaysia hospital gave the opportunity to conduct the current study. The use of two different methods was purposely to determine the $CTDI_{air}$ and evaluate the SSDP for different types of MSCT scanners in Johor Bahru hospitals. An overview on the problem statement was shown in Figure 1.2 for better understanding.

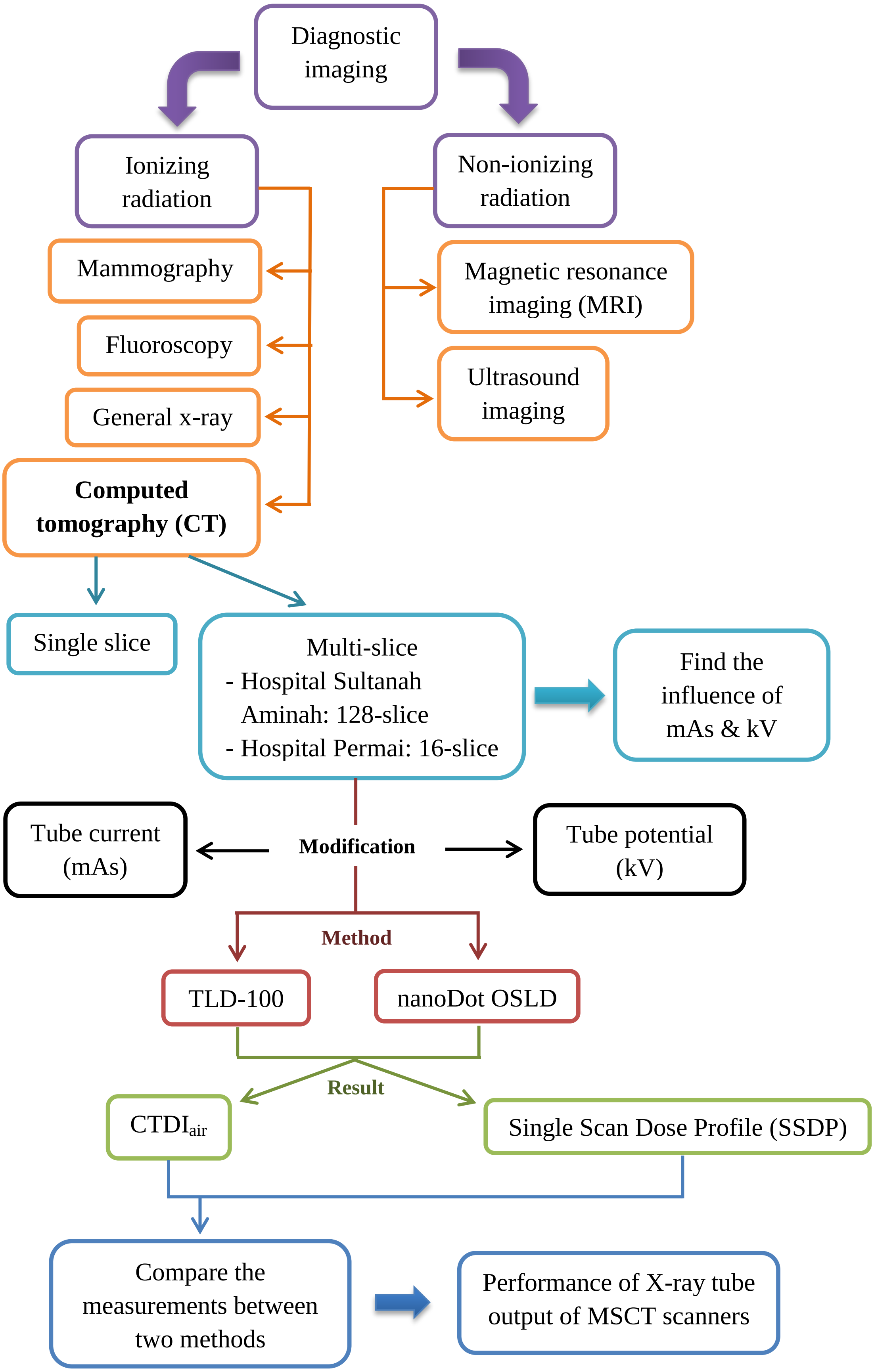

Figure 1.2 Schematic diagram of problem statement on current study

1.3 Objective of Study

The objectives of this study are:

1. To determine the computed tomography dose index free in air ($CTDI_{air}$) in multi-slice computed tomography (MSCT) scanners using thermoluminescence dosimeter (TLD-100) and optically stimulated luminescence dosimeter (nanoDot OSLD).
2. To assess the single scan dose profile (SSDP) in MSCT scanners using TLD-100 and nanoDot OSLD.
3. To evaluate the performance of X-ray tube output from MSCT scanners in Johor Bahru hospitals.

1.4 Scope of Study

The current study involved collecting $CTDI_{air}$ data and assessing SSDP in two types of MSCT scanners from hospitals in Johor Bahru, Malaysia using TLD-100 and nanoDot OSLD. The protocols were based from routine CT abdominal examinations for male adult abdomen. The input parameters such as the tube current (mAs), tube potential (kV), scan time (s) and nominal beam width (number of detector × beam collimation) were varied according to the settings from the manufacturers. Evaluation of each measurement was done by plotting the single scan dose profile (SSDP) graphs and statistically analysing it. The MSCT scanners dose profile provides the information on the characterization and performance of X-ray tube output of the scanners.

1.5 Significance of study

The abundance of information on MSCT scanners characterization and performance evaluation does not limit the current study. Due to the limitation of study on this matter in the Johor Bahru hospitals as stated earlier, this study was important in finding the dose profile of MSCT scanners and evaluating the scanners' X-ray tube output performances. The information was valuable to be recorded as consistency check of CT machines.

1.6 Thesis Outline

The first chapter briefly introduced the background, purpose and importance of this study. The reader might get the whole idea on what the study was all about. The second chapter gave a glimpse on the CT history and provided the review on the previous work and research which were related to the current study. Chapter 3 explained in detail all the steps that were taken to complete the whole procedures for this study. This included the description on the types of materials, the methods used and how the data were analysed. The next chapter showed the results of this study, together with the appropriate explanations. Lastly, Chapter 5 consisted of the conclusion which answered all the objectives stated earlier and some suggestions that can be done for the future work.

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