DETERMINATION OF PAEDIATRIC DOSE REFERENCE LEVELS (DRLS) IN COMPUTED TOMOGRAPHY SCANNERS IN TWO PUBLIC HOSPITALS IN KLANG VALLEY

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by

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LIST OF ABBREVIATIONS

AAPM	American Association of Physicist In Medicine
ALARA	As Low As Reasonably Achievable
cm	Centimeter
CT	Computed Tomography
$CTDI_{vol}$	Computed Tomography Dose Index Volume
$CTDI_{w}$	Computed Tomography Dose Index Weighted
CTPA	Computed Tomography Pulmonary Angiogram
DLP	Dose Length Product
DNA	Deoxyribonucleic Acid
DRL	Dose Reference Level
ED	Effective Dose
ICRP	International Commission of Radiological Protection
IEC	International Electrochemical Commission
kV	Kilovolt
mAs	miliAmperesecond
mGy	miliGray
mSv	miliSieverts
MOH	Ministry of Health Malaysia
MSCT	Multi-Slice Computed Tomography
NRPB	National Radiological Protection Board
PMMA	Polymethyl methacrylate
SSCT	Single-Slice Computed Tomography

LIST OF APPENDICES

PENENTUAN TAHAP RUJUKAN DOS (DRLS) KANAK-KANAK DALAM PENGIMBAS TOMOGRAFI BERKOMPUTER DI DUA HOSPITAL AWAM DI LEMBAH KLANG

ABSTRAK

Pengimbas Tomografi Berkomputer (CT) telah memberikan sumbangan besar dalam mendiagnosis penyakit pesakit di hospital dan kemudahan kesihatan di seluruh dunia dengan tepat dan berkesan. Walau bagaimanapun, kerana dos yang dihasilkan adalah sangat tinggi berbanding dengan radas penyinaran sinar-x yang lain, terdapat kebimbangan yang meningkat di kalangan pakar perubatan pediatrik khususnya dan orang ramai amnya mengenai kesan jangka panjang yang disebabkan oleh pendedahan tersebut. Agensi Tenaga Atom Antarabangsa (IAEA) dan Suruhanjaya Antarabangsa Mengenai Perlindungan Radiologi (ICRP) telah mengesyorkan Tahap Rujukan Dos (DRL) sebagai strategi untuk mengoptimumkan dos yang diterima dalam pesakit pediatrik. Tujuan penyelidikan ini adalah untuk menganggarkan nilai Isipadu Indeks Dos Tomografi Berkomputer ($CTDI_{vol}$), Produk Panjang Dos (DLP) dan Dos Berkesan (ED) bagi kanak-kanak di Hospital Tunku Azizah (HTA), Kuala Lumpur dan Hospital Selayang (HS), Selangor. . Sebanyak 654 pemeriksaan x-ray CT telah dijalankan di HTA, manakala 304 pemeriksaan x-ray CT telah dijalankan di HS antara Januari 2020 dan Disember 2021. Analisis retrospektif dibahagikan kepada pemeriksaan kepala, dada dan perut dan dikategorikan kepada empat kumpulan umur : <1, 1-5, 6-10 dan 11-15 tahun. Nilai CTDIvol, DLP dan ED yang direkodkan dalam Sistem Pemprosesan Imej dan Aplikasi Pemonitoran Dos yang disediakan pembekal dibandingkan dengan nilai $CTDI_{vol}$, DRL daripada kajian lain. Hasil kajian mendapati bahawa nilai dos $CTDI_{vol}$ untuk HTA dan HS adalah lebih rendah berbanding dengan

kajian lain kecuali CTDIvol untuk pemeriksaan perut menyebabkan perbezaan maksimum 35% untuk HTA dan HS. Nilai DLP untuk pemeriksaan dada menghasilkan perbezaan maksimum 32.48% untuk HTA dan 48% untuk pemeriksaan abdomen di HS. Dos berkesan tertinggi di HTA dianggarkan untuk kepala 6.02 mSv, dada 25.16 mSv, perut 50.60 mSv dan untuk HS, dos berkesan tertinggi dianggarkan untuk kepala: 5.76 mSv, dada: 14.88 mSv, perut: 11.01 mSv. Kesimpulannya, nilai dos $CTDI_{vol}$ dan DLP dalam kajian ini berada pada nilai optimum kecuali nilai DLP bagi pemeriksaan dada dan abdomen bagi HTA dan pemeriksaan abdomen bagi HS yang memberi gambaran bahawa terdapat ruang untuk proses penambahbaikan supaya parameter output boleh dioptimumkan untuk protokol pemeriksaan CT di masa hadapan.

DETERMINATION OF PAEDIATRIC DOSE REFERENCE LEVELS (DRLS) IN COMPUTED TOMOGRAPHY SCANNERS IN TWO PUBLIC HOSPITALS IN KLANG VALLEY

ABSTRACT

Computed Tomography (CT) scanners have made significant contributions in diagnosing patients' illnesses in hospitals and health facilities around the world accurately and effectively. However, because the dose produced is very high compared to other x-ray irradiation apparatus, there has been an increased concern among paediatric medical experts and the public in general regarding the long-term effects caused by the exposure. The International Atomic Energy Agency (IAEA) and International Commission On Radiological Protection (ICRP) have recommended Dose Reference Levels (DRLs) as a strategy to optimize doses received in pediatric patients. The purpose of this research is to estimate Computed Tomography Dose Index Volume ($CTDI_{vol}$), Dose Length Product (DLP) and Effective Dose (ED) values for children in Tunku Azizah Hospital (HTA), Kuala Lumpur and Selayang Hospital (HS), Selangor. A total of 654 CT x-ray examinations were conducted at HTA, while 304 CT x-ray examinations were conducted at HS between January 2020 and December 2021. The retrospective analysis was divided into head, chest and abdominal examinations and categorized into four age groups: <1, 1-5, 6-10 and 11-15 years. CTDIvol, DLP and ED values recorded in the Image Processing System and vendor-provided dose monitoring application were compared with $CTDI_{vol}$, DRL values from other studies. The results of the study found that the dose values of $CTDI_{vol}$ for HTA and HS were lower compared to other studies except for CTDIvol

for the for-abdomen examinations resulting in maximal difference 35% for HTA and HS. The DLP value for chest examination resulting maximal differences 32.48% for HTA and 48% for abdomen examinations at HS. The highest effective doses at HTA were estimated for head 6.02 mSv, chest 25.16 mSv, abdomen 50.60 mSv and for HS, the highest effective doses were estimated for head: 5.76 mSv, chest: 14.88 mSv, abdomen: 11.01 mSv. In conclusion, the dose values of $CTDI_{vol}$ and DLP in this study are in the optimal value except for DLP values for the chest and abdomen examinations for HTA and the abdomen examinations for HS which gives the impression that there is room for an improvement process so that the output parameters could be optimized for future protocol examinations.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Computed tomography examination or more commonly known as CT examination results from a combination of an x-ray machine and a highly sophisticated computing system to produce cross-sectional images (tomography) from a combination of x-ray images taken from various scanning angles. The entire image resulting from the CT examination was formed using computer software to produce object structures in various shapes such as a single plane or 3-dimensional (3D) (Herman, 2009).

1.2 Background of the study

CT scan in diagnostic imaging has contributed a major impact on the medical field. It was introduced in the 1970s and continues to grow in line with technological advancement. Clear anatomical images are a major factor to the rapidity of diagnostic imaging examinations of patients. First introduced in 1998, multi slice CT has contributed to the speed of CT examination of patients in hospitals with the ability to perform one rotation in a second. With faster examination times allows examinations of patients to be carried out quickly and effectively, allowing physicians to diagnose a patient's seizures without performing surgical procedures. In addition, artifact images can be minimized because of patient movement during CT examination, and this provides an advantage over patient examination.

Survey in Malaysia (Figure 1.1) recorded a significant increase where in 2007 the number of CT machines in Malaysia were 50 units and in 2017 increased to 332 units which recorded an increase of 564% in a span of 10 years. This growth reflects an expanding reliance on CT in public and private healthcare sectors, particularly for head, chest, and abdominal scans. Such widespread use is evident in examinations like CT Pulmonary Angiograms (CTPA) and scans for cancer diagnosis, including cervical and abdominal cancers in adults.

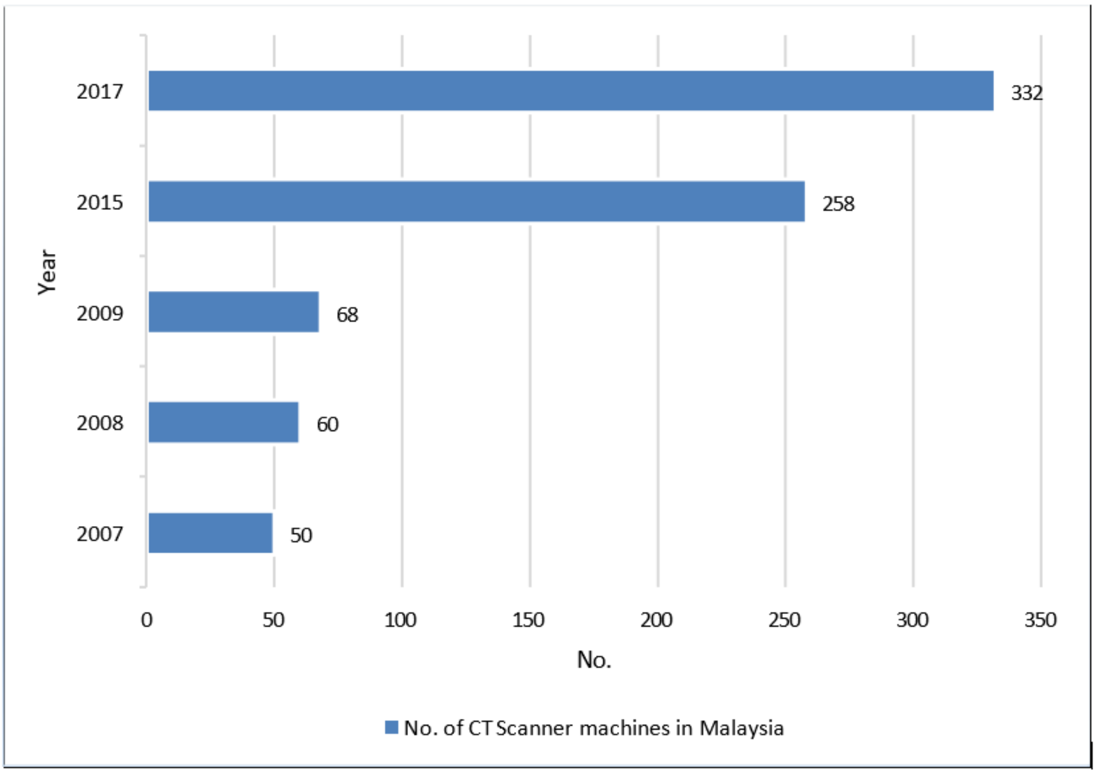

Figure 1.1: Number of CT Scanner machines in Malaysia Sources, Ministry of Health Malaysia

However, the increasing use of CT also raises concern about radiation exposure, particularly among paediatric patients. Paediatric patients, typically defined as individuals from birth up to 15 years of age have differ substantially from adults in both anatomy and physiology. Due to their smaller physical size and higher tissue sensitivity to ionizing radiation, children are more susceptible to radiation-induced effects. Study by Brenner et al. (2001) have established a heightened cancer risk in paediatric patients undergoing CT scans compared to adults, especially when protocols are not adequately adjusted for paediatric anatomy and physiology. According to Brenner et al. (2001), Jong et al. (2005), Miglioretti et al. (2013), and Samei et al. (2017) the risk of paediatric patients getting brain cancer and leukaemia at cumulative doses between 50 and 60 mGy is 3 times higher.

Therefore, the concept of Dose Reference Levels (DRLs) has been emphasized internationally as a means to standardize and optimize patient doses in diagnostic radiology. A DRL is defined as a benchmark dose level for typical radiological examinations performed on standard-sized patients as a reference. It is proposed by the International Commission on Radiological Protection (ICRP) serve as references to identify unusually high radiation doses and support dose optimization without compromising diagnostic quality (ICRP, 2017). ICRP recommends setting DRLs at the 75th percentile of dose distributions collected from wide surveys of standard practice. DRLs are not to be exceeded routinely and are used to prompt investigations and corrective actions when consistently surpassed (ICRP, 2017).

1.3 Problem statement

Despite the significant increase in CT utilization in Malaysia, there is still a lack of established paediatric DRLs within the local setting. Moreover, this is particularly concerning given the heightened radiation sensitivity of paediatric patients and the increased risk of long-term health effects such as brain cancer and leukemia associated with cumulative radiation doses exceeding 50-60 mGy (Brenner et al., 2001; Rice et al., 2007).

Currently, many CT protocols in Malaysian hospitals are adapted from adult standards or international benchmarks that may not adequately reflect the anatomical and physiological characteristics of local paediatric populations. Without locally defined DRLs, there is a risk of inconsistent dose optimization practices across facilities, potentially leading to overexposure in children or suboptimal image quality (MOH Malaysia, 2013a, 2013b).

Therefore, there is a urgent need to determine local paediatric DRLs for CT procedures particularly within public hospitals in high-population regions such as the Klang Valley. Establishing these DRLs will serve as a critical step toward enhancing radiation safety, guiding protocol development, and ensuring that paediatric CT examinations are conducted with the lowest possible radiation dose while maintaining diagnostic performance.

1.5 Objectives

The objectives of the research:

i. To estimate of paediatric patients' doses using the terms $CTDI_{vol}$, DLP and ED.
ii. To compare DRL from this study with DRL from other studies.

iii. To estimate effective doses from computed tomography scanner of paediatric patients using patient-specific information.

iv. To develop Local DRL for Tunku Azizah Hospital, Kuala Lumpur and Selayang Hospital, Selangor.

1.6 Scopes of the study

This study is focused on determining local DRLs for CT examinations conducted in two public hospitals located in the Klang Valley. The scope is limited to paediatric patients aged 0–15 years who undergo CT examinations of the head, chest, and abdomen using multi-slice CT scanners.

The study includes:

- Collection and analysis of CT dose parameters such as $CTDI_{vol}$ (Volume Computed Tomography Dose Index), DLP (Dose Length Product), and estimated Effective Dose (ED) for paediatric patients.
- Comparison of local DRLs obtained from this study with established international DRLs.
- Estimation of effective radiation dose using patient-specific data including scan parameters and body region examined.
- Development of local DRLs that reflect optimized radiation usage tailored to paediatric patients in the Malaysian healthcare setting.

This research does not encompass adult patients, interventional radiology, or other imaging modalities beyond CT. The study is retrospective in design, using anonymized patient scan data collected from the hospital PACS and CT scanner dose reports.

1.7 Significance of the study

A demand for diagnostic imaging examinations using CT machines is increasing every year in line with the development of CT scanner machine technology in the medical field Brenner, D.J. & Hall, E.J. 20047; Broder, Fordham & Warshauer, 2007; Miglioretti, D.L. et al. 2013; Mitchell. 2008; R Smith-Bindman, Miglioretti & Larson. 2008). With the latest CT technology can produce more accurate body image quality and help radiologists diagnose patients more accurately and quickly. Good image quality depends on the lack of image noise produced. To obtain a low image noise value, a high amount of radiation dose needs to be emitted by the CT irradiation apparatus. Good image quality is proportional to the total dose of radiation emitted by the CT scanner machine. We need to determine the resulting total dose is as low as reasonably achievable (ALARA) without compromising the quality of the x-ray image.

The higher the dose received by the patient undergoing CT examination the clearer the quality of the image produced. A study conducted inpediatric patients are in the 50mGy range performed more than once and this trend is particularly worrying because CT scans can damage body tissue cells at different ages and can enhance stochastic and non -stochastic effects (Brenner, D.J et al. 2001; Brenner, D.J & Hall, E.J 2007; Chodick et al. 2007; Dorfman et al. 2011; Preston, DL et al. 2007). A stochastic effect is a long -term effect received by a patient due to low radiation dose exposure that is likely to cause the presence of cancer cells in the patient's body while a non-stochastic effect is an immediate effect received by a patient undergoing CT examination at high radiation doses such as Erythema and burn effect.

MOH established a national DRL for patients undergoing CT examination which refers to adult patients only. The development of DRLs specifically for paediatric patients needs to be established as implemented by other countries in the world to optimize the dose received by paediatric patients.

1.8 Thesis outline

This thesis is structured into five chapters to systematically guide the reader through the research process, findings, and implications regarding the determination of paediatric DRLs for CT examinations in selected Malaysian hospitals. Chapter 1 introduces the study, highlighting the importance of CT imaging in modern diagnostics, especially for paediatric patients. This chapter also presents the background, problem statement, objectives, significance, and scope of the study, laying the foundation for the subsequent chapters.

Chapter 2 provides a detailed review of existing literature relevant to the study. It discusses the principles of CT imaging, radiation risks in paediatric patients, and the international development and implementation of DRLs. The chapter also examines global practices in radiation dose optimization and the importance of establishing local DRLs to ensure patient safety and standardized diagnostic practices.

Chapter 3 outlines the methodology adopted for this research. It describes the study design, patient criteria, and CT scan protocols used. The chapter also explains how radiation dose metrics such as CTDIvol, DLP, and effective dose (ED) were calculated, as well as the statistical tools employed for data analysis and the ethical considerations addressed during the study.

Chapter 4 presents and discusses the results obtained from the data analysis. It includes dose estimates for different paediatric age groups and CT examination types, comparisons with international DRLs, and identification of factors contributing to dose variations. This chapter also interprets the findings in relation to established literature and discusses the implications for clinical practice and patient safety.

Chapter 5 concludes the study by summarizing the key findings and discussing their relevance to radiology practices in Malaysia. It emphasizes the importance of establishing local paediatric DRLs to enhance radiation protection, improve diagnostic consistency, and inform future policy development. Recommendations for clinical implementation, training, and further research are also provided to support improvements in diagnostic performance.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A CT scanner is an advanced medical imaging device composed of three essential components such as X-ray, detector and examination table. These components enable the generation of high-resolution, cross-sectional images of the human body which are crucial for accurate diagnosis.The imaging process begins with an X-ray observed by a detector moving around the object at a position opposite to the x-ray tube along the X-ray axis (refer to Figure 2.1).

Figure 2.1: A Modern CT Scan machine
Sources:https://www.researchgate.net/publication/309609776,Prevalent_Degradations_and_Processing, Challenges of Computed Tomography Medical Images A Compendious Analysis/figures?lo=*1*

The increasing of sophisticated detection technology and more line up on CT machines allows CT machines to perform more multi slices or multidetector which also helps to make the resulting image clearer and in a very short period. For example, the 640 multi-slice CT machine, can perform x-ray examination through large parts of the adult body or on the whole body of a paediatric patient 75% faster than the 640 multi-slice machines. CT scan rapidity is less than 1 second, make it very helpful to patients particularly children, the elderly and critically ill patients due to their condition which is demanding to remain silent or hold their breath for a long-time during CT examination to reduce movement errors.

The X-ray groove of the CT machine from the x-ray tube moving around the patient produces a series of continuous radiation exposures on the transverse incision (Fig. 2.3). This X-ray exposure stream is controlled by a collimator to ensure that no deviation of the X-ray stream strays from its proper location. However, the collimator of the CT scanner is not able to fully control the angle of the ionizing radiation beam that strays out of the inspection location. This deviation resulted in a persistent overlap of x-rays during CT examination and this occurrence was the cause of the increase in dose to higher number of patients.

The amount of groove deviation is quite difficult to decide during practical work movements, but it can be modified by measuring the CT Dose Index (CTDI) (Shope, Gagne & Johnson 1981). CTDI is the total value of the absorbed dose integration in the z -axis direction divided by the nominal slice width and the CTDI value is simply a Standard Output measurement of CT scanner radiation dose that allows comparisons of different CT scanner radiation outputs to be performed

(Khursheed et al., 2002).

2.2 Radiation Effects

Computed tomographic examinations (CT) are associated with a relatively high dose compared to conventional x-ray examinations, numerous papers have been published on the possible lifelong cancer risk of children who undergo CT examinations. Click or tap here to enter text.Click or tap here to enter text. A patients undergoing X-ray examination is estimated 100-500 times higher than general X-ray machines and this results in an overexposed risk that increases the risk of cancer in individuals exposed to ionizing radiation in the long term (Brenner et al., 2001; Khursheed et al., 2002; Lee et al., 2016; Turner et al., 2010; Wagner et al., 2018).

The risk of cancer in children is 2 to 3 times higher than in adults because the child's tissue cells divide by faster and 10 times more sensitive to the effects of ionizing radiation that cause carcinogenesis (Brenner et al., 2001).

The ability of x-rays to convert the DNA molecules of normal body cells to abnormal occurs due to exposure to ionizing radiation. Many studies have been done due to these factors to overcome the problem of over-exposure in patients undergoing x-ray examination. It is estimated for CT abdominal examination for adult patients is as much as 10mGy while for abdominal CT examination of neonatal patients can reach 2 times more than adult patients (Brenner et al., 2001; Huda et al., 2011).

Another study conducted in the UK found that paediatric patients who underwent a bone marrow x-ray examination had a 3.2-fold risk of developing leukaemia, while those receiving a CT scan of the head with a dose value > 50mGy had a 2.8-fold risk of developing brain cancer (Lee et al., 2016) . (Brenner et al., 2003) reported, 70% of the ionizing radiation dose received by patients during x -ray examination is from CT examination and contributes 1.5% - 2% to the cause of cancer. However, the benefits received because of CT examination outweighed the risks of radiation effects on patients if CT examination is performed according to proper protocols to protect patients from the effects of ionizing radiation exposure (Dougeni et al., 2012; McCollough et al., 2015).

2.2.1 Stochastic Effects

Stochastic effect is defined as the probability that a risk occurs after prolonged exposure to ionizing radiation. Doses received by patients that penetrate tissues can have an impact on human health because the energy of ionizing radiation is able to break the normal structure of human body cells and damage the structure of the chemical components of body tissue cells. In general, damaged body cells can recover if not damaged too badly while permanent damage will occur through the death of body cells or the occurrence of mutation processes.

The mutation occurs when the cell structure of DNA is damaged which in turn causes the process of cell division to occur abnormally then eventually leads to cancer. Figure 2.2 illustrates that the probability of a person getting cancer is directly proportional to the radiation dose exposure received and has no threshold value. As shown in the Figure 2.3, the risk of fatal cancer increases with higher radiation doses in medical exposure involving ionizing radiation such as CT scans and cardiac examinations.

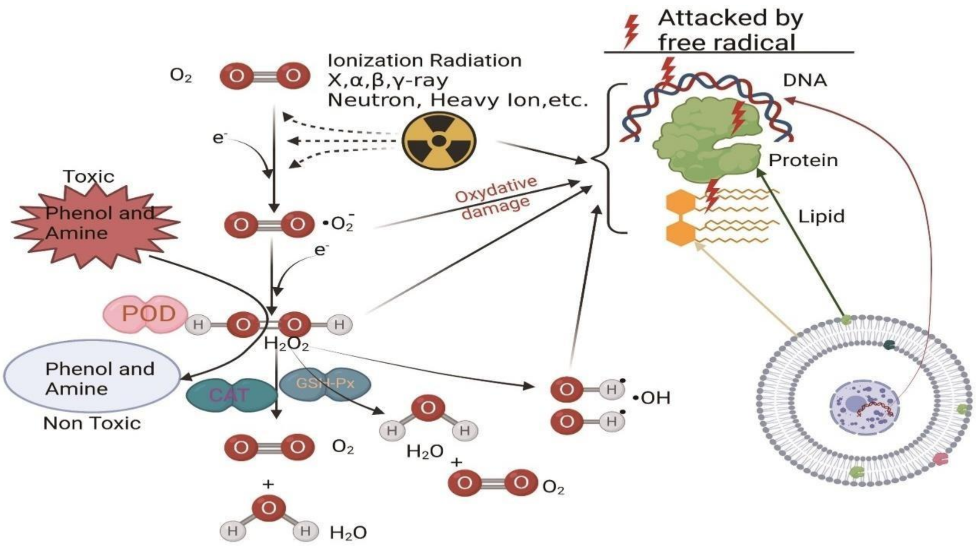

Figure 2.2: The role of DNA damage induces by Low/High Dose Ionizing Radiation in Cell Carcinogenesis
Sources: https://www.xiahepublishing.com/2472-0712/ERHM-2021-00020

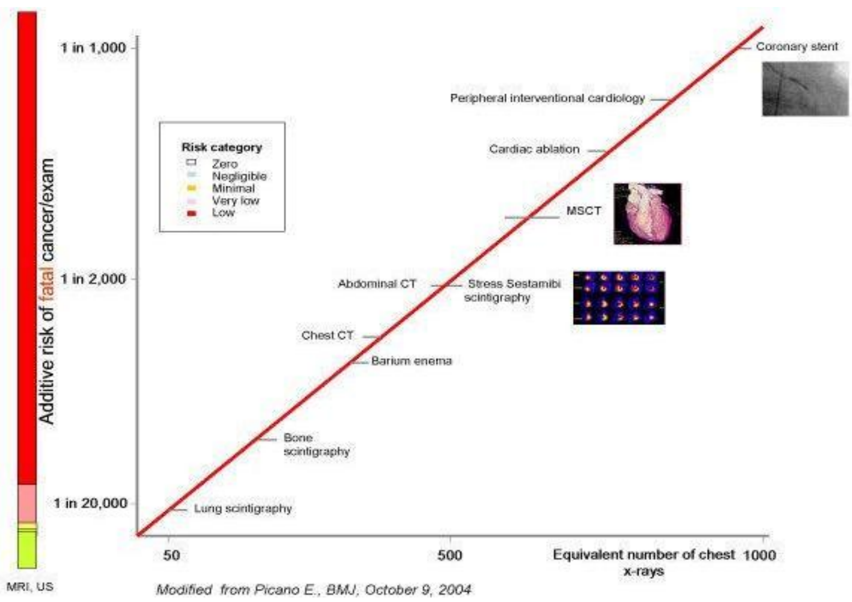

Figure 2.3: Graphical presentation of cancer risk and radiation dose (in multiples of exposure from a conventional chest x-ray exam) for some common cardiovascular examinations. Modified from ref. 7, based on novel estimates of Biological Effects of Ionizing Radiation VII (BEIR VII)
Sources: https://www.researchgate.net/publication/5872380

Cells exposed to ionizing radiation will undergo Deoxyribonucleic Acid (DNA) damage where the cells become irregular and result in very rapid cell division where tissue cells mature in an abnormal time interval and this process is called cancer. Leukaemia, thyroid, and bone cancers will appear in a few years or more because of exposure to ionizing radiation. It is important to set an acceptable dose exposure limit to allow estimation that a person will develop cancer after exposure to ionizing radiation in a certain quantity. someone less than 20 years old is 2 times more likely to get leukaemia while those less than 10 years old are 3 times more likely to get leukaemia than adults.

2.2.2 Non-Stochastic Effects

Non-stochastic effects or deterministic effects are damage to body cells that occurs when the dose received exceeds a threshold value. The number of dead or damaged cells is directly proportional to the total dose received by the individual. Stewart et al. (2012) found if the dose received is less than the threshold value, there will be no damage to the body's cells as those cells are able to recover. The ability of these body cells to recover is not the same between human beings.

2.2.3 CT Dose

Starting from 2002, the International Electrochemical Commission (IEC) has stipulated that all CT machines must display $CTDI_{vol}$ and DLP on the control console panel before and after CT examination is implemented as a radiation safety measure (Chapple et al., 2002). CTDI values were obtained based on 16 cm Phantom Head and 32 cm Phantom Head for abdominal and chest examination. Both phantoms are made of Polymethyl methacrylate (PMMA). A 100 mm chamber pencil is inserted into one of the 5 blank holes filled with PMMA rods. The ion chamber pencil is shown in a clockwise position at values 12, 3, 6, 9 and on the hole in the centre of the phantom. Checks were recorded using a dose detector meter (Figure: 2.4).

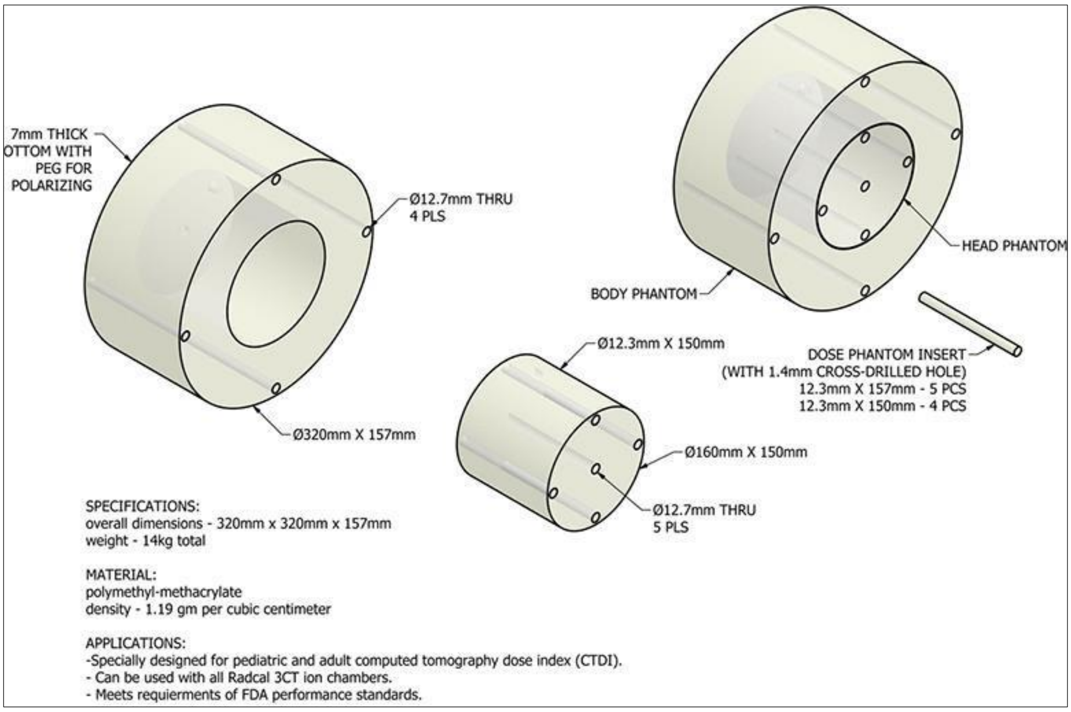

Figure 2.4: PMMA Phantoms

Sources: https://radcal.com/20ct20/images/20ct20-detail-2-large.jpg

The CTDI calculation equation is as follows (Equation 2.1 and 2.2):

$$\mathrm{CTDI_w} = \frac{1}{3}\mathrm{CTDI}(\mathrm{center})(\mathrm{mGy}) + \frac{2}{3}\mathrm{CTDI}(\mathrm{peryphery})(\mathrm{mGy}) \tag{2.1}$$

$$\mathrm{CTDI_{vol}} = \frac{\mathrm{CTDI_w}}{\mathrm{pitch}}(\mathrm{mGy}) \tag{2.2}$$

The value of $CTDI_{100}$ in the middle of the phantom is multiplied directly by a coefficient of 1/3, while for peripheral $CTDI_{100}$ it is the result of multiplying the coefficient of 2/3 by the average value of the dose reading from positions 12, 3, 6 and 9 on the phantom. The $CTDI_{100}$ value is a measure of the average dose over the pencil ionization chamber (100 mm) regardless of the topography of the human body, the $CTDI_{100}$ value is not used for clinical purposes. $CTDI_w$ values are closer to body dose than $CTDI_{100}$. For MSCT, $CTDI_{vol}$ is more accurate than $CTDI_{100}$. $CTDI_{vol}$ is obtained by dividing $CTDI_w$ by the pitch factor. The $CTDI_{vol}$ and DLP values as found on the control panel connected directly to Picture Archive Communication Systems (PACS) do not represent the actual dose received by the patient. The dose of CT examination depends on the size of the patient and the radiation output of the CT machine. Because of this, $CTDI_{vol}$ values are less accurate to use for paediatric patient-based dose (McCollough et al., 2015). (Strauss et al., 2017) estimated that the dose value of paediatric patients was 2-3 times lower than the actual measurement if we used a 32cm PMMA phantom as a reference value.

The DLP value which is the product of the $CTDI_{vol}$ (mGy) with the inspection distance (cm) is compared to the ionizing radiation energy given to the body organ within a certain distance. These $CTDI_{vol}$ and DLP values were developed as a standard method for comparing radiation exposure levels between CT machines using different phantom sizes. Both dose indicators namely $CTDI_{vol}$ and DLP are highly sensitive to changes in the examination protocol such as tube voltage, tube current (mA), gantry rotation time, pitch, and Bowtie filter but not on patient’s size.

2.3 Factors That Affect Radiation in CT Examinations

2.3.1 CT Protocol

Examination techniques, radiation geometry and physical characteristics of the patient will affect the radiation energy given to the patient. Before CT examination was performed, anterior-posterior and lateral side scout anatomical examination was performed as a CT system data collection process. These data were collected to determine how much kilovoltage (kV) x-rays were needed to penetrate the patient's body and how much number of electrons miliampere (mA) were needed to be used in image reconstructions. The factors involved are mAs, image quality and x-ray dose. Bauhs et al. (2008) stated that using high mAs will cause overexposure and will produce a clearer image because noise is reduced yet it causes high doses to be applied to the patient. To get on with the high dose to patients, the manufacturer has developed a system that can produce mAs at an optimal rate.

The entire Multislice CT (MSCT) is equipped with 'Anatomic X-ray Tube Current Modulation' (ATCM) which is a technique in which the tube current can be adjusted automatically along the rotation of the x-ray on the y-axis or along the z- axis according to the size of the patient in the body. This results in the production of a good image along with reducing the dose received by the patient. a special collimator device was also installed to reduce overexposure to the patient (Kalender et al., 2009). This however will not reduce the quality of the images produced (Tsalafoutas, 2010). (Karim et al., 2016) has conducted dose reduction studies on patients using ATCM and found up to 68% dose reduction has been recorded on sensitive organs in the body.

In addition to the factors mentioned earlier, geometric and anatomical factors of the human body also played a role in reducing the average dose by 22.3% without affecting the quality of images produced using the "CARE" dose technique (Greess et al., 2002). For chest area beyond CT examination of the abdomen using the same examination protocol (Kritsaneepaiboon et al., 2012).

During the MSCT helical CT examination performed, the patient's table moved at a constant speed through the gantry. The speed of movement of the patient's table, the rotation time of the tube and the overall width of the image during CT examination, produce several types of radiation beams to the patient. The resulting grooves are overlapping, connected, or spaced apart from each other which will influence the CT pitch factor. Overlapping radiation streams will produce a pitch factor < 1, connected radiation streams give a pitch factor at a value of 1 and radiation streams > 1 are formed streams that are spaced apart from each other (Figure 2.5).

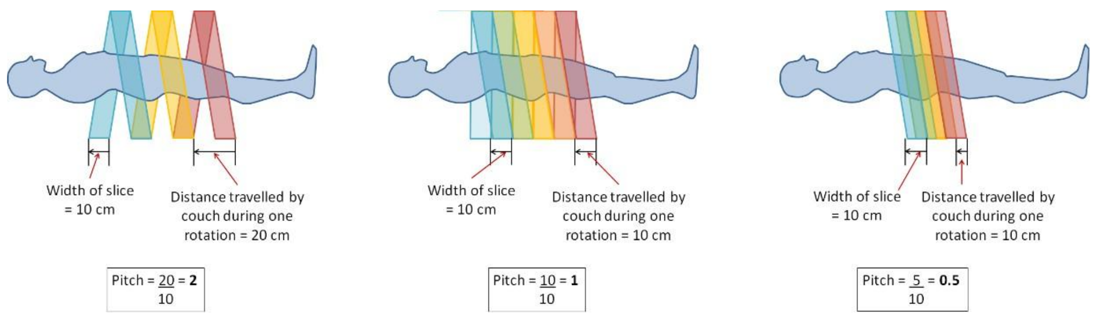

Figure 2.5: Pitch Concept in CT examination
Sources: https://sites.google.com/site/frcrphysicsnotes/acquiring-an-image-part-1

Pitch also contributes to the total dose received by the patient. Adding the pitch factor could reduce the dose of the patient for Single Slice Computed Tomography (SSCT) type machine but not effective for Multi-Slice Computed Tomography (MSCT) type machine. The movement of the patient's table produces interspaces between the radiation streams. Fast movement also produces a pitch factor >1 and slow movement will produce a lower pitch factor while a pitch factor <1 will produce overlap between radiation streams. Meanwhile the pitch factor = 1.0 will show the radiation streams that are connected to each other. The addition of pitch factor to the CT screening protocol for MSCT will result in an increase to mAs. This situation occurs because the MSCT-ATCM application system plays a role in controlling the noise on the generated image and in turn will increase the dose value for the patient (Mahesh et al., 2001).

2.3.2 Patient's Physical factor

The risk of a paediatric patient getting cancer by undergoing CT examination is between 6-9 times than that of adult patients (Dougeni et al., 2012; McCollough et al., 2015; Sulieman, 2015). This is because age and body size factors play a very dominant role for a person to develop cancer (Morin et al., 2003). When CT scans are performed on paediatric patients or small adult patients, they will get a higher effective dose (Lewis et al., 2016). Lewis et al. (2016) found through a study using phantoms of various sizes found that the dose values received by small sized phantoms were relatively higher compared to adult phantoms (Figure 2.6). This suggests that size factors also influence the value of the dose that the patient will receive.

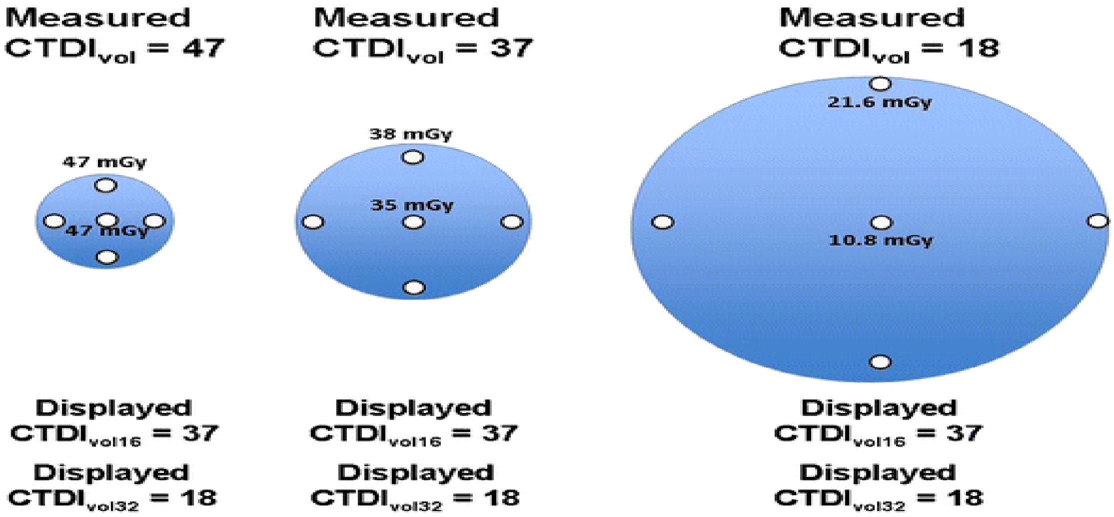

Figure 2.6: Measured versus displayed CTDIvol values
Sources: https://link.springer.com/article/10.1007/s00247-011-1978-6/figures/1

A study using TLD on patients, the indicator dose readings were found to need to be adjusted to allow them to be appropriate and represent the estimated value of actual paediatric patient size on chest and abdomen/pelvis CT examination values (Brady et al., 2011; Gancheva et al., 2015). The results showed that the dose value of $CTDI_{vol}$ for CT examination of the head was the same as CT examination using TLD while the indicator dose value for CT examination of chest and abdomen was multiplied by a value of 2.08 (Chapple et al., 2002; Huda et al., 2011).

The DLP value ($CTDI_{vol}$ x examination distance in cm units) should be multiplied by a value of 2.0, referring to the ionizing radiation energy given to organs in a paediatric patient's body which is the value of radiation load overall radiation examination results of paediatric patients (Smith et al., 2008). Molen et al. (2007) found this inspection distance is calculated as the length of the resulting image without considering the over ranging length because data information in the area is not required during the data interpolation process.

2.4 Dose Reference Level

ICRP 1991 recommended the concept of ALARA based on previous studies that found 30% of paediatric CT scans were avoidable scans. Brenner et al., (2001) and Molen et al.,(2007) found to be exchanged with other diagnostic testing methods that were not involving x-rays. ICRP (2017) have proposed and introduced the concept of DRL as an effort to ensure optimal dose reception to patients.

The objective of DRL development is to optimize the use of x-rays in medicine and to avoid exposure to excessive radiation doses imposed on patients in line with the ALARA concept. Sutton et al. (2014) suggested that the DRL also acts as a guide or benchmark between 'good and normal practices' as well as 'bad and abnormal' practices. The LDRL value will be compared with the national or international DRL value for improvement purposes if the comparison results find that the LDRL value for HTA and HS is above the reference DRL value. This difference will also show that the CT screening protocol practices conducted at the two institutions are comparable to the reference DRL values. Lewis et al., (2016) and Shrimpton et al., (2016) took data from several MSCTs and SSCTs found that 75% of the health facilities participated in the study had shown $CTDI_{vol}$, DLP and effective dose readings less than national DRL values. The remaining 25% had given radiation doses exceeding the DRL value and were considered unreasonable overexposure for CT examination. for the remaining 25% of available CT scanner facilities, equipment and techniques used were investigated to determine why the dose produced was higher than other CT facilities and improvement process was needed so that these CT facilities were within 75% DRL to protect patients from receiving doses unnecessary exposure.

When standard procedures of regular diagnostic practice are carried out properly it is not expected to pass the DRL level. DRL is not a dose limit or constraint, but it is a guidance for good radiation protection practice. Basically, the DRL responds to the improvement process if the resulting dose value consistently exceeds the DRL value. The DRL concept also allows for flexibility for goals to be achieved as a guide to effective and safe patient management. For MSCT type CT irradiation apparatus, the appropriate $CTDI_{vol}$ and DLP values are used as DRL.

2.5 Local Dose Reference Level (LDRL) and other countries DRL

Dose indicators (DLP and $CTDI_{vol}$) for CT screening were developed through 75th percentile dose limit values. These values are rounded to the nearest decimal value to provide simple values or user -friendly values to the radiologist, physicist and radiographer. The readings on these 3rd quarter values were then compared with paediatric DRLs from countries that already had national DRL values. The CT scan dose value studied when it exceeds the compared DRL value, this gives an indication that the dose value optimization process should be carried out through re- evaluation of CT screening protocol parameters or should be justified why the value found in the study exceeds the DRL value of the compared countries if the value of the examination dose is to be maintained.

2.6 CTDI Volume ($CTDI_{vol}$)

$CTDI_{vol}$ is the sum of the absorbed dose integration values in the z -axis direction divided by the minimum slice width (Turner et al., 2010). The $CTDI_{vol}$ value on theCT apparatus control panel screen is representative of the radiation dose dependent on the PMMA plastic phantom 16cm for CT examination of the head and 32 cm for CT examination of the chest and abdomen.

2.7 Dose Length Product (DLP)

The DLP value is directly proportional to the $CTDI_{vol}$ value as well as the CT inspection distance because the DLP value is the product of the $CTDI_{vol}$ value multiplied by the CT inspection distance. The DLP value of CT examination increased with increasing age group and body size of the patient. Apart from that it is also influenced by the value of the $CTDI_{vol}$ check reading.

2.8 Effective Dose (ED)

Examination of ionizing radiation on the human body through a CT machine can be described as an illustration of a complex 3D imaging design in which many internal organs, tissues and cells of the body are exposed to ionizing radiation during x- ray examination. The level of risk to the patient can be estimated by the total absorbed dose of the organ multiplied by the specific organ risk factor for which this concept has been proposed by the ICRP and is known as ED. This concept allows exposures to uneven radiation doses to be converted to uniform radiation dose exposures where both have the same risk of stochastic effects (ICRP, 2017).

Estimating Effective Dose (ED) from DLP values as a more practical approach compared to calculations based on detailed organ doses (Paul et al., 2012; Shrimpton