UNIVERSITI PUTRA MALAYSIA

DOSE REDUCTION USING CARE DOSE4D TECHNIQUE OF SIEMENS DUAL-SOURCE COMPUTED TOMOGRAPHY ON PEDIATRIC CONGENITAL HEART DISEASE

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By

CHEN HONGYING

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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June 2022

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Congenital heart defects (CHD) are the most prevalent birth defects. It is very important to diagnose CHD early and accurately so that patients can get timely and effective treatment. CT scan can accurately evaluate the anatomical structure and major malformations of the cardiac great vessels, the adjacent relationship between the mediastinal organs and tissues from morphology, and quantitatively evaluate cardiac function. However, ionizing radiation is the biggest drawback in CT scanning. This research using a cross-sectional prospective study to investigate the value of Siemens dual-source Somatom Definition Flash CT scanner using CARE Dose4D technique in decreasing radiation dose and ensure image quality in pediatric CHD. There were two groups used Siemens dual-source Somatom Definition Flash CT scanner. The CARE Dose4D group (n=32) with CARE Dose4D technique with automatic modulated tube current and 80 kVp tube voltage, there were patients of angiography pulmonary and thorax CT scanning. Control group (n=42) (Data from previous research: Fan et al.,2020) using the retrospective electrocardiogram (ECG) triggered sequential technique with 100 mAs tube current and 70 kVp tube voltage. The volume CT dose index (CTDIvol) and dose length product (DLP) on each patient was recorded to calculate the effective dose (ED). Calculated image noise signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR). All images of 32 pediatric patients in the CARE Dose4D group were clear. The contrast medium density of superior vena cava was moderate, the CT values of all vessels were similar, and the contrast mediums in all atrioventricular and vascular were full, with clear boundaries, no effect on image reconstruction. The CNR values descending aorta of males was lower than females in CARE Dose4D group ($P=0.022<0.05$). According to the results of this study, we believe that CT examination combined with CARE Dose4D technology can be applied to CHD diagnosis, and the long-term monitoring of radiation dose is more important in practice. The X-ray radiation dose optimization of children and infants still needs in-depth research.

Key words: Pediatric; CHD; Radiation dose; CT; Low dose; CARE Dose4D

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENGURANGAN DOS MENGGUNAKAN TEKNIK CARE DOSE4D TOMOGRAFI KOMPUTER DUAL-SUMBER SIEMENS TENTANG PENYAKIT JANTUNG KONGENITAL PEDIATRIK

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Kecacatan jantung kongenital (CHD) adalah kecacatan kelahiran yang paling lazim. Adalah sangat penting untuk mendiagnosis CHD awal dan tepat supaya pesakit boleh mendapatkan rawatan tepat pada masanya dan berkesan. Imbasan CT boleh menilai dengan tepat struktur anatomi dan kecacatan utama saluran besar jantung, hubungan bersebelahan antara organ mediastinal dan tisu dari morfologi, dan menilai secara kuantitatif fungsi jantung. Walau bagaimanapun, sinaran mengion adalah kelemahan terbesar dalam pengimbasan CT. Penyelidikan ini menggunakan kajian prospektif keratan rentas untuk menyiasat nilai pengimbas CT Flash Definisi Somatom dwi-sumber Siemens menggunakan teknik CARE Dose4D dalam mengurangkan dos sinaran dan memastikan kualiti imej dalam CHD kanak-kanak. Terdapat dua kumpulan yang menggunakan pengimbas CT Flash Definition Somatom dwi-sumber Siemens. Kumpulan CARE Dose4D (n=32) dengan teknik CARE Dose4D dengan arus tiub termodulat automatik dan voltan tiub 80 kVp, terdapat pesakit imbasan CT angiografi pulmonari dan toraks. Kumpulan kawalan (n=42) (Data daripada penyelidikan terdahulu: Fan et al., 2020) menggunakan teknik urutan tercetus retrospektif elektrokardiogram (ECG) dengan arus tiub 100 mAs dan voltan tiub 70 kVp. Indeks dos CT volum (CTDIvol) dan produk panjang dos (DLP) pada setiap pesakit direkodkan untuk mengira dos berkesan (ED). Nisbah isyarat kepada hingar imej (SNR) dan nisbah kontras kepada hingar (CNR) dikira. Semua imej 32 pesakit kanak-kanak dalam kumpulan CARE Dose4D adalah jelas. Ketumpatan medium kontras vena cava superior adalah sederhana, nilai CT semua vesel adalah serupa, dan medium kontras dalam semua atrioventrikular dan vaskular penuh, dengan sempadan yang jelas, tiada kesan ke atas pembinaan semula imej. Nilai CNR menurun aorta lelaki adalah lebih rendah daripada wanita dalam kumpulan CARE Dose4D ($P = 0.022<0.05$). Menurut hasil kajian ini, kami percaya bahawa pemeriksaan CT digabungkan dengan teknologi CARE Dose4D boleh digunakan untuk diagnosis CHD, dan pemantauan jangka

panjang dos sinaran adalah lebih penting dalam amalan. Pengoptimuman dos sinaran X-ray bagi kanak-kanak dan bayi masih memerlukan penyelidikan yang mendalam.

Kata kunci: Pediatrik; CHD; Dos sinaran; CT; Dos rendah; Dos PENJAGAAN4D

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Every stage of life is worth cherishing, this beautiful period, because of your care and help, I am very happy and grateful.

I will study harder and put what I learn into practice. I will try my best to do better and fight with death to save more patients.

May health and happiness be with you always.

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

ALARA	As low as reasonably achievable
AP	Anteroposterior projection
ASD	Atrial septal defect
BD	Birth defect
BMI	Body mass index
CHD	Congenital heart defect/ disease
CNR	Contrast-to-noise ratio
CT	Computed tomography
CTDIvol	Volume CT dose index
DLP	Dose-length product
DR	Dose reduction
DSCT	Dual-souce CT
ECG-gated	Electrocardiograph gated
Echo	Echocardiography
ED	Effective dose
FBP	Filtered back projection
HU	Hounsfield units
IR	Ionizing Radiation
LDCT	Low-dose spiral CT
LP	Lateral projection
MDCT	Multi-director row CT
MRI	Magnetic resonance imaging
MSCT	Multi-slice spiral CT
NIR	Non-ionizing radiation

NMMR	National Medical Research Register
PACS	Picture archiving and communication system
PDA	Patent ductus arteriosus
ROI	Regions of interest
SD	Standard deviation
SNR	Signal-to-noise ration
TCM	Tube current modulation
TEE	Transesophageal echocardiography
TOF	Tetralogy of Fallot
3DE	Three-dimensional echocardiography
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
UPM	Universiti Putra Malaysia
VSD	Ventricular septal defect

CHAPTER 1

INTRODUCTION

1.1 Research Background

Congenital heart disease (CHD) is the most common type of congenital malformations accounting for nearly one-third of all birth defects (BDs). It refers to an abnormal anatomical structure during embryonic development due to the formation disorders or developmental abnormality in the heart and great vessels, or the failure of complete closure of the channels that should have closed automatically after birth (normal in the fetus). The incidence of CHD cannot be underestimated. According to Gilboa et al. (2016) study estimated that more than 2.0 million children and adults in the United States had CHDs in 2010, including about 1.0 million children were living with CHDs. In China, according to the epidemiological survey, the Report on the Prevention and Treatment of Birth Defects in China (2012) demonstrated that CHD ranks first among all BDs, accounting for 26.7% of all detected cases in 2011. There are more than 130,000 new cases of CHD in China every year. According to Health Indicator 2007 by the Malaysian Department of Statistics demonstrated that nearly 1 out of 100 babies (nearly 1 present or 5,000 babies) is born with CHD in Malaysia each year.

There are several special types of CHD. Patients can be combined with a variety of malformations, variation of symptoms, some patients can be lifelong asymptomatic. CHD can be complicated by multiple heart malformations at the same time. Some complex and severe deformities can develop serious and life-threatening symptoms shortly after birth. According to patho-physiological changes, the hemodynamics of CHD can be classified as cyanosis or non-cyanosis, can also be divided into three categories by shunt type: no shunt type (such as pulmonary stenosis and aortic stenosis), left to right shunt type (such as, ventricular septal defect (VSD), atrial septal defects (ASD) and patent ductus arteriosus (PDA)) and right to left shunt type (such as tetralogy of Fallot (TOF) and transposition of the large vessels). It should noted that there are some simple malformations such as VSD, PDA, etc., which may have no obvious symptoms in the early stages. However, the disease is still potentially more severe and needs timely treatment to avoid losing the opportunity for surgery. And CHDs are a high incidence of BDs, which are the main cause of neonatal and infant deaths. Therefore, it very important to diagnose CHD early and accurately so that patients can get timely and effective treatment. With the rapid development of medical technology, the diagnosis of CHD mainly depends on imaging examination. At present, medical imaging technology and equipment has a rapid development and perfection, there are many imaging examination methods for CHD in children mainly include plain chest X-ray, Cardiac catheterization or angiography (invasive procedure), echocardiography (Echo), magnetic resonance imaging (MRI) and computed tomography (CT), which can help clinicians to know the degree, type and scope of lesions, make a clear diagnosis through comprehensive analysis, and guide the formulation of treatment plan. For the imaging of pediatric CHD,

Cardiac catheterization or angiography is an important inspection method to evaluate the lesions in anatomic cases. It is an invasive examination. It can be used for pressure measurement. However, the stereoscopic structure cannot be shown, and general anesthesia is required for the children. Secondly, this method should be performed under high X-ray radiation dose, which requires high technical level of the operator (Soongswang et al.,2000; Cheng et al.,2010). Echo is the preferred method. It can noninvasively measure the size of the heart chamber and the thickness of the wall of the heart to evaluate the cardiac function. It has a high diagnostic accuracy for the intracardiac structure, but it is only limited for the display of the extracardiac structure. He (2016) found that dual-source CT had a higher diagnostic accuracy than Echo for abnormal extracardiac structures, and the combination of the two was conducive to the comprehensive and accurate diagnosis of complex CHD. For patients with fast heart rate, dual-source CT could still complete the scanning at a low dose. MRI has good temporal and spatial resolution, which can obtain various 3D data, reconstruct any plane, and show the anatomical malformations of congenital heart disease. Meanwhile, it can evaluate cardiac function and it is radiation-free. However, MRI involves a strong magnetic field, so metal objects are not allowed to exist in the body, and the scanning time is long. If the child cannot stay still during the scanning process, the child may need to be injected with sedatives or given general anesthesia. Especially for children with acute and critical CHD, MRI is not the preferred method of examination.

With the continuous development of multi-slice spiral CT (MSCT) and CT angiography, and its advantages in show heart anatomical structure, compared with MRI has better spatial resolution, scanning speed, rarely requires general anesthesia, scanning the volume of data obtained can be multi-angle, multi-dimensional reconstruction. Moreover, CT is more and more widely used in clinical diagnosis as a non-invasive method to effectively evaluate the deformity of cardiovascular and extracardiac anatomical structures (Paul, et al.,2010). However, since CT examination can lead to serious radiation exposure problems, effective cumulative doses may induce chromosomal DNA damage. At present, the effective X-ray radiation dose can be reduced by adjusting the pitch, reducing the X-ray exposure time, narrowing the scanning range, adjusting the current of the tube and reducing the voltage of the tube. In particular, the introduction and application of dual-source CT (DSCT), which provides a combination of high spatial resolution and high temporal resolution, its biggest highlight is the new large pitch scanning mode. The pitch is inversely proportional to the amount of radiation and increasing the pitch can greatly reduce the dose of radiation. So DSCT has been widely used in the clinical examination of CHD in children, and personalized scanning can effectively reduce ED by setting up a reasonable scanning scheme.

1.2 Problem Statement

Early diagnosis of CHD is of great significance in evaluating the prognosis of infants and children. For infants and children of imaging examination methods in

CHD, and there are many new improvements and development in recent years, The gold standard for the diagnosis of pediatric CHD is cardiovascular angiography, which can clarify the anatomical connections between the great vessels of the heart and provide hemodynamic information, but it is an invasive examination.

In recent years, with the increasingly accurate diagnosis of CHD in children by non-invasive inspection, X-ray, Echo, MRI and CT, the diagnostic cardiac catheterization angiography is gradually decreasing. Among them, CT scan can accurately assess the anatomical structure and major malformations of the great vessels of the heart, judge the adjacent relationship between mediastinal organs and tissues from morphology, and conduct quantitative evaluation of the heart, which is helpful to display pericardial effusion, thickening and calcification. With the development of scanning and postprocessing technique, CT has become more and more mature in cardiovascular diseases. However, ionizing radiation is the biggest disadvantage of CT scanning in children. The incidence of malignant tumors after X-ray exposure in infants can be 10 times higher than that in adults. (Hall and Brenner,2012).

The CARE Dose4D technology launched by Siemens CT, which automatically adjusts the tube current based on the thickness and density of the human tissue being examined, can reduce the X-ray radiation exposure of patients without compromising the diagnosis. The CARE Dose4D technology has been used in CT scans of various parts of adults, such as adult chest CT scan (Wu et al.,2011), liver CT scan (Zeng et al.,2016), lower limb deep vein and pulmonary artery CT angiography (Chen et al.,2015). In 2016, Zeng et al. found that CT technology can not only reduce the X-ray radiation dose in children's tooth scanning.

Cardiac CT angiography (CTA) has a high x-ray radiation dose due to its wide scanning range and complex tissue structure. On the premise of meet the demand of diagnosis, as far as possible to reduce the X-ray radiation dose (As low as reasonably achievable principle, ALARA) is the focus of the CT technology and its development direction. The commonly used methods to reduce the X-ray radiation dose mainly carried out from the aspects of tube current, tube voltage, pitch, scan length and time, etc.

After a major innovation of manually parameters change, iterative reconstruction technology has been widely used to effectively reduce the X-ray radiation dose of CT scanning. The automatic X-ray radiation dose adjustment technology, Care Dose4D can automatically adjust the tube current according to the purpose of CT examination and the body shape of the patient, to realize personalized intelligent scanning and reduce the scanning X-ray radiation Dose of patients. The research on low dose is mainly carried out from the aspects of tube current, tube voltage, pitch, scan length and time, etc. The scanning scheme with fixed parameters in CT examination will be difficult to present the structural differences of individual parts and will lead to excessive exposure and X-ray radiation dose increase or

insufficient exposure of patients (Sun et al., 2018). For example, when using fixed tube current scanning in chest CT, the tip of the lung, clavicle and sternum usually absorb a large amount of radiation, which is easy to reduce the X-ray radiation dose of the lung and cause serious artifacts of the tip of the lung (Zhang, 2020).

Automatic tube current modulation (ATCM) enables dynamically selects tube current to ensure a consistent noise for each CT slice (Yu et al.,2010). According to Greess's literature report (2000), the X-ray radiation dose in the pelvic cavity can be reduced by 25% using autoregulation technology. CARE Dose4dD belongs to automatic tube current regulation.

At present, iterative reconstruction technology has been widely used, which can effectively reduce the X-ray radiation dose of CT scan. CARE Dose4D can automatically adjust the tube current according to the purpose of CT examination and the patient's body shape, realize personalized intelligent scanning, reduce the scanning X-ray radiation dose of patients, improve image quality, and has clinical application value in adult head and neck CTA (Shen et al., 2022) and chest CT (Yuan et al.,2016). However, there are few clinical studies on the application of CARE Dose4D technology in infants with CHD.

1.3 Objectives

1.3.1 General Objectives

Evaluation of the clinical application value and significance of Siemens dual-source Somatom Definition Flash CT with Care Dose4D technology in non-ECG-gated heart CT angiography in reducing X-ray radiation dose in infants and children with CHD.

1.3.2 Specific Objectives

1. To determine CTDIvol, DLP, and ED of CARE Dose4D technique CT scan.
2. To correlate the dose differences in different body weight and BMI according to the measured dose parameters (CTDIvol, DLP and ED).3. To evaluate the image quality of CARE Dose4D technology of Siemens dual-source Somatom Definition Flash CT scanner.

1.4 Hypothesis

1. There is significant difference between different body weight and BMI according to the measured dose parameters (CTDI vol, DLP and ED).

2. The image quality of the CARE Dose4D technology of the Siemens dual-source Somatom Definition Flash CT scanner is inferior to the image quality of the Siemens dual-source CT using the retrospective ECG triggered sequential technique.

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