STUDY ON THE EFFECTS OF PATIENT MISCENTRING ON RADIATION DOSE AND IMAGE QUALITY IN CT IMAGING

SITI HUMAIRAH BINTI MOHD RAZLAN TEO

SCHOOL OF HEALTH SCIENCES

UNIVERSITI SAINS MALAYSIA

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By

SITI HUMAIRAH BINTI MOHD RAZLAN TEO

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Siti Humairah bt Mohd Razlan Teo

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LIST OF ABBREVIATIONS

AAPM	American Association of Physicists in Medicine
AMDI	Advanced Medical Dental Institute
CT	Computed Tomography
CTDI	Computed Tomography Dose Index
CTDIvol	CTDI volume
CTDIw	Weighted CTDI
DLP	Dose length product
FOV	Field of view
HUSM	Hospital Universiti Sains Malaysia
PMMA	Polymethymethacrylate
ROI	Region of interest
SD	Standard deviation
SNR	Signal to noise ration

LIST OF SYMBOLS

Gy	Gray. Unit of dose measurement
HU	Hounsfield unit
kVp	Tube kilovoltage, peak kilovoltage
mAs	Tube current

ABSTRAK

Kesalahan menempatkan kedudukan pesakit ketika menerima rawatan sering terjadi semasa rawatan diagnostik yang boleh menyebabkan kesalahan mentafsir data yang diterima. Justeru, kajian ini dijalankan untuk mengkaji kesan-kesan ketidaksamaan kedudukan pesakit semasa pemeriksaan imbasan CT ke atas dos pesakit dan kualiti imej yang terhasil. Parameter imbasan CT, maklumat kedudukan pesakit telah diambil daripada protocol kepala dan *thorax-abdomen-pelvic* protokol yang diperlukan di dalam sistem *128-slice Siemens SOMATOM Definition AS + CT.* Melalui kajian ini juga kesalahan semasa pengimejan CT dikaji mengikut paksi (paski x dan paksi y) dengan menggunakan kaedah tinjauan retrospektif terhadap data-data pesakit yang diambil daripada perisian pemantauan dos *(GE DoseWatch software, Version 1.2).* Beberapa julat minimum dan maksimum telah diperoleh daripada data ini dan dijadikan sebagai garis panduan di dalam kajian phantom. Seterusnya fantom *CTDI phantom* dan fantom air masing-masing digunakan untuk mengkaji pengukuran dos dan kualiti imej. CTDIw digunakan untuk mengira dos yang merentasi lingkungan kawasan pada phantom. Di dalam kajian ini, peralihan *isocentre* dari paksi positif dan negatif boleh menyebabkan peningkatan dan penurunan dos CTDIw merentasi fantom. Kajian ini juga menunjukkan bahawa paksi x dan y masing-masing mempunyai perkaitan (r) yang lemah dengan CTDIw iaitu 0.1796 dan -0.2127 untuk fantom CTDI yang berukuran 16 cm. Manakala fantom yang berukuran 32 cm, perkaitan (r) antara CTDIw dan paksi adalah lemah bagi paksi x (r = -0.3555) dan perkaitan yang kuat bagi paksi y (r = 0.5582). Dalam penilaian kualiti imej, nilai *SNR* dikaji. Didapati tiada perkaitan yg terhasil diantara peralihan paksi x dan nilai SNR (r = -0.0268), namun nilai min HU and min sisihan piawai mempunyai perkaitan yang lemah dengan peralihan paksi x. Bagi paksi y, didapati perkaitan antara

peralihan paksi y dan nilai SNR sangat kuat (r = 0.8156). Begitu dengan perkaitan diantara min HU dan min sisihan piawai bersama peralihan paksi y.

ABSTRACT

Incorrect setting of patient positioning on the treatment table always happened in diagnostic imaging which leads to misinterpretation of data and degrades the image quality. This study focuses to evaluate the effects of patient miscentring on patient dose and image quality in CT imaging. The CT scan parameter, patient positioning information was taken from the head and thorax-abdomen-pelvic protocols acquired in 128-slice Siemens SOMATOM Definition AS + CT system. This study started with the retrospective survey on patient miscentring shifting data by using data registration (DoseWatch, version 1.2, GE Healthcare) to collect information about patient isocenter shifting. The range of miscentring for minimum and maximum had been obtained and will be used as guidelines in phantom studies. CTDI phantom and water phantom were used in dose measurement and image quality assessment respectively. CTDIw is used to calculate the dose across FOV of the phantom. In this study, isocentre shifting of both axes (positive or negative axis) can cause an increase or a decrease of CTDIw across the FOV. This research showed that the shift x- and y- axes and the phantom dose (CTDIw) have weak correlation which is 0.1796 and -0.2127 respectively for the 16cm CTDI phantom. While for 32 cm, the correlation is -0.3555 (weak) and 0.5582 (strong) between both variables. In image quality assessment, SNR is observed. Miscentring of both axes also associated with the quality of the image produced. There is no correlation between x-axis shifting and SNR (r = -0.0267). However, the correlation between mean HU and mean SD with the shift x-axis is weak. There is a strong positive association between the y-axis shifting and the SNR (r = 0.8156). The correlation between mean HU and mean SD also good with the y-axis.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Computed tomography (CT) scan is the advanced technology that combines a series of x-rays measurements taken from different angles around the patient's body by using a computer-processed and produces cross-sectional images of the anatomical structures inside the body. CT scan images also provide a piece of more-detailed information than plain radiographs (MayoClinic, 2018). However, the CT scan procedure produces higher exposure and radiation dose to patients. A previous study indicated CT delivers 40% of the collective dose to the population in medical x-ray examination in the United Kingdom (UK) (Habibzadeh et al., 2011).

Patient centring is an important factor during patient positioning in diagnostic radiology. A properly positioned patient has its centre of mass at the isocentre of CT gantry (Philips Healthcare, 2016). Proper positioning of the patient will allow the appropriate region of interest to be selected for a diagnostic scan. However, in some cases, the patient is not positioned centrally at the isocentre of the CT scanner and it will lead to the patient's miscentring. Position of the patient that is away from the isocentre of CT gantry resulted in misinterpretation of the patient size and attenuation properties and it may also lead to image quality reduction as increasing image noise and poorer dose optimization to the patient (Courname et al., 2019). Even though miscentring can increase the patient dose, it also may degrade the image quality produced. In Ali et al., 2017, reported the positive off-centering of CT gantry patients with fixed mAs, measured point organ doses were significantly lower, while negative off-centring showed significantly higher doses.

This study aims to evaluate the effects of patient miscentring in CT imaging on the patient dose and image quality by using the phantom study. All data collection and phantom study were performed at the two centers, Imaging Unit, Advanced Medical and Dental Institutes (AMDI), Universiti Sains Malaysia (USM), Penang and Radiology Department, Hospital Universiti Sains Malaysia (HUSM), Kubang Kerian, Kelantan.

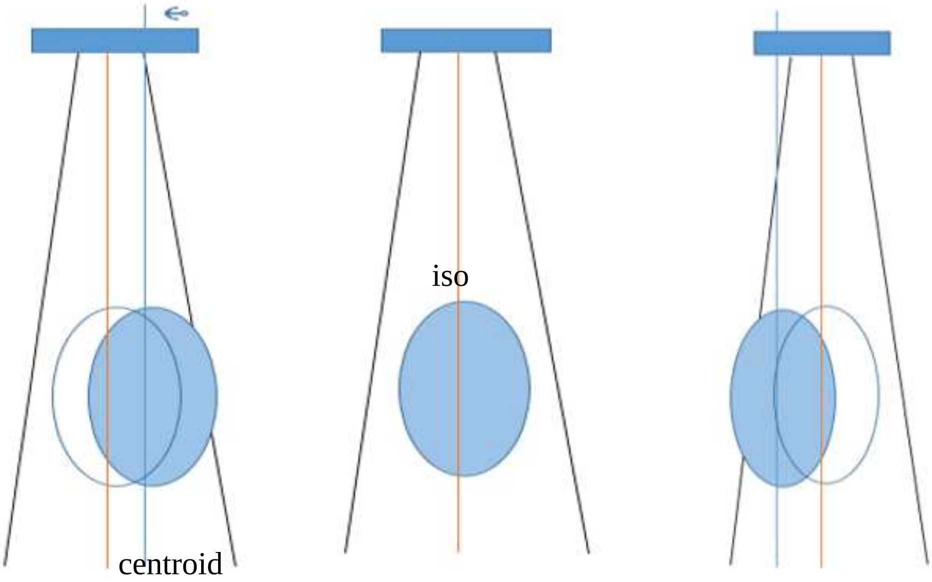


Figure 1.1: The CT gantry with scanned object is well-centred (centre), miscentred in negative x-axis (left), miscentred in positive x-axis (right). (Sukupova et al., 2016)

Figure 1.1 shows miscentring of the x-axis shifting of CT scanning. When isocentre and centre of mass of the phantom or the patient aligned together, the radiation imparted through CT tube gives the same dose for both sides of mass. When the centre of phantom was moved to the right or the left, the opposite side will expose to the high radiation dose.

1.2 PROBLEM STATEMENT

Previous studies stated that patient miscentring is due to the position of the patient that is away from the isocentre of CT gantry resulted in misinterpretation of the patient size and attenuation properties and it may also lead to image quality reduction by affecting an increase in image noise and leads to poorer dose optimization to patient. (Courname et al., 2019). Habibzadeh et al., 2011 reported an increase in surface radiation dose with off-centring from isocentre in their study of the impact of miscentring in both clinical and phantom settings. Other studies also stated that vertical off-centring of the patient that undergo chest CT imaging is a common and serious problem regardless of the patient size (Kaasalainen et al., 2014). Therefore, patient dose and image quality of CT imaging have become a huge and important topic in medical diagnosis since the earliest days of CT invention (Toth et al., 2007). Because of these problems, nowadays patient centring is one of the most important factors that need to be reviewed and has gained more attention during imaging to optimize patient doses and image quality.

1.3 RESEARCH OBJECTIVES

1.3.1 Main objective

This study aims to evaluate the effects of the patient miscentring on the patient dose and image quality in CT imaging.

1.3.2 Specific objectives

The specific objectives of this study are:

1. To investigate patient miscentring (x- and y-axis) errors during CT imaging by a retrospective survey on patient data from the dose monitoring software (GE DoseWatch software).
2. To evaluate the effects of patient miscentring on CT dose using dose measurement with CTDI phantoms.
3. To evaluate the effects of patient miscentring on image quality using water phantom study.

1.4 SIGNIFICANCE OF STUDY

Patient centring is an important factor that needs critical evaluation during patient positioning in CT imaging procedure because it affects the patient dose and image quality produced. The miscentring of phantoms or patients would lead to the degradation of image quality and increasing in radiation doses that caused poorer dose optimization (Sukupova et al., 2016). Therefore, this study may encourage the technologist to pay more attention to accurate patient positioning and ensuring the patient centring for dose optimization to the patient during CT imaging.

CHAPTER 2

LITERATURE REVIEW

2.1 Patient miscentring

Patient miscentring in CT imaging is described as the centroid position of the region-of-interest (ROI) or patients do not meet the isocentre of the gantry. This is the most common problem that occurred during CT imaging. According to the statement from Philips HealthCare (2016), when a patient is placed on a CT scanner during CT acquisition, the technologist should make the best judgement to ensure the patient is centred at the isocentre to get proper and accurate positioning. However, the technologists frequently do mistake by not accurately positioning the centroid of the patient at the isocentre of the gantry.

A previous study reported that the positive off-centering of CT gantry patients with fixed mAs, measured point organ doses were significantly lower, while negative off-centring showed significantly higher doses. Hence, the organ on or near the surface showed there were significant changes in point dose measurement and doses to internal organs also reported not show much different about concerning miscentring (Ali et al., 2017).

A centroid is the geometric centre of the object’s shape or also known as centre of the patient. The centre of the patient is crucial and important to determine the patient's miscentring during scanning (Habibzadeh et al., 2012). The miscentring of phantoms or patients would lead to the increasing of image noise which leads to a decrease in image quality and an increase in radiation doses that caused poorer dose optimization (Sukupova et al., 2016). Therefore, the patient centring should get greater attention among the technologist and medical doctors during CT imaging procedure to ensure optimum dose delivered and good image quality. In this study, the effects of patient miscentring on the patient dose and image quality were studied.

2.2 CT Dosimetry

Absorbed dose is determined as the energy absorbed by tissue in the human body as a result of exposure to ionizing radiation (RadiologyInfo.org, 2018). The surface dose is the dose that is absorbed in the patient skin. The dose at the surface is usually higher than the absorbed dose due to existing of scattered radiation. The SI unit for dose measurement is the gray (Gy), which is defined as one Joule of energy absorbed per mass in kilograms of matter (RadiologyInfo.org, 2018).

When a patient underwent a CT examination, CT doses metrics such as CT dose index volume, CTDIvol (in mGy), and dose length product, DLP (in mGy.cm) are the important dose parameters and will be displayed after each CT exposure. Computed tomography dose index (CTDI) is the CT dose metrics including weighted CTDI (CTDIw) and CTDI volume (CTDI_{vol}). According to AAPM Report No.96 (2008), CTDI varies across the field of view (FOV) as the dose at the surface is higher compare to at the centre of phantom or FOV. Average CTDI across the FOV is estimated by the CTDIw, where

$$CTDI\mathrm{w} = \frac{1}{3} CTDI_{center} + \frac{2}{3} CTDI_{periphery} \qquad \text{(Equation 1)}$$

The 1/3 and 2/3 values are equivalent to the relative areas indicated by the center and peripheral values. For a specific kVp and mAs, these values are a useful indicator of the production of scanner radiation.

CTDI_{vol} does not measure the amount of radiation received in any particular patient, but merely shows the intensity of the radiation to the patient. It specifies the radiation intensity required to conduct a specific CT examination (Huda et al., 2011).

Dose length product (DLP) is a measure of the total amount of radiation used to perform any CT examination (Huda et al., 2011). It is related to CTDI$_{vol}$, but CTDI$_{vol}$ represents the dose through a slice of the phantom. DLP accounts for the length of radiation output along the long axis of the patient (Huda et al, 2011). Equation 3 represents DLP is the product of CTDI$_{vol}$ and scan length.

$$CTDI_{\text{vol}} = \frac{CTDI\text{w}}{\text{Pitch value}} \qquad \text{(Equation 2)}$$

$$DLP = CTDI_{\text{vol}}\, x\; Total\ scan\ length \qquad \text{(Equation 3)}$$

These dose metrics can be affected by patient miscentring. From the previous study, the measurement of miscentring differences on the CTDIvol values was determined by polymethylmethacrylate (PMMA) and water phantom simulation. Based on the previous findings, it showed when phantom is placed above isocentre (positive miscentring), CTDIvol dose increased by 47% with low standard deviation (SD) of HU signal while when the phantom is placed below isocentre (negative direction), CTDIvol dose is decreased by 35% but image become noisier (Sukupova et al., 2016).

The miscentring of the patient is one of the important factors that should be avoided since it can increase the patient's surface dose. An increase in radiation dose can give patient unnecessary radiation dose during CT exposure. This study is aimed to evaluate the miscentring problem during CT examination and to study the effects of patient miscentring on CT doses by using a phantom study with CTDI phantom and CTDI dose was measured and calculated.

2.3 Image quality

Quality of image is one of the important parameters that should be considered and assessed during the imaging procedure. Good quality images will give a better description of the patient’s anatomical view and accurate description of the anatomical region of interest with high diagnostic value. Image quality is also related to the noise and signal when it is produced. The noise or also known as standard deviation, SD is defined as unwanted changes in pixel value on a homogenous image. It often appeared as a grainy structure on the image produced during image acquisition. The more graininess the image, the degradation of image quality will be increased. Certain factors affect image quality such as spatial resolution, image noise, artefacts, distortion, and also magnification. The acquisition parameters or exposure protocols in CT study can also affect image quality including tube current, tube rotation time, peak voltage, pitch, and beam collimation. The noise in CT imaging depends on the dose, size, and density of the scanned object and also patient centring during imaging (Courname et al., 2019). In this study, the image quality aspect is measured by signal-to-noise ratio (SNR) value, which compares the level of the signal (CT number in Hounsfield unit, HU) to the level of background noise (SD) as shown by Equation 4.

$$\boldsymbol{Signal\ to\ noise\ ratio\ (SNR)} = \frac{\boldsymbol{CT\ number\ (HU)}}{\boldsymbol{Standard\ deviation\ (SD)}} \qquad \textbf{(}\text{Equation 4)}$$

Therefore, noise is important as it can degrade the performance of CT imaging (Toth et al., 2007). Findings from another study have shown that the higher the SNR ratio, the less noise presented in the image, thus image quality will be better (Belle and Murphy, 2019). Since the earliest days of CT, the impact of dose and noise has been a hot topic of interest to the medical doctors and physicists in diagnostic radiology (Toth et al., 2007). Therefore, inaccurate patient positioning may lead to miscentring and it can affect the quality of the image.

CHAPTER 3

RESEARCH METHODOLOGY

This study consists of three parts of an experimental study which are Part 1 is the retrospective survey on patient data to evaluate the miscentring in x- and y- shift and Part 2 is the phantom studies for CT dose measurement and Part 3 is image quality assessment as shown in the figure below:

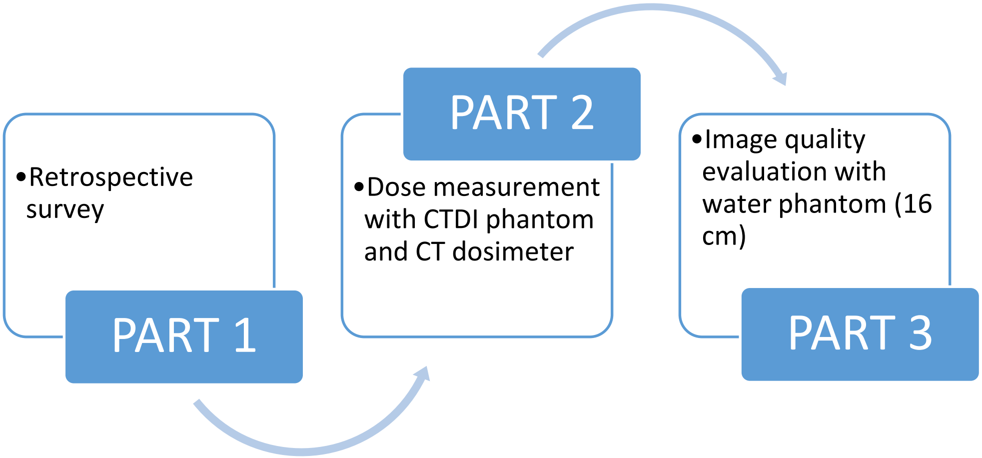


Figure 3.1: Parts of research methodology

3.1 RESEARCH TOOLS

3.1.1. CT Scanner

All phantom studies involving CT examination was carried out at the Radiology Department, Hospital Universiti Sains Malaysia (HUSM), Kubang Kerian, Kelantan. A 128-slices CT system (SOMATOM Definition AS+ CT scanner, Siemens Healthcare, Germany) (Figure 3.2) was used during the phantom study. All CT images used for image quality assessment were acquired using the helical mode and the exposure protocol was set using a CareDose 4D system for automatic exposure adjustment (AEC system).

Figure 3.2: Siemens CT scanner (SiemensHealthineer.com, 2020)

3.1.2. Experimental phantoms

There were two types of phantom used in this study which were Polymethylmethacrylate (PMMA) CTDI phantom and water phantom that are available at the Radiology Department, HUSM Kelantan. There were three cylindrical phantoms involved in this study with different sizes and types which were two CTDI phantoms of different sizes; 16 cm and 32 cm and also 16 cm water phantom. The CTDI phantom was used for dose (CTDI) measurement and the water phantom was used to determine the CT number, noise, and SNR values for image quality assessment. The CTDI phantom sized 16 cm represents the standard size of adult head and pediatric patient, while the 32 cm CTDI phantom represents the adult body size.

Figure 3.3: 16cm Siemens CT water phantom

Figure 3.4: 16cm and 32cm Siemens CTDI phantom (TechFlow, 2020)

3.1.3. CT Dose Detector

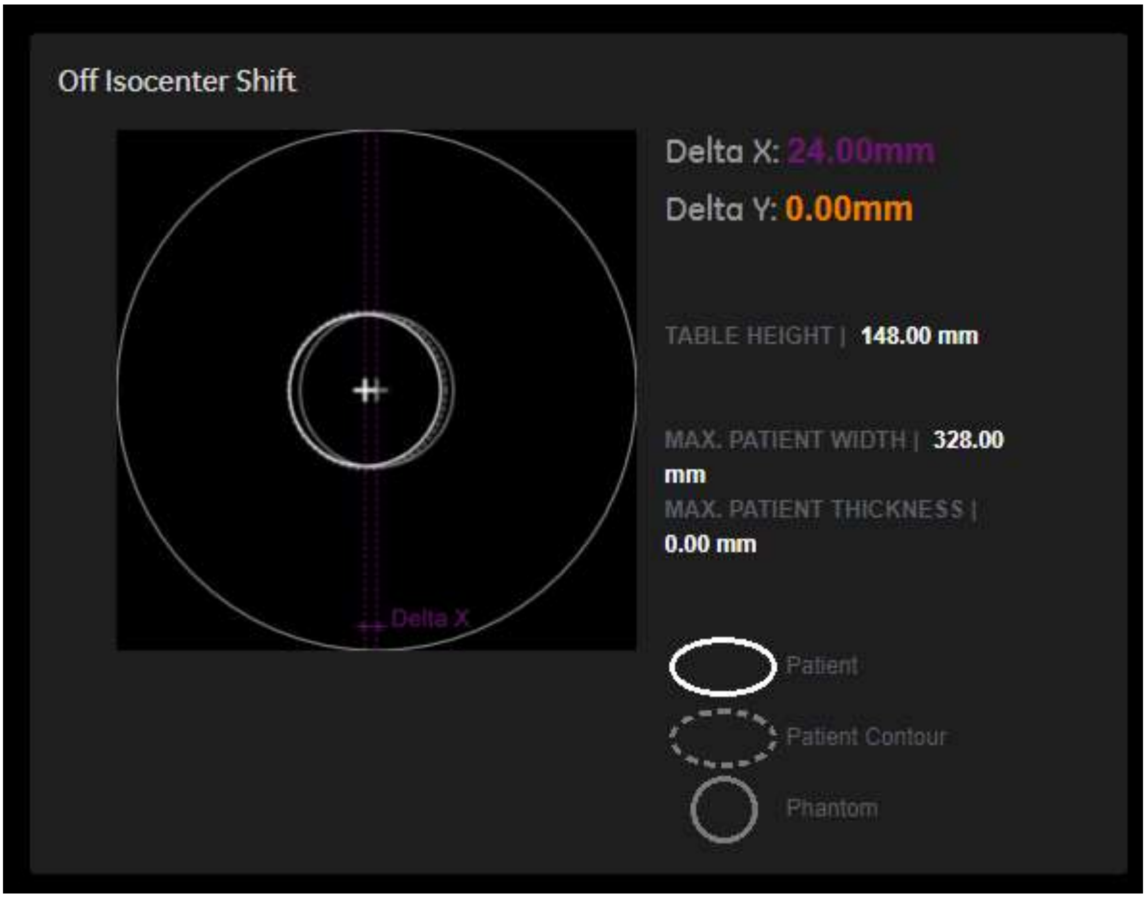
Figure 3.5: RaySafe Xi UnFors detector (FlukeBiomedical.com, 2020)

An ionization chamber is an important tool used in the measurement and calibration of CT dose. In this study, a CT dose detector (UnFors RaySafe Xi CT dosimeter) was used to measure the CTDI and the Dose Length Product (DLP) value in Part 2 of the study. The CT dose detector in which an ion chamber type (having 100 mm active length) was connected to the detector display to get the reading of CT dose (in mGy) during exposure to radiation. The ionization chamber is a simple gas-filled ion chamber which consists of a pair of charged electrodes that collect the ions formed within their respective electric fields. It is connected to the electrometer to read the radiation dose.

3.2 RESEARCH METHODOLOGY

PART 1: RETROSPECTIVE SURVEY

A retrospective survey was done on clinical data to observe the patient miscentring shifting during the previous CT examinations performed at AMDI, USM, Penang. The clinical data were retrieved from the data registration in dose monitoring software (GE DoseWatch, Version 1.2, GE Healthcare) to collect information on patient isocentre shifting during the CT abdomen and head examinations. All the CT imaging was performed by the two CT scanners at Advanced Medical and Dental Institute (AMDI) including Siemens SOMATOM Definition AS+ CT scanner and GE Discovery NM/CT 670 SPECT/CT scanner. The available shifting data collected from the GE DoseWatch software within the period from September 2014 up to September 2019 with complete protocols of the abdomen and head CT examination. The selection of patients is based on a random sampling method including both genders and all races involving adult patients (≥ 18 years old). From these available shifting data, the range for both axes; shifting x-axis, and shifting y-axis was collected. From shifting axes values, the minimum and maximum range of miscentring for both x-axis and y-axis shifting were obtained and were used as the guideline in phantom studies which in dose measurement and image quality assessment.



Off Isocenter Shift

Delta X: 24.00mm

Delta Y: 0.00mm

TABLE HEIGHT | 148.00 mm

MAX. PATIENT WIDTH | 328.00 mm

MAX. PATIENT THICKNESS | 0.00 mm

Figure 3.6: Display page on patient off centring shift in GE DoseWatch software.

PART 2: DOSE MEASUREMENT

Two CTDI phantoms with different sizes were used in this study which is 16 cm and 32 cm that represents the adult’s head and abdomen, respectively. The phantoms were marked with 0, 2, 4, and 6 cm range as in Figure 7 and positioned on the table couch aligned perpendicularly to the laser light to stimulate the patient miscentring.