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## **Study on the Computed Tomography Dose Index volume (CTDI<sub>vol</sub>) and CT Mode Relationship in Multislice CT Scan**

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### **Abstract**

The aim of this study was to measure the Computed Tomography (CT) dose at difference scanning modes: helical and axial scanning modes in multislices CT. The CT doses in this study were expressed in a quantity of Computed Tomography Dose Index volume (CTDI<sub>vol</sub>). The CTDI<sub>vol</sub> values measurements were determined by using a pencil beam ion chamber (VICTOREEN CT Probes, Model 500-100) with 10cm active chamber on polymethyl methacrylate (PMMA) CTDI head and body phantoms; scanned through multislice CT scan. The dependency of CT dose was investigated on two helical modes; High Quality mode and High Speed mode and three axial modes; one, two and four section modes. In High Quality mode; pitch of 0.75 utilized with the table speed of 3.75, 7.5, 11.25 and 15mm per rotation while in High Speed mode; pitch of 1.5 utilized with the table speeds of 7.5, 15, 22.5 and 30mm per rotation. The values of CTDI<sub>vol</sub> were measured at a fixed tube voltage of 120kV, tube current of 150mA and 180mA for head and body scanning respectively. The results showed the High Quality mode gave higher CTDI<sub>vol</sub> values in which it indicated of higher CT doses delivered compared to High Speed mode with other parameters remain unchanged. The dose decreases as the table speed and beam collimation increases.

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At different axial mode; the values of  $CTDI_{vol}$  were approximately same for each one, two and four section modes. Compared to helical mode,  $CTDI_{vol}$  value obtained in axial mode is in between the value obtained in High Quality mode and High Speed mode.

**Keywords:** CT dose index; CT mode

## **1. Introduction**

Computed Tomography (CT) is probably most significant development in history of medical imaging since the discovery of x-rays in 1895. Since its invention; CT imaging has seen massive advances in technology and clinical performance. Multislice CT or multi detector rows CT (MDCT) represents the new breakthrough in CT technology since it provides a huge gain in performance that can be used to reduce scan time, reduce section collimation or to increase scan length substantially.

Majority examinations of multi slice CT scan are performed in helical mode and issues regarding dose still an area of some debate on these system especially for those who had repeated CT examinations since the effective dose from CT scan on average is ~10 mSv [1]. Therefore, once a CT examination is considered justified, scanning parameters should be optimized and dose reduction techniques ought to be used to perform the examination at the lowest possible dose. The designs of single slice and multi-slice scanners are similar in most aspects that affect radiation dose, but multi-slice scanning can result in higher radiation risk to the patient due to increase capabilities allowing long scan lengths at high tube currents [2]. Radiologists and technologists tend to modify the scanning parameters and scanning protocols in daily scanning for dose reduction purpose. The three most effective ways to reduce radiation dose in CT is by lowering the tube current (mA), tube voltage (kV) and increasing the pitch [3]. As for single slice helical CT scan, the dose reduces as the pitch increases. However, in MDCT, the radiation dose was identical for all pitch selections on the multislice helical CT system due to automatic proportionate increase in the tube current when the pitch selection was increased [4,5].

This study was conducted in order to determine the relationship between  $CTDI_{vol}$  values and different CT mode in multislice CT scan examination. In multislice CT, two scanning modes are available; the axial and helical scanning. Axial scanning mode requires two alternate stages; data acquisition and patient positioning. During data acquisition stage, only the x-ray tube rotates around the patient while during patient positioning stage, no data are acquired and patient is transported to the next prescribe scanning location. This poor scanning efficiency directly limits the volume coverage speed versus performance and therefore the scan throughput of the axial CT. In helical scanning mode, the data are continuously acquired while the patient is simultaneously transported at a constant speed through the gantry. For multislice helical scanning, each rotation of gantry will provide more than one image corresponds to the number of detector rows. This study however, was conducted using 16-slices multi detector row CT (MDCT) in which can be considered as an old technology in CT scan development. Today 128-slices and even more advance 320-slices CT systems allow whole body scanning in short scan times with considerably reduced radiation dose to patients for routine CT scanning [6]. It is not surprising that dose reduction in CT scan has become the main concern for both the manufacturers and the end users of this imaging modality.

## 2. Materials and Methods

This study focused on measurements of  $CTDI_{vol}$  at different scanning mode of multi detector row CT scanner (MDCT). The MDCT used in this study was a single-source helical CT scanner (*LightSpeed™ 2.X*; GE Medical System); consists of 16 detector cells in the Z direction. Each of the detector cells are 1.25 mm and the detector configurations available were 4 x 1.25 mm, 4 x 2.5 mm, 4 x 3.75 mm, 4 x 5.0 mm, 1 x 1.25 mm, and 2 x 0.63 mm. All dose measurement used a pencil beam ion chamber (VICTOREEN CT Probes, Model 500-100) with 10cm active chamber and 3.2cm<sup>3</sup> active volume which used together with the exposure meter (Rad Check Plus Meter; Model 06 526-2200). The measurements were done on the polymethyl methacrylate (PMMA) CTDI with a diameter of 16 cm for head phantom and 32 cm for body phantom. The phantom was positioned so that the central axis of the phantom coincided with the rotation axis of the scanner. The pencil ion chamber was placed at the centre of the phantom while the other holes of the phantom were closed with acrylic rods provided. Figure 1 (a) shows the position of pencil beam ion chamber in the head of PMMA phantom while Figure 1 (b) shows the position of pencil ion chamber in body of PMMA phantom.

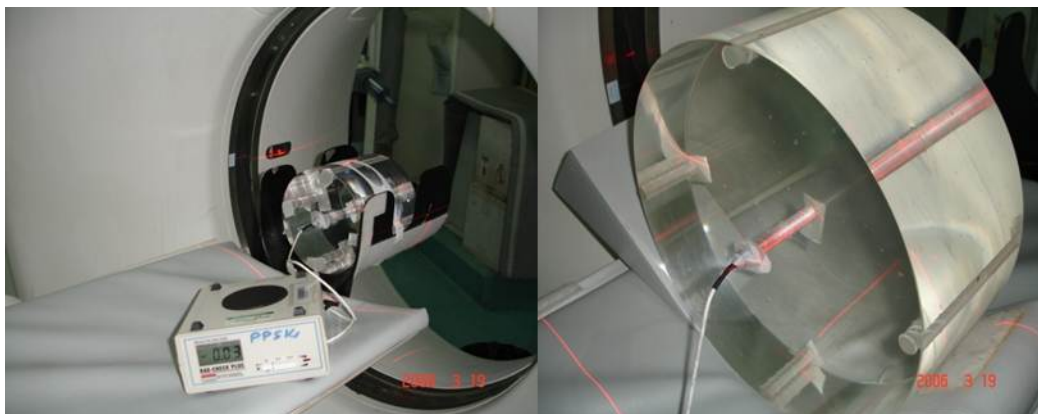


Fig. 1.(a) Position of pencil ion chamber in the head of PMMA phantom; connected with exposure meter and (b) Position of pencil beam ion chamber in the body of PMMA phantom

A constant tube voltage used; 120kVp for both scanning while tube current 150 mA and 180mA were used for head scanning and body scanning respectively. The values of  $CTDI_{vol}$  measured based on two scanning modes; helical CT mode and axial CT mode. In single-source MDCT, there were two helical CT modes available; High Quality (HQ) mode and High Speed (HS) mode. High Quality mode utilized 0.75 detector pitch while High Speed mode utilized 1.5 detector pitch. The detector pitch refers to the ratio of table speed per 360° gantry rotation per number of the detector rows. Four detector configurations was applied in both modes; 4 x 1.25mm, 4 x 2.5mm, 4 x 3.75mm and 4 x 5.0mm. The detector configurations, beam collimation, pitch and table speed for each detector configuration for both modes were summarised in Table 1.

Table 1: Table beam collimation, pitch and table speed for each detector configuration in High Quality and High Speed mode.

Detector configuration	Beam collimation	Pitch		Table Speed (mm/rotation)	
		High Quality	High Speed	High Quality	High Speed
4 x 1.25mm	5 mm	0.75	1.5	3.75	7.50
4 x 2.50 mm	10 mm	0.75	1.5	7.50	15.0
4 x 3.75 mm	15 mm	0.75	1.5	11.25	22.5
4 x 5.00 mm	20 mm	0.75	1.5	15.0	30.0

For the evaluation of axial CT mode, there are three section modes available; one, two and four section modes. Two detector configurations applied for one section mode; 4 x 1.25 mm and 4 x 2.5 mm and beam collimation of 5 mm and 10 mm for each detector configuration respectively. Four detector configurations applied in two and four section modes; 4 x 1.25 mm, 4 x 2.5 mm, 4 x 3.75 mm and 4 x 5.0 mm and beam collimation of 5 mm, 10 mm, 15 mm and 20 mm for each detector configuration respectively.

### 3. Results

The absorbed radiation doses in this study were expressed in the quantity of Computed Tomography Dose Index volume ( $CTDI_{vol}$ ). This dose quantity relates to measurements for the chosen High Quality (HQ) and High Speed (HS) modes in helical scanning and 3 different sections (one, two and four sections) in an axial scanning for head and body examination. To represent radiation dose for a specific scan protocol, which almost involves a series of scans, it is essential to take into account any gaps or overlaps between the radiation dose profiles from consecutive of the x-ray source.  $CTDI_{vol}$  values in this study represent the average radiation dose within the scan volume for PMMA CTDI head and body phantoms.

#### 3.1 CT Dose Index ( $CTDI_{vol}$ ) for helical scanning mode.

Table 2 summarized the values of  $CTDI_{vol}$  in head and body PMMA phantom which utilized the High Quality (pitch = 0.75) and High Speed mode (pitch = 1.5). The absorbed doses of head and body scanning in High Quality mode were higher than High Speed mode. For example, at detector configuration of 4 x 1.25 mm the dose measurement for High Quality mode and High Speed mode were 1.53 mGy and 0.74 mGy respectively.

#### 3.2 CT Dose Index ( $CTDI_{vol}$ ) for axial scanning mode

The values of  $CTDI_{vol}$  were measured at one section mode, two section modes and four section modes for head and body scanning was summarized in Table 3 and Table 4 respectively. The values were measured according to the different detector configurations which correspond to the beam collimation available in each mode. The result shows that the CT dose obtained at each mode were approximately the same. For both head and body scanning, the highest  $CTDI_{vol}$  value was obtained at one section mode; detector configuration of 4 x 1.25 mm

and beam collimation of 5 mm while the lowest value was obtained at four section modes; detector configuration of 4 x 5.0 mm and beam collimation of 20 mm. For example, the highest CTDI<sub>vol</sub> value for head scanning; 0.37 mGy was obtained at one section mode; detector configuration of 4 x 1.25 mm and beam collimation of 5 mm while the lowest value; 0.25 mGy was obtained at both four and two section modes; detector configuration of 4 x 5.0 mm and beam collimation of 20 mm.

Table 2: CTDI<sub>vol</sub> values for High Quality and High Speed mode on head and body scanning

Detector configuration	CTDI <sub>vol</sub> values for Head PMMA study		CTDI <sub>vol</sub> values for Body PMMA study	
	High Quality mode	High Speed mode	High Quality mode	High Speed mode
	(Pitch = 0.75)	(Pitch = 1.5)	(Pitch = 0.75)	(Pitch = 1.5)
4 x 1.25mm	1.53 mGy	0.74 mGy	0.79 mGy	0.40 mGy
4 x 2.50 mm	1.20 mGy	0.59 mGy	0.66 mGy	0.32 mGy
4 x 3.75 mm	1.16 mGy	0.58 mGy	0.65 mGy	0.32 mGy
4 x 5.00 mm	1.08 mGy	0.42 mGy	0.59 mGy	0.29 mGy

Table 3: CTDI<sub>vol</sub> obtained at axial mode; head scanning

Detector configuration	Beam collimation	CTDI <sub>vol</sub> at different axial modes (mGy)		
		One section	Two section	Four section
4 x 1.25mm	5 mm	1.1	1.08	1.09
4 x 2.50mm	10 mm	0.89	0.87	0.86
4 x 3.75mm	15 mm	-	0.86	0.86
4 x 5.00mm	20 mm	-	0.79	0.79

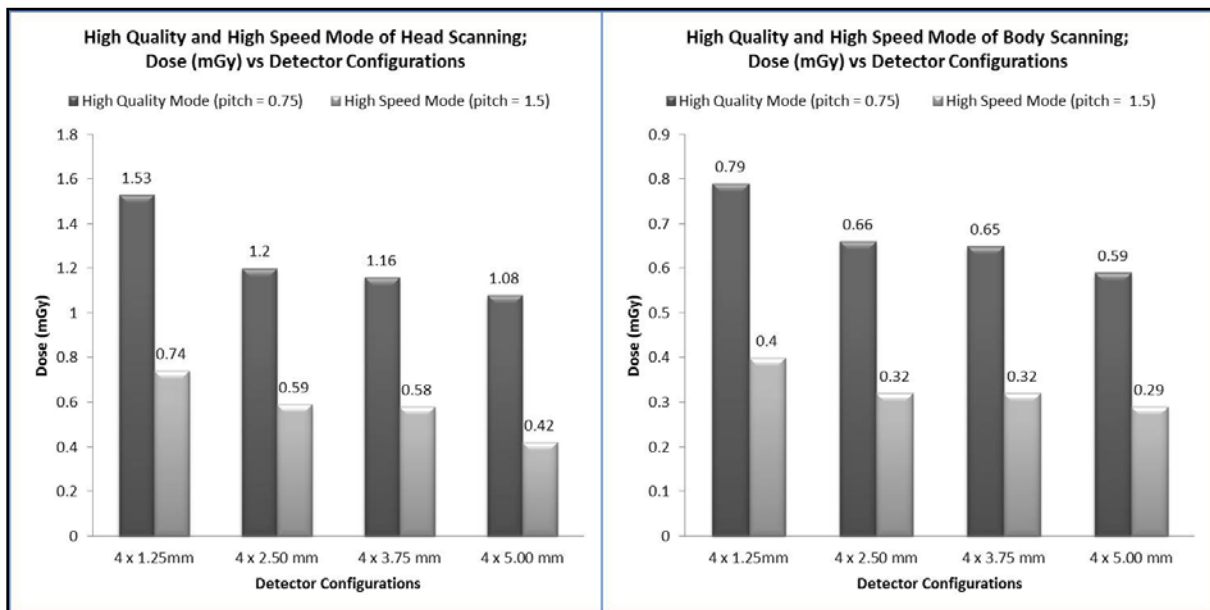
Table 4: CTDI<sub>vol</sub> obtained at axial mode; body scanning

Detector configuration	Beam collimation	Dose at different axial modes (mGy)		
		One section	Two section	Four section
4 x 1.25mm	5 mm	0.37	0.37	0.34
4 x 2.50mm	10 mm	0.30	0.30	0.26
4 x 3.75mm	15 mm	-	0.29	0.27
4 x 5.00mm	20 mm	-	0.25	0.25

#### 4. Discussion

During the introduction of helical CT, the only new parameter arise was table feed per gantry rotation, because there was shift from “step and shoot” technology to continuous table movement with continuous transport of patient through a scanner without pausing to perform a slice. The practical impact of this new parameter was to introduce the new term “pitch”. In this study, the definition of pitch used was the *ratio of table travel per rotation in millimeters divided by the beam collimation* as defined by GE Medical System. A total beam collimation are corresponds to the distance (mm) in the z direction covered by all detector rows that are active during a scan.

In this study, the values  $CTDI_{vol}$  obtained at higher pitch (High Quality mode) results in a lower radiation dose when other parameters remain unchanged. Bar charts in Figure 2 (a) and (b) shows the  $CTDI_{vol}$  values obtained in High Speed mode (pitch = 1.5) were half than values in High Quality mode (pitch = 0.75) for both head and body scanning where it can be summarized that doubling the pitch will reduce the radiation dose by half. These findings are in broad agreement with Zarb, F. et al (2011) who concluded that dose was inversely proportional to pitch. As pitch increases, the radiation dose decreases since the time at any one point in space spent in the x-ray beam also decreases [3].



(a)

(b)

Figure 2:  $CTDI_{vol}$  obtained at High Quality mode and High Speed mode for each detector configurations (a) head scanning and (b) body scanning

With helical CT scanners, table speed, beam collimation and pitch are interlinked parameters, faster table speed for a given collimation, resulting in higher pitch. Increasing the table speed would reduce the radiation dose

since there is shorter exposure time (if other scanning parameters are held constant)[5]. Figure 3 (a) and (b) illustrate the trends of radiation dose changed when table speed increase in High Quality mode and High Speed mode respectively. Both figures showed the radiation dose decreases as the table speed increase. At a higher pitch, the table speed becomes faster, reducing the scanning time as well as the radiation dose. Lower pitch implies slower table speed and thus increase the scanning time and therefore increases the radiation dose. Since the table speed in High Speed mode was faster than High Quality mode, the radiation dose was less in High Speed mode.

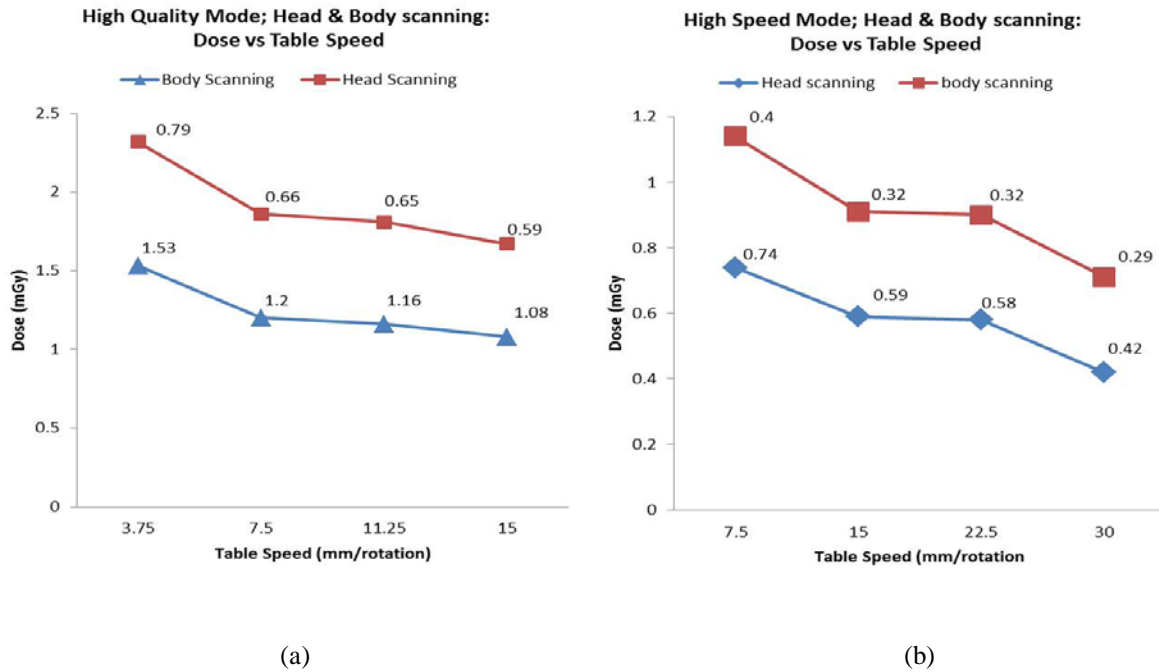


Figure 3: CTDI<sub>vol</sub> obtained at different table speed of head and body scanning (a) High Quality mode and (b) High Speed mode

The beam collimation also affects the radiation dose. Narrow beam collimation led to higher radiation dose [5]. From this study, CTDI<sub>vol</sub> values decrease as the beam collimation increase as demonstrated in Figure 4(a) and (b). In multislice CT scan, as the total width of collimation is small, it will produce larger penumbra and the CT dose will increased [7]. This explained why the CT doses decrease as the beam collimation increase.

In axial mode, CTDI<sub>vol</sub> values significantly changed as the beam collimation changed. Bar chart in Figures 5 shows the dependency of CTDI<sub>vol</sub> values on beam collimation. The values decrease as the beam collimation increase. Larger the collimation sizes give less radiation dose compared to smaller collimation size. Note that, the radiation dose was approximately same at the same collimation even in the different modes. As discussed earlier, a wider collimation will cause a smaller penumbra that will led to decrease in radiation dose. The different axial mode only indicates the different number of images produce per rotation. In one-section mode, only one slice will be scan, in two-section mode; two slices will be scan and in four-section mode; four slices will be scan. As shows in Figure 6, at detector configuration of 4 x 1.25mm, 5mm anatomy covered per rotation

of gantry. The detector configuration determined the beam collimation for all axial modes. This shows the radiation dose depends only on the collimation size.

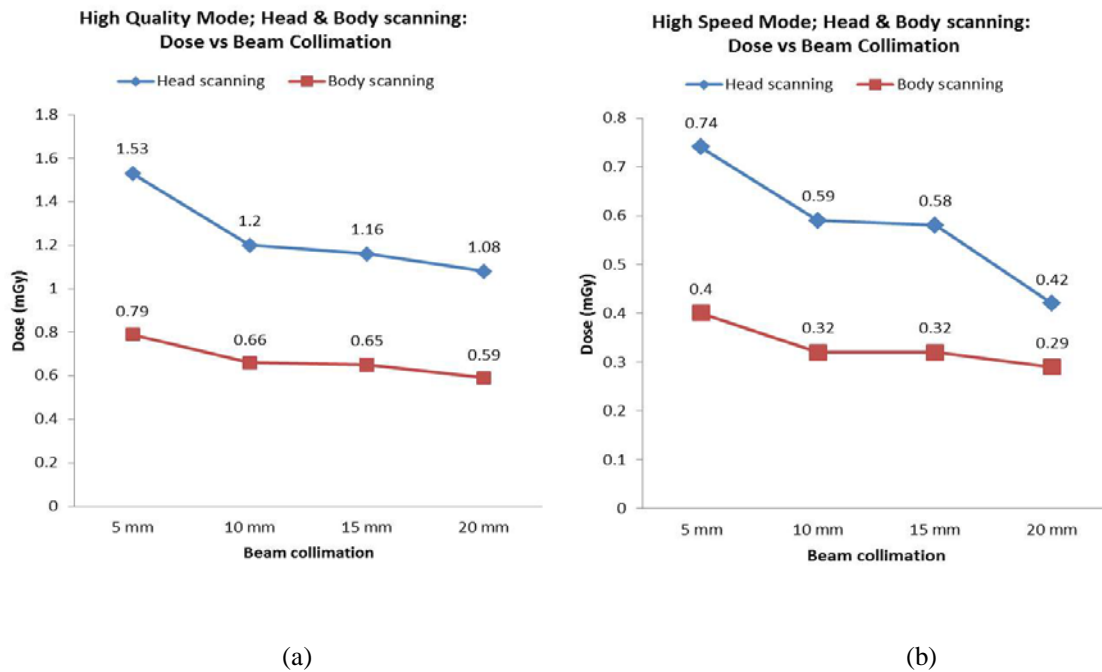


Figure 4: CTDI<sub>vol</sub> values obtained at different beam collimation of head and body scanning (a) High Quality mode and (b) High Speed mode

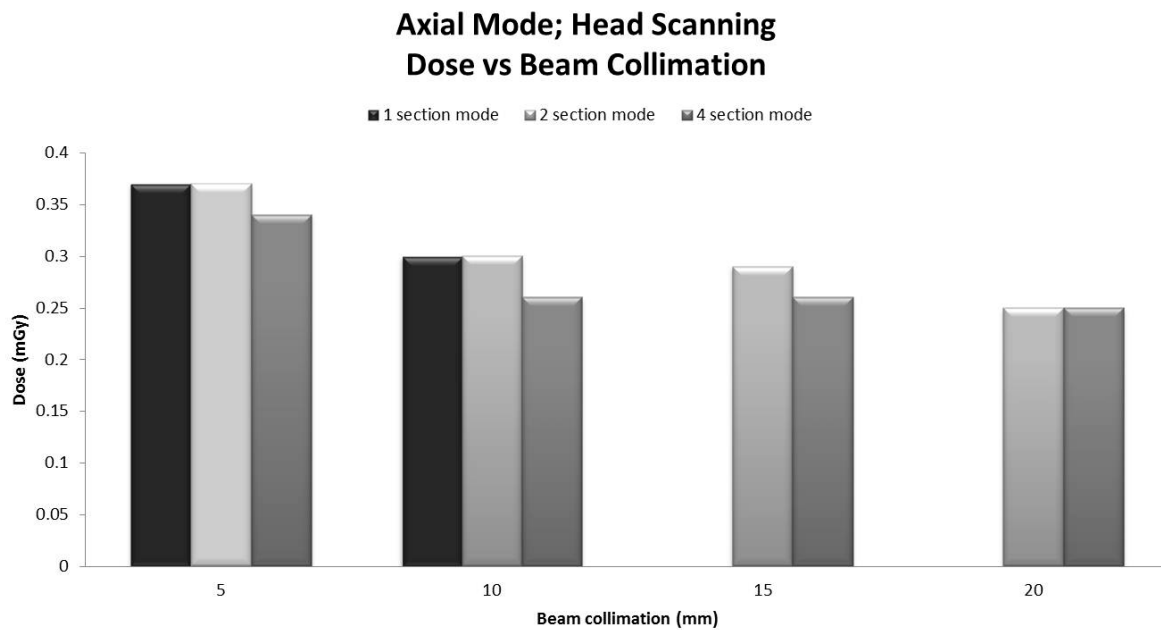


Figure 5: CTDI<sub>vol</sub> obtained at different beam collimation of head scanning in axial mode



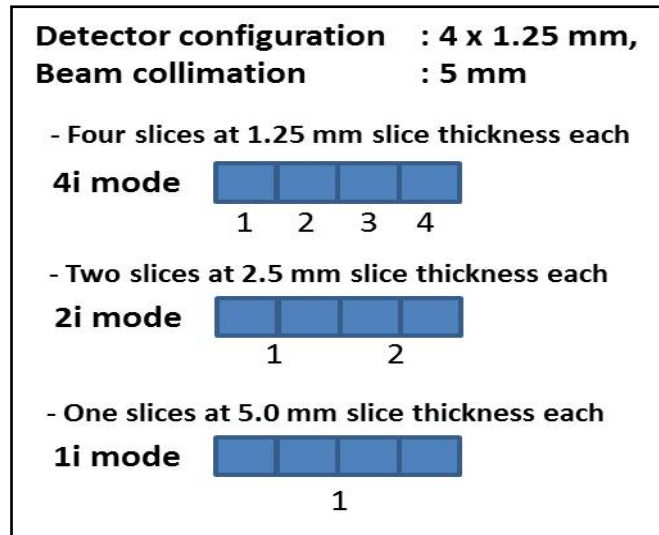


Figure 6: Different axial mode; 1i, 2i and 4i mode at same detector configuration of 4 x 1.25mm, beam width of 5mm

Compared to helical mode,  $CTDI_{vol}$  values obtained in axial mode were in between of the values obtained in High Quality mode and High Speed mode. Bar charts in Figure 6 shows the highest  $CTDI_{vol}$  value obtained in High Quality mode, the lowest value was at High Speed mode while  $CTDI_{vol}$  values obtained in axial mode were in the middle of those in helical modes.  $CTDI_{vol}$  is a useful indicator of the dose for a specific exam protocol because it takes into account protocol-specific information such as pitch. If pitch of axial scan is 1, radiation dose in helical mode is given by:  $CTDI_{vol} (helical) = CTDI_{vol} (axial) \times 1 / pitch$  [8]. For example, with a pitch of 1.5, the radiation dose from helical scanning is 67% lower than radiation dose from axial scanning and a pitch of 0.75 correspond to a helical radiation dose 133% higher than axial radiation dose. However, a correction factor is needed when the pitch is not 1.0 [8]. This study shows that the axial radiation dose was lower than radiation dose in High Quality mode and higher than radiation dose in High Speed mode.

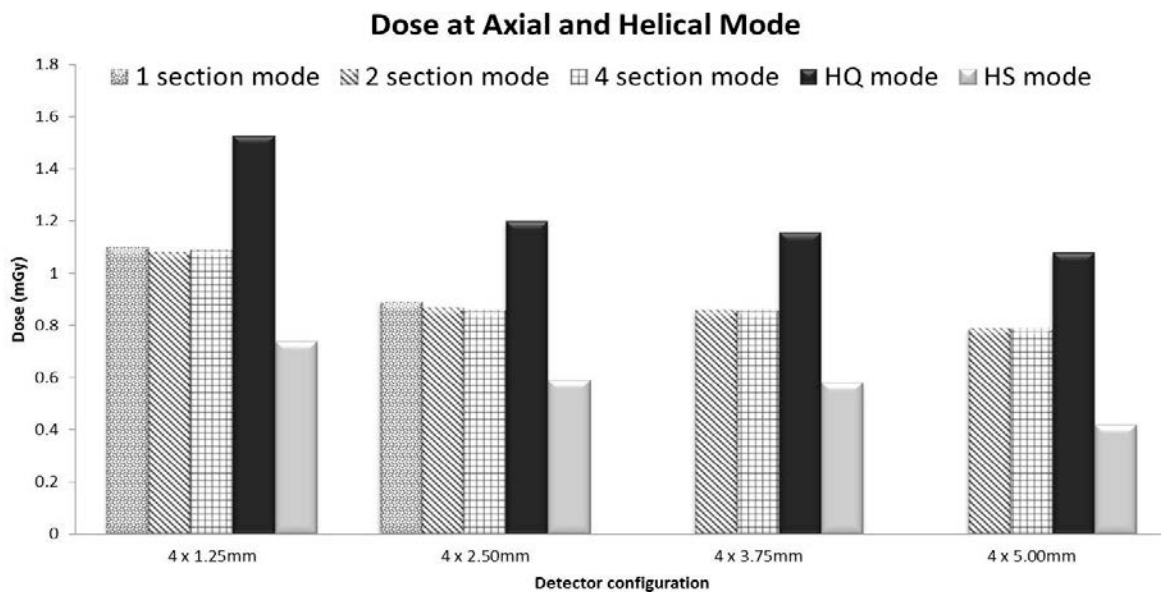


Figure 6:  $CTDI_{vol}$  values obtained at all axial and helical mode.

## 5. Conclusion

Based on this study, in helical mode, pitch becomes a very important parameter that affects the value  $CTDI_{vol}$ ; higher pitch mode delivered less radiation dose. Pitch is affected by the table speed; increasing the table speed will result in higher pitch, therefore  $CTDI_{vol}$  value decreases as table speed increases.  $CTDI_{vol}$  values also depend on beam collimation; the values decrease as beam collimation increases. In axial mode the number of slice during the axial mode does not affect  $CTDI_{vol}$  values. The values depend on the beam collimation at each mode. At the higher beam collimation, the patient will receive less radiation dose compared to smaller beam collimation.

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