128 slice computed tomography dose profile measurement using thermoluminescent dosimeter

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Abstract. The increasing use of computed tomography (CT) in clinical practice marks the needs to understand the dose descriptor and dose profile. The purposes of the current study were to determine the CT dose index free-in-air ($CTDI_{air}$) in 128 slice CT scanner and to evaluate the single scan dose profile (SSDP). Thermoluminescent dosimeters (TLD-100) were used to measure the dose profile of the scanner. There were three sets of CT protocols where the tube potential (kV) setting was manipulated for each protocol while the rest of parameters were kept constant. These protocols were based from routine CT abdominal examinations for male adult abdomen. It was found that the increase of kV settings made the values of $CTDI_{air}$ increased as well. When the kV setting was changed from 80 kV to 120 kV and from 120 kV to 140 kV, the $CTDI_{air}$ values were increased as much as 147.9% and 53.9% respectively. The highest kV setting (140 kV) led to the highest $CTDI_{air}$ value (13.585 mGy). The p-value of less than 0.05 indicated that the results were statistically different. The SSDP showed that when the kV settings were varied, the peak sharpness and height of Gaussian function profiles were affected. The full width at half maximum (FWHM) of dose profiles for all protocols were coincided with the nominal beam width set for the measurements. The findings of the study revealed much information on the characterization and performance of 128 slice CT scanner.

1. Introduction

The discovery of X-ray by Wilhelm Conrad Roentgen in 1895 marked the true start of imaging [1]. The introduction of X-ray computed tomography (CT) to medicine in the early 1970s was done by Godfrey Newbold Hounsfield [2]. The introduction of computed tomography dose index (CTDI) as a metric to quantify the radiation output from a CT examination was made by Shope et al. in 1981 [3]. The word “index” was particularly incorporated in CTDI’s name to distinguish the quantity from the radiation dose absorbed by patients [3]. The concept of CTDI was introduced as a simple way to evaluate the CT dose descriptor.

Since the advent of CT, there were a lot of reports on the radiation exposure of CT systems [4]. Those reports described various measurement methods to characterize the radiation delivered by CT and many of them were based on single scans measurements. A long (100 mm) pencil ionization chamber is commonly used to make CTDI measurements which integrates the longitudinal single scan dose profile (SSDP) using a single axial scan [5]. By far the most common method for measuring SSDP is using thermoluminescent dosimeter (TLDs) due to its abundance of advantages, though several other methods have been described as well [6].

One of the dosimetric quantities to characterize the exposure from CT scanners concerns the CTDI and can easily be determined free-in-air for a single scan on the axis of rotation of the scanner ($CTDI_{air}$) [7]. $CTDI_{air}$ is a course indicator of patient exposure for an examination and thus, it is an important element in the implementation of patient dosimetry. The SSDP is referring to the CT output characteristics of air-kerma distribution along the z-axis of CT scanner using a single axial scan [8]. The concept of dose descriptor (CTDI) and dose profile (SSDP) provide a lot of information on the characterization and performance of CT scanners. Besides, the effect of different tube potential (kV) in measuring CT dose is worthy of special attention. Therefore, the aim of this study is to determine the CT dose index free-in-air ($CTDI_{air}$) in 128 slice CT scanner and to evaluate the single scan dose profile (SSDP) using thermoluminescent dosimeter (TLD-100).

2. Materials and Methods

2.1 Multi-slice CT scanner

Free-in-air measurements were carried out in 128 slice CT scanner Siemens SOMATOM Definition AS+ in Hospital Sultanah Aminah, Johor Bahru. The protocols were based from routine CT abdominal examinations for male adult abdomen. The protocols used to measure the dose profiles consisted of single axial scan of 5.0 mm slice thickness, 32 × 1.2 mm nominal beam width and scan time of 0.5 s. The tube current was fixed at 100 mAs, while the tube potential was modified to 80 kV for Protocol I, 120 kV for Protocol II and 140 kV for Protocol III.

2.2 Thermoluminescent dosimeter

The type of thermoluminescent dosimeter (TLD) used in this study was lithium fluoride doped with magnesium and titanium (LiF: Mg, Ti) chips or better known as TLD-100, manufactured by Harshaw Chemicals. TLD-100 was preferred because it is well-known with its high precision and sensitivity and has long-term stability. The TLDs used were in the form of chips with dimensions of 3.2 mm × 3.2 mm and 0.89 mm thickness [9].

The TLD-100 chips were calibrated at the Secondary Standard Dosimetry Laboratory (SSDL) in Malaysia Nuclear Agency (Nuclear Malaysia), which they were irradiated at 8 mGy to determine the TL response of the dosimeter to a measured exposure or absorbed dose of radiation of clearly defined energy [10]. The TLDs were read-out using Harshaw Thermoluminescence Dosimetry (TLD) Reader Model 3500. The readings obtained from this process were used to get the calibration factor. The annealing of TLDs was performed in TLD annealing oven for 1 hour at 400°C, 2 hours at 100°C and cooled down slowly to ambient temperature [11].

2.3 Dose profile measurements

Three sets of TLD-100 cases custom built made of perspex were prepared (figure 1). The length of case was 150 mm and it was grooved with 5 mm width and 3.5 mm depth where sets of three TLDs can be placed. The distance between the centre of each groove was 7 mm and the central part of the case was designed in such a way that it gives the possibility to place 11 TLDs adjacent to each other. A total of 213 TLDs (three batches of 71 TLDs) were used in the measurements. The groove of the central part was stacked with 11 TLDs (high sampling area) to ensure the accuracy of measurement at the central part as the X-ray beam is concentrated at the centre of target. The quantity of chips was odd because the dose profiles were plotted according to the position along the z-axis and there was a position of z=0 or the midpoint of dose profile. To arrange the TLD chips into the cases, the vacuum tweezers (Dymax 5 - Charles Austen Pumps Ltd) was used to avoid any scratches on the chips. The cases were covered with black covers which were also made of perspex for storage purpose.

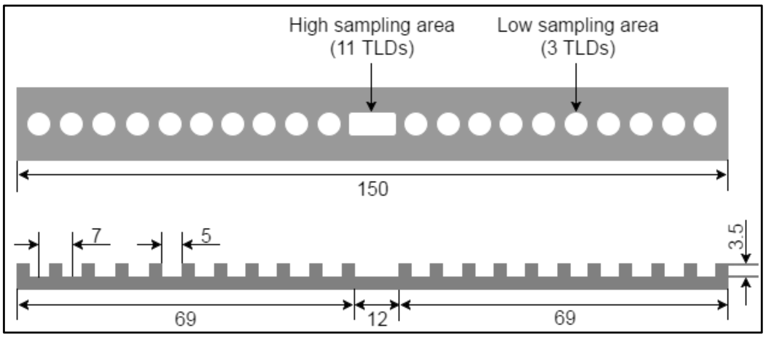


Figure 1. The schematic diagram of the custom-built TLD-100 case.

The case was placed at the isocenter of CT scanner as shown in figure 2 and the chips were irradiated according to the protocols that have been mentioned in subsection 2.1. For all protocols, all parameters were set constant except the tube potential (kV). The irradiated TLD chips were read out using Harshaw Thermoluminescent Dosimetry (TLD) Reader Model 3500. A list of readings from the chips was referring to the total charge collected in unit nC. The TLD reader's background and the background reading of TLD chips were also read out to get the final values of $CTDI_{air}$ for each protocol. From the air kerma values obtained from the TLDs, the SSDP was plotted in accordance to the position (mm) along the z-axis using OriginPro 9.0 software.

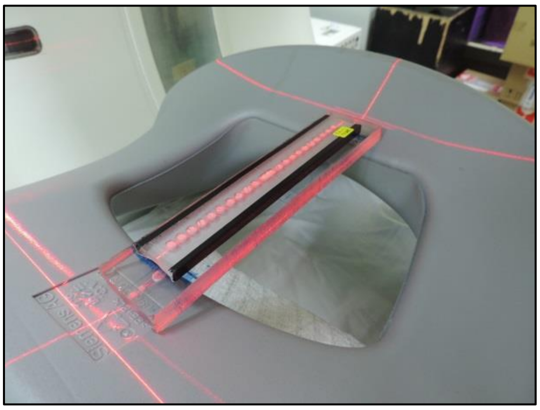


Figure 2. The TLD-100 case at the isocenter of CT scanner.

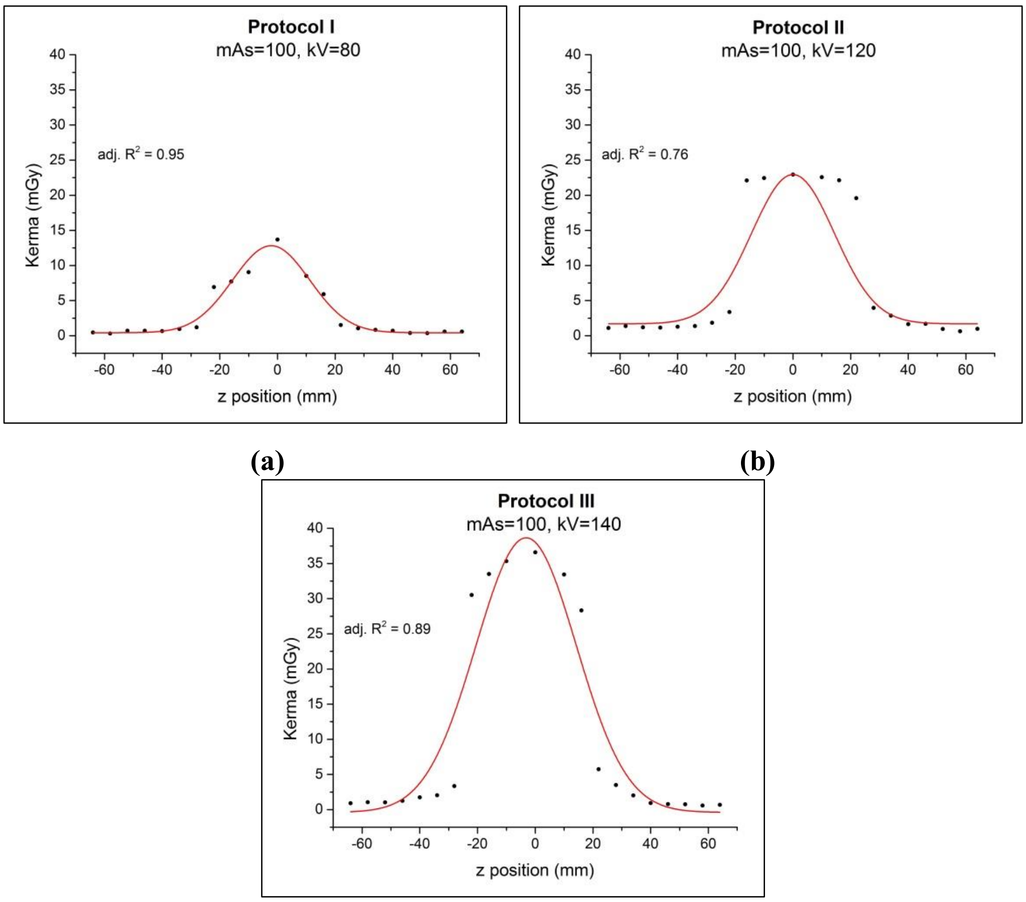
3. Results

The parameters for each protocol and the values of $CTDI_{air}$ obtained from the free-in-air measurements are shown in table 1. There were three different sets of protocols with different kV settings. While the tube current was fixed at 100 mAs for all protocols, the kV was changed to 80 kV for Protocol I, 120 kV for Protocol II and 140 kV for Protocol III. The lowest value of $CTDI_{air}$ was contributed by Protocol I which was 3.560 mGy when the kV setting was 80 kV and the highest $CTDI_{air}$ value was 13.585 mGy with 140 kV from Protocol III. It was found that as the kV values were increased, the $CTDI_{air}$ values were increased as well. When the kV setting was changed from 80 kV to 120 kV and from 120 kV to 140 kV, the $CTDI_{air}$ values were increased as much as 147.9% and 53.9% respectively. For the statistical analysis, the findings were tested with the Kruskal-Wallis test to show how much the data is significantly different from one protocol to another. According to the test, the *p*-value was less than 0.05. This test was chosen because it is a non-parametric method to compare two or more independent samples, where in this study, there were three protocols to be compared.

Table 1. The parameters and $CTDI_{air}$ values for each protocol.

Protocol	Slice Thickness (mm)	Nominal beam width (number of detector × slice width)	Scan time (s)	Tube current (mAs)	Tube potential (kV)	$CTDI_{air}$ (mGy)	*p*-value
I	5.0	32 × 1.2 mm	0.5	100	80	3.560	
II	5.0	32 × 1.2 mm	0.5	100	120	8.827	< 0.05
III	5.0	32 × 1.2 mm	0.5	100	140	13.585	

Figure 3 (a-c) shows the single scan dose profiles (SSDP) for the three protocols. The dose distribution profiles were plotted based on the kerma readings in unit mGy against the position in unit mm along the z-axis. The doses were distributed like a bell shape and therefore, they were fitted using Gaussian function in Origin Pro 9.0 software. It was observed that the peak of the dose profiles were getting higher and sharper when the kV increased. The full width at half maximum (FWHM) which gives the information on the nominal beam width of CT scanner can be determined from the SSDP using the same software [3]. The FWHM were found to be 36.2, 36.4 and 38.6 for Protocol I, Protocol II and Protocol III respectively.



(a) **(b)**

(c)

Figure 3. The single scan dose profile (SSDP) for (a) Protocol I, (b) Protocol II and (c) Protocol III.

4. Discussion

According to table 1, the increase in $CTDI_{air}$ when the kV settings were varied increasingly showed that the change of kV affected the patient exposure from CT scanner. Although $CTDI_{air}$ did not show the patient dose because CT dose index is not the same as patient dose, $CTDI_{air}$ is an important element in the implementation of patient dosimetry [7]. CTDI gives information such as on how a CT machine operates, the patient size and scanned anatomy to estimate the patient dose [3]. This is where the use of CTDI is important for the implementation of patient dosimetry. The tube potential which is measured in kilovolt (kV) shows the amount of energy supplied to the machine to radiate the X-ray and controls the quantity of the X-ray beam. For CT scan, there are a few factors that influence the value of CTDI such as kV, mAs, tube rotation time, pitch and beam collimation. In this study, the effect of kV setting was observed. The higher kV results in the higher CTDI values. According to the results obtained from the study, it was proven true that when the kV was higher, the $CTDI_{air}$ value was higher as well. The *p*-value of less than 0.05 acquired from the Kruskal-Wallis test indicated that these results were reliable and significantly different. This is important to determine the $CTDI_{air}$ and evaluate the dose profile for each protocol.

The SSDP is usually measured in 140 to 150 mm long phantoms [6]. Therefore, to imitate the measurement using phantom, the same integration length was applied for the measurement free-in-air, which was also 150 mm. The cases of TLD-100 were grooved such that there were high sampling area (11 TLDs) at the central part and low sampling areas (three TLDs) at the adjacent sides. This was done so because the CT beam was concentrated at the centre part of target. Therefore, to get more accurate results at the concentrated part, 11 TLD chips were placed adjacent to each other. Referring to figure 3 (a-c), there were apparent difference between the measured kerma values in the central part and the adjacent sides. For high sampling area which was the central part or the peak near slice centre, each measured point on the profile was derived from a single TLD value. While for the positions adjacent to the high sampling area or the long dose tail, the dose values were obtained by averaging over three TLD values.

The SSDP showed some characteristics of CT scanner's exposure. The sharp peak near the slice centre where z=0 resulted primarily from contribution of the primary X-ray beam and the centre part has the highest contribution of doses [12]. The maximum kerma was found to be at the midpoint of the axis, which was exactly at z=0. This was true since the central part of target is the position where the X-ray beam was the most concentrated. The long dose tails were caused by the scattered radiation [3]. The nominal beam width of CT scanner was fixed to be 38.4 mm (32 × 1.2 mm) for all protocols. It was found that the FWHM for the protocols were 36.2 (Protocol I), 36.4 (Protocol II) and 38.6 (Protocol III). There were an underestimation of 5.7% and 5.2% for Protocol I and II respectively, while Protocol III had an overestimation of 0.5%. For more accurate results, the measurement free-in-air for the beam width of more than 32 mm should be performed with an integration length of more than 150 mm [13]. Besides that, although TLD-100 offers many advantages as stated earlier in the Material and Methods section, this TL dosimeter also have several disadvantages. It has high uncertainty (~18.3%) and non-continuous reading, which may affect the evaluation of SSDP [14]. Overall, the FWHM were coincided with the nominal beam width used during measurements since the percentage of the under and overestimations were less than 10% (the acceptable value). The CT dose profiles reflected the efficiency of the scanner to irradiate the X-ray beam in accordance to the nominal beam width. The analysis made from the measurements of $CTDI_{air}$ and evaluation of SSDP pointed out that the performance of CT scanner were in optimum state.

5. Conclusion

In the current study, the computed tomography dose index free-in-air ($CTDI_{air}$) was determined and the single scan dose profile (SSDP) was evaluated in 128 slice CT scanner using thermoluminescent dosimeter (TLD-100). The changes of tube potential (kV) have influenced the $CTDI_{air}$ values and CT dose profiles. The increase in kV values led to the increasing of $CTDI_{air}$ values by as much as 147.9%

when the kV setting was changed from 80 kV to 120 kV. The statistical analysis using Kruskal-Wallis test which showed a *p*-value of less than 0.05 validated that the data were significantly different from one protocol to another. The SSDP indicated the behaviour of the exposure of CT scanner. The FWHM obtained from SSDP implied the CT scanner's nominal beam width. The FWHM were coincided with the nominal beam width used during measurements and both of them are in good agreement.

There were several limitations to this study. First, this study only involved the measurements of CTDI free-in-air using TLD-100. Future study with other dose measuring apparatus like optically stimulated luminescence dosimeter (OSLD) must be performed to confirm our findings. Second, our result was confined to one type of CT scanner which was 128 slice CT scanner Siemens SOMATOM Definition AS+. The study could be extended to different protocols with different parameter settings in various CT scanner. This work may contribute to the establishment of the national diagnostic reference level (DRLs) in term of SSDP. In conclusion, the $CTDI_{air}$ and SSDP are useful methods for characterizing and assessing the performance of the CT scanner. By applying both methods, we can conclude that the 128 slice CT scanner's performance was in optimum condition.

6. References

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