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A system to investigate and adjust profile pattern of computed tomography dose index along the longitudinal-axis

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ABSTRACT

The purpose of this study to develop software to extract and investigate the profiles of the tube current and volume computed tomography dose index ($CTDI_{vol}$) along the longitudinal axis (z-axis). The tube current and $CTDI_{vol}$ were extracted from the Digital Imaging and Communications in Medicine (DICOM) header of every image along the longitudinal axis. We evaluated the profiles of the tube current and $CTDI_{vol}$ from eight computed tomography (CT) scanners. If the $CTDI_{vol}$ did not fluctuate along the fluctuation of the tube currents, then the system will adjust the $CTDI_{vol}$ with tube currents. It is found that TCM is not always activated. If TCM is activated, the profiles of TCM vary from one scanner to another. The Siemens and Philip scanners have adjusted the $CTDI_{vol}$ profile with tube current, but the Toshiba scanner has not. By developed software, $CTDI_{vol}$ profile of the Toshiba can be easily adjusted. In conclusion, software to investigate the profile pattern of $CTDI_{vol}$ along the longitudinal axis has been successfully developed. The software is easy to use and works quickly. From this study, medical staff must be careful when using the $CTDI_{vol}$ along longitudinal axis contained in each DICOM header.

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1. INTRODUCTION

The health risks from radiation dose in computed tomography (CT) has motivated efforts to optimize CT dose [1]–[7]. One such technique is the tube current modulation (TCM) technique [8]–[10]. Nowadays, the majority of CT scanners have been equipped with this feature [11], [12]. In the TCM technique, the tube current fluctuates according to the attenuation of the body part being scanned [12], [13]. If the part has low total attenuation, then the tube current decreases proportionally and the output dose decreases. Conversely, if the part has high total attenuation, then the tube current increases, and the output dose increases [12]–[16]. The fluctuation of tube current is indirectly determined by the user by setting up the expected noise index [17], [18].

Changes in the tube current in TCM obviously have a direct effect on the fluctuation of the output dose of CT [19], [20] which is described by the CT dose index volume ($CTDI_{vol}$) metric [10]. However, the record of its fluctuation may not be standardized for every CT manufacturer. To the best of our knowledge, there has been no study of this issue for common CT manufacturers. Non-standardized dose reports along the longitudinal axis may result in inaccuracies in estimating the $CTDI_{vol}$ in a specific location and therefore in organ dose estimation at that location.

Recently, many researchers [21]–[23] have reported that the estimation of size specific-organ dose is more accurate if the $CTDI_{vol}$ for targeted organ location is considered, not from the average $CTDI_{vol}$ along all the longitudinal axis. Therefore, finding fluctuation $CTDI_{vol}$ along the longitudinal axis is important.

This study has three goals. The first is to develop a system which can easily be used to extract profiles of tube current and $CTDI_{vol}$ along the longitudinal axis. The second is to investigate profiles of tube current and $CTDI_{vol}$ along the longitudinal axis in eight clinical CT scanners. The third is to develop a system to adjust the $CTDI_{vol}$ so that it fluctuates along the fluctuation of tube currents.

2. RESEARCH METHOD

2.1. System to acquire profiles of tube current and $CTDI_{vol}$

A system to acquire profiles of tube current and $CTDI_{vol}$ from CT images was developed. The system was integrated into IndoseCT software [24]. Tube current and $CTDI_{vol}$ were extracted from DICOM header. Figure 1 shows the graphical user interface (GUI) of our developed system.

The profile of tube currents indicates whether the image studied has employed TCM or not. If the $CTDI_{vol}$ profile fluctuates along with the tube current profile, the option for adjusting the $CTDI_{vol}$ profile is not needed. However, if the changes in the tube current profile is not followed by the $CTDI_{vol}$ profile, the $CTDI_{vol}$ profile must be adjusted ($CTDI_z$) with following (1):

$$\mathrm{CTDI}_{\mathrm{Z}} = \mathrm{CTDI}_{\mathrm{VOL}}(z)\frac{I(z)}{\hat{I}(z)} \tag{1}$$

where $I(z)$ is tube current at any location along the longitudinal axis (z-axis) and $\hat{I}(z)$ is average tube current along the the longitudinal axis. The adjustment was done by checking the option of "Adjust $CTDI_{vol}$ with mA". Subsequently, the average $CTDI_{vol}$ appears on the screen.

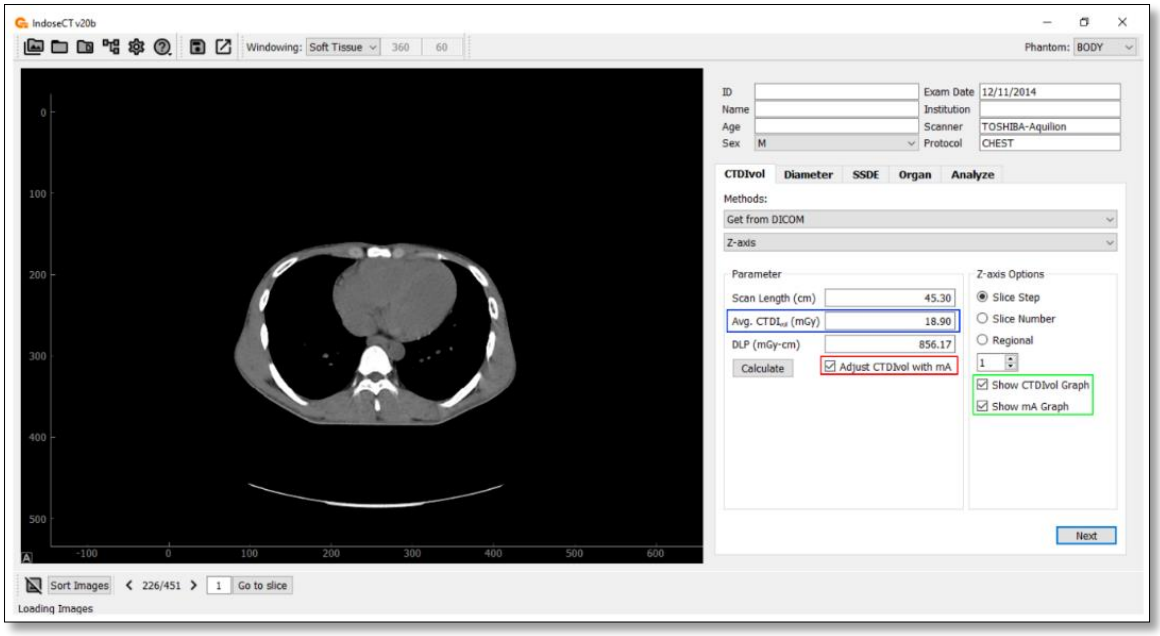

Figure 1. Screenshot of IndoseCT to extract the values of tube current and $CTDI_{vol}$ which also provides an "Adjustment $CTDI_{vol}$ with mA" option

The system provides two options to display the tube current and $CTDI_{vol}$, either for a single slice or for every slice along the longitudinal axis (in 3D options). Our system also provides a greater slice step for all the slice calculations, such as 2, or 3, and so on. Using a greater slice step will lead to faster calculation.

2.2. Investigation of eight CT scanners

Profiles of tube current and $CTDI_{vol}$ along the longitudinal axis for eight CT scanners as presented in Table 1 were investigated. The input parameters for every scanner are shown in Table 2. We retrospectively used phantom images and images from four different patients.

Table 1. Eight scanners investigated in this study

No	Manufacturer	Scanner	Object
1	Toshiba	Alexion 4	Anthropomorphic phantom
2	Philips	Brilliance 16	Image quality phantom by Philips
3	Siemens	Sensation 64	A male patient (retrospective)
4	Siemens	Somatom perspective	Polyester phantom with 24 cm diameter
5	Siemens	Somatom definition AS	A male patient (retrospective)
6	Philips	Inguity	America Association of Physicists in Medicine (AAPM) phantom
7	Toshiba	Activion 16	A patient (retrospective)
8	Toshiba	Aquilion	A patient (retrospective)

Table 2. Input parameters for the eight scanners

Scanner #	Number of slices	Tube voltage (kV)	Time rotation (s)	Slice thickness (mm)	Beam collimation (mm)	Pitch	FOV (mm)	Ref
1	88	120	1	7	4	1.5	400	-
2	214	120	0.75	2	16 × 1.5	0.563	319	-
3	48	120	0.5	10	28.8	1.4	374	XYZ_EC
4	526	110	0.6	1	38.4	0.6	350	XYZ_EC
5	470	120	1	1	19.2	1.2	341	XYZ_EC
6	158	120	1	5	64 × 0.625	1.0	260	3D Modulation
7	73	120	0.75	5	16 × 1	0.938	390	3D
8	406	120	0.5	2		1.438	490	3D

3. RESULTS AND DISCUSSION

3.1. Profiles of tube current and $CTDI_{vol}$ in eight CT scanners

Profiles of tube current and $CTDI_{vol}$ along the longitudinal axis for eight scanners of Toshiba-Alexion 4, Philips-Brilliance 16, Simens-Sensation 64, Siemens-Somatom Perspective, Siemens-Somatom Definition AS, Philips-Inguity, Toshiba-Activion 16, and Toshiba-Aquilion are shown in Figures 2(a)-(h). Scanners of Toshiba-Alexion 4 and Philips-Briliance 16 produced constant profiles of tube current and $CTDI_{vol}$, indicating that TCM was not activated. The TCM feature was utilized on the remaining scanners, i.e., Siemens-Sensation 64 to Toshiba-Aquilion. However, the profiles of tube current and $CTDI_{vol}$ were different. For scanners Siemens-Sensation 64 to Philips-Inguity, the use of the TCM feature produced fluctuating tube current profiles which were followed by the fluctuations in the $CTDI_{vol}$ profiles. However, the fluctuations of the tube current profiles on scanners of Toshiba-Activion 16 and Toshiba-Aquilion were not followed by the CTDIvol profiles, which remained constant at the mean dose from all slices.

The $CTDI_{vol}$ profiles on scanners of Toshiba-Activion 16 and Toshiba-Aquilion were adjusted with the developed system. The $CTDI_{vol}$ profiles before and after adjustment are shown in Figures 3(a) and (b). The adjustment of the $CTDI_{vol}$ profiles, which were initially constant, then fluctuates with the tube current profiles.

It is noted that the fluctuation of the tube current profile when using the TCM technique should be directly followed by the fluctuation of $CTDI_{vol}$ profile. However, this is not necessarily recorded by some CT vendors. Each vendor has a different way for displaying the output dose ($CTDI_{vol}$) profile in TCM. Scanners from Siemens and Philips displayed profiles of $CTDI_{vol}$ which fluctuated with the tube currents, while Toshiba displayed a constant $CTDI_{vol}$ in TCM mode. This is risky if medical staff are not aware this phenomenon and immediately assume that the $CTDI_{vol}$ profile displayed in every slice always follows the profile of the tube current. Our software adjusts the $CTDI_{vol}$ profile along the tube current profile automatically in real time, as seen with scanners of of Toshiba-Activion 16 and Toshiba-Aquilion.

Classification of CT scanner based on this issue is illustrated in Figure 4. Based on its tube current mode, the scanners can be separated into FTC (fixed tube current) and TCM (tube current modulation). In the TCM implementation, $CTDI_{vol}$ is not always adjusted with tube current. This classification should be kept in mind when dealing with dose along the longitudinal axis.

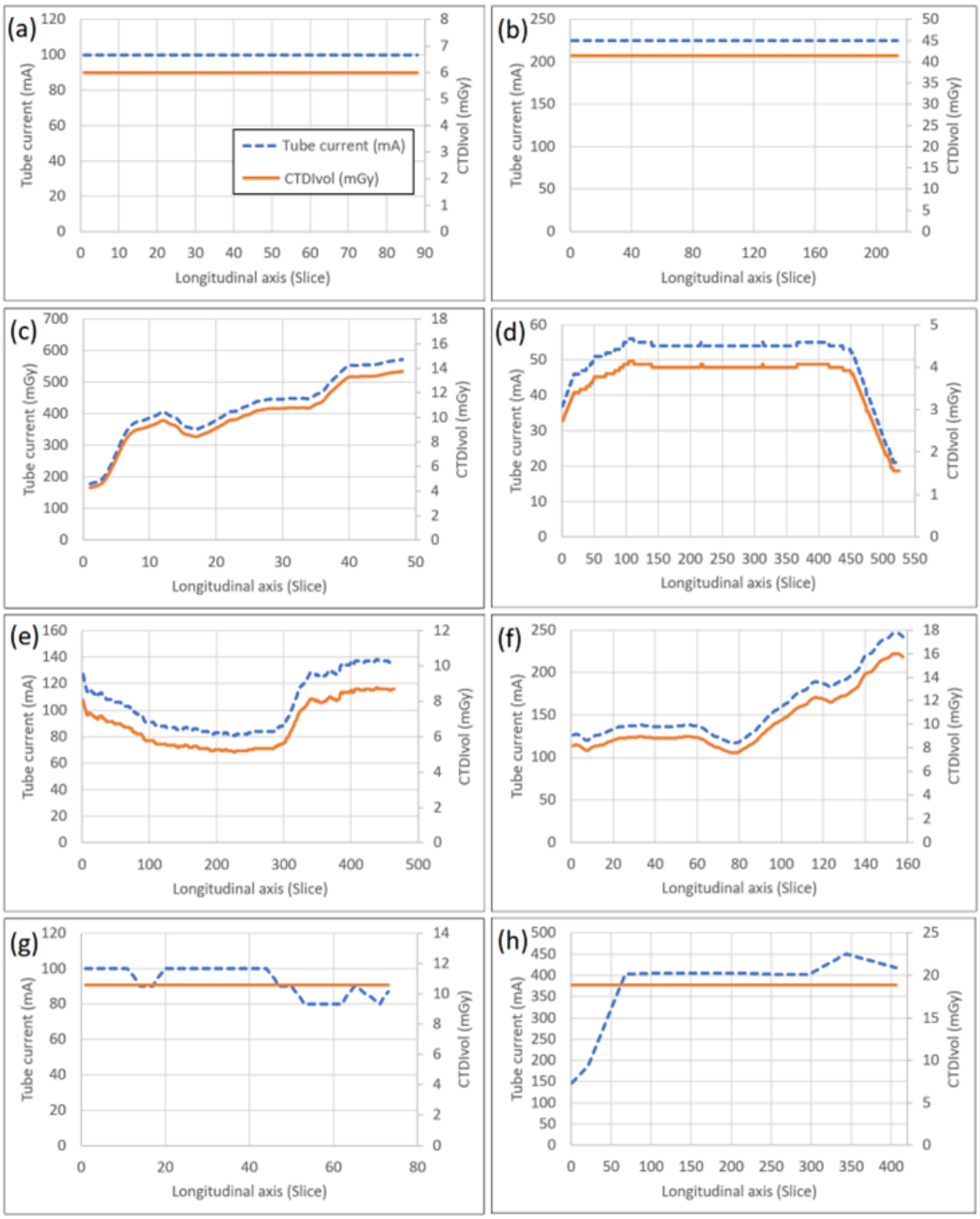

Figure 2. Profiles of tube current and $CTDI_{vol}$ along longitudinal axis in 8 scanners: (a) Toshiba-Alexion 4, (b) Philips-Brilliance 16, (c) Simens-Sensation 64, (d) Siemens-Somatom Perspective, (e) Siemens-Somatom Definition AS, (f) Philips-Inguity, (g) Toshiba-Activion 16, and (h) Toshiba-Aquilion

This is especially important if we wish to estimate organ doses located in a certain area along the longitudinal axis. The increase in $CTDI_{vol}$ in certain organs causes an increase in the organ dose. Increasing the $CTDI_{vol}$ causes an increase in the size-specific dose estimate (SSDE) for the same diameter, and subsequently an increase in SSDE causes an increase in the organ dose [25].

It is not sufficient to estimate organ dose by simply taking into account global fluctuations of $CTDI_{vol}$ in the longitudinal axis direction. It is important to find the local $CTDI_{vol}$, instead of the global one. With local $CTDI_{vol}$, local SSDE values can be obtained. With the local SSDE value, the organ estimation becomes more accurate [22]. However, this approach alone is not sufficient to accurately estimate organ

doses. The position of the organ, whether in the center or on the edge radially away from the longitudinal axis, also needs to be determined to obtain a more accurate result [26]. It should be noted that dose estimation in each organ is greatly affected by modulation of the tube current, body size, organ position in the body, scan position, scan length, and protocol used [27]–[30].

This study has some limitations. The observed TCM was only in the longitudinal axis direction. Angular and organ-based (OB) TCMs were not investigated. With angular TCM, better dose optimization is obtained with more homogeneous noise throughout the scanned body area [31].

Another limitation of this study was that a limited number of scanners and manufacturers were used. We also did not analyze the differences of each vendor in applying TCM to the existing examinations. Although the main principles of TCM used are the same, its application varies from manufacturer to manufacturer [8].

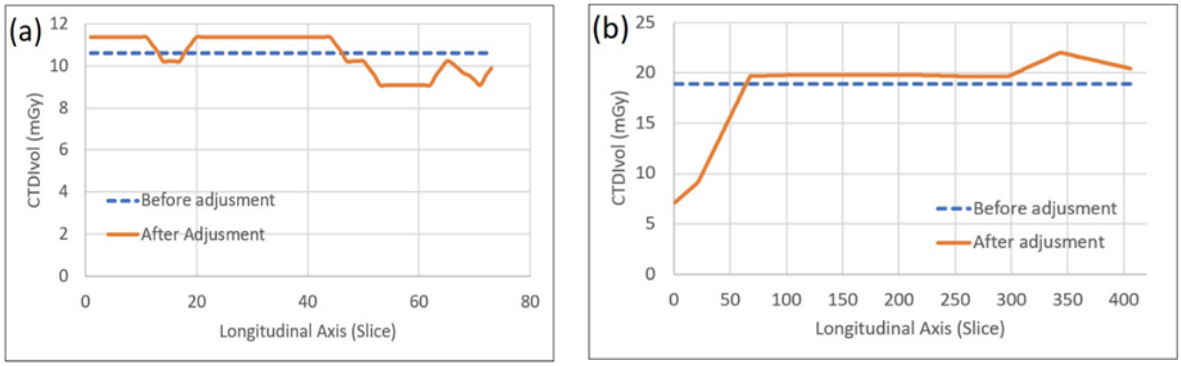

Figure 3. Profiles of $CTDI_{vol}$ along the longitudinal axis before and after adjustment with tube current (mA) on (a) Toshiba-Activion 16 and (b) Toshiba-Aquilion

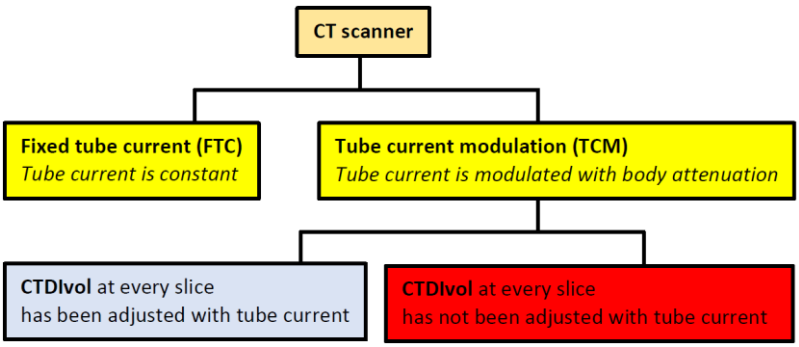

Figure 4. Classification of CT scanners according to tube current modulation (TCM) application. CT scanners consist of fixed tube current (FTC) or tube current modulation. In TCM, $CTDI_{vol}$ is not always adjusted with tube current

4. CONCLUSION

The software to investigate and adjust profile patterns of $CTDI_{vol}$ along the longitudinal axis has been developed. The software is easy to use and works quickly. This study reveals an important finding that medical staff must be careful when using the $CTDI_{vol}$ value along longitudinal axis contained in each DICOM image, because this value has not necessarily been adjusted with the tube current value.

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