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Computed Dosimeter Dose Index on a 16-Slice Computed Tomography Scanner

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Abstract

A computed tomography dose index can be used to quantify the radiation dose received during a CT scan and it is an indicator of the radiation dose to the polymetaylenmetaAcrylate (PMMA) standardized phantom. The objective of this study was 2-fold. The first was to measure the computed tomography (CT) radiation dose for the head and body polymetaylelenmetaAcrylate (PMMA) phantoms and to determine the accuracy of the CT radiation dose parameter displayed on the CT scanner console; these were measured in this investigation and compared with the dose displayed on the CT scanner console. The dose was calculated using the formalism described in the American Association of Physics in Medicine (AAPM) Report 96. The second was to compare the dosimetric results of the head and body polymetaylelenmetaAcrylate (PMMA) phantoms with dose reference levels published in international journals, as well as to measure the central cumulative dose ($DL^{'}(0)$), as recommended by the American Association of Physics in Medicine (AAPM) report 111. This is a new, cutting-edge methodology for estimating the CT radiation dosage provided by the abdomen, thorax, and head of a PMMA phantom. We used a Philips Big Bore CT scanner with 16 slices. A CT dosimeter head phantom with a diameter of 16 cm, a CT dosimeter body phantom with a diameter of 32 cm, a 100 mm pencil chamber (PC), and a 20 mm short chamber (SC) were employed. These were coupled to an electrometer and a dosimetric readout device. The measured volume computed tomography dose index (CTDIvol) values were in good agreement with the CT radiation dose displayed on the corresponding CT scanner console. The percentage disagreement was less than 10%, with a maximal difference of 1.7% and 5.5% for the body and head phantom, respectively. The central cumulative dose (DL (0)) measurements (for $L^{'}$ = 100 mm) also matched nominal or the corresponding computed tomography dose index (CT) scanner console volume computed tomography dose index (CTDIvol) values. In this case, the agreement is always below 3% for abdomen scans and 1.0% for head examinations. This result implies that the radiation dose supplied by the 16-slice computed tomography (CT) system was in good agreement with the international dose reference level and we observed something different.

Keywords

radiation dose, computed tomography dose index, dosimetric reference levels, computed tomography scan

Introduction

Computed tomography (CT) is a highly effective tool used by radiologists to detect illness in the human body. It was introduced in the early 1970s and was the first computer-based medical imaging modality.[1] The computed tomography dose index (CTDI) is used to calculate the radiation dosage during a CT scan.[2] The CTDI is measured in the radiation dose of the X-ray source using a pencil chamber (PC) with a length of L = 100 mm. It is defined as follows:

$$\mathrm{CTDI} = \frac{T}{L}\int_{\mathrm{L}}^{\mathrm{Z}} D(z)dz. \qquad (1)$$

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Where,T is the total x-ray slice collimation.

The dose profile in the crania-caudal direction is denoted by −D (z).[1]

The general irradiation of a patient undergoing sequential computed tomography dose index (CT) examination to illustrate the CTDI approach in the patient dosimeter is shown in Figure 1,[3] where each circle represents a unitary dose expressed in arbitrary units. The dose absorbed in the patient slice of interest (highlighted in the figure) is given by the five central CT irradiations in the figure. The figure also shows that the first and final irradiations (placed at a distance from the slice of interest) do not contribute to the dose in this anatomical region. Consequently, the dose in the patient slice of interest is given by adding the contributions in the slice of interest (highlighted in the figure). It is equal to 10 in arbitrary units (Figure 1).

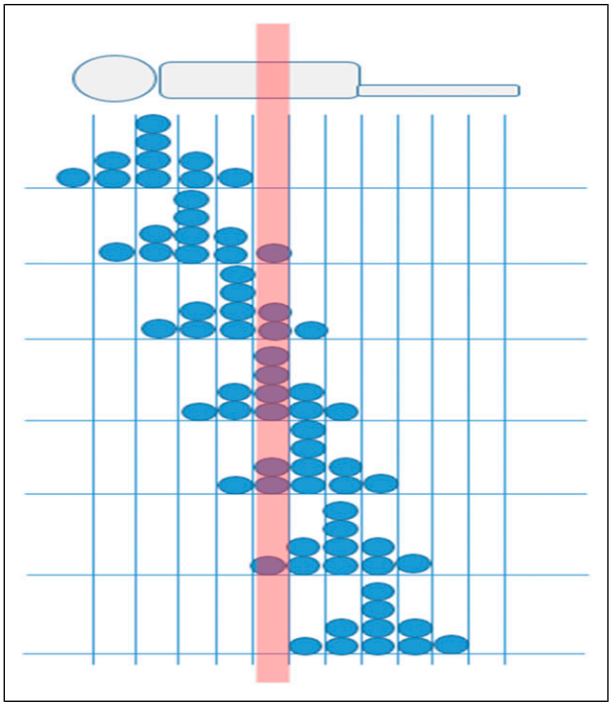

Figure 1. The typical dose profile in a sequential computed tomography (CT) examination is moving along the z-axis. The dose in the slice of interest is calculated by adding the contributions in the slice.[4]

The relationship between the CTDI and the dose in the patient slice is defined in equation (1). For simplicity, the patient slice was assumed to be 10 mm (x-ray) slice thickness (T = 10 mm). As shown in Figure 2, the pencil chamber (PC) averages Rx (X-ray) contributions to the dose over its length, L. As a result, in Figure 2, a final reading M = 1 in arbitrary units was obtained.

This reading M is also expressed by the relation $M = \frac{1}{L}\int_L^Z D(Z)dz$ allows rewriting equation (1) as follows:[1]

$$\mathrm{CTDI} = \frac{L}{T}M \tag{2}$$

Equation (2) yields a CTDI of 10 (au) for L = 100 mm and T = 10 mm. This is the same value of the dose absorbed in the patient slice obtained above by adding the dose contributions as shown in Figure 1. This numerical equivalence is crucial because it indicates that the CTDI value of a clinical CT scan is a dosimetric indicator estimating the dose in a patient slice. The weighted CTDI is the average dose over the central slice of a series of contiguous slices obtained during a head or body CT examination.[5,6] The CTDI measured using dosimetric phantoms is also referred to as the weighted computed tomography dose index (CTDIw). It is given by the following equation:

$$\mathrm{CTDI}_w = \frac{1}{3}\mathrm{CTDI}_C + \frac{2}{3}\mathrm{CTDI}_p, \tag{3}$$

where CTDIc = CTDI at the central position of the PMMA phantom[1] and CTDIp = the CTDI averaged over the four peripheral positions of the PMMA phantom.

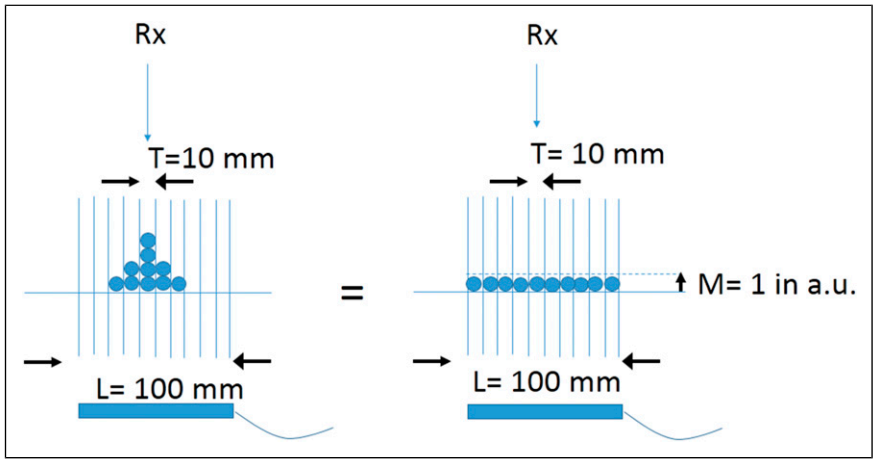

Figure 2. The pencil chamber (PC) reading averages the Rx (X-ray) contributions over its length, L.

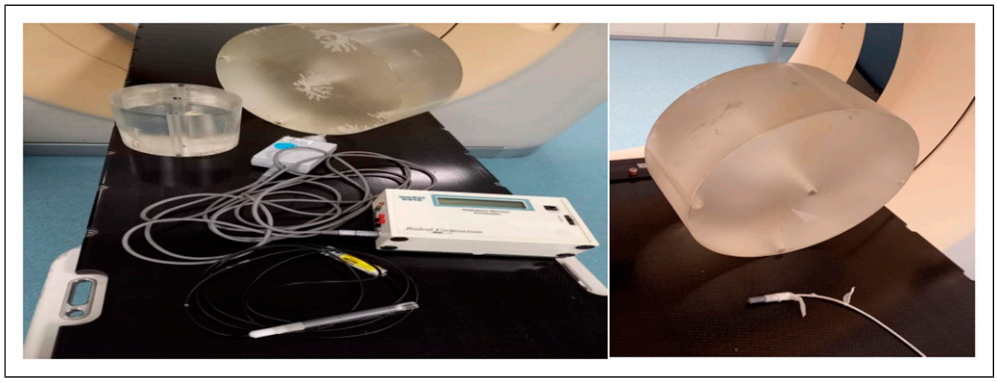

Figure 3. Set-up for CTDI determination.

For helical CT examinations, the parameter estimating the dose in a patient slice is the CTDIvol.[7] It is defined as follows:

$$\mathrm{CTDI_{vol}} = \frac{\mathrm{CTDIw}}{p_f}, \tag{4}$$

where p_f is the pitch factor.[1,2]

The central cumulative dose $DL^{'}(0)$ was introduced by the new modern American Association of Physics in Medicine (AAPM) to address the shortcomings of the conventional CTDI-based dosimetric approach.[8] This dosimetric indicator is defined as the dose in a patient slice caused by a CT examination with a scan length of $L^{'}$. The method is highly practical because it allows for direct measurements of all clinical helical scans using short camber (SC) in the typical dosimetric head and body PMMA phantoms. $DL^{'}(0)$ is the equilibrium dose (Deq) that is comparable to the CTDIvol for a scan length of $L^{'} = 100$ mm.[4,9] utilizing dose measurements obtained from the phantom's central hole (Deq, c) and those obtained from the phantom's peripheral hole (Deq, p)[1,10]

$$\frac{1}{3}DL'(0)c + \frac{2}{3}DL'(0)p \equiv \mathrm{CTDI_W} = D(eq) \tag{5}$$

where

$DL^{'}(0)$ c=is refers to the $DL^{'}(0)$ measured in the central position of the dosimetric phantom and $DL^{'}(0)p$ = is the mean value of $DL^{'}(0)$ measured in the peripheral locations of the same phantom.

Equation (5) explains one of the advantages of the American Association of Physics in Medicine (AAPM) dosimetric approach. It enables the assessment of (CTDIvol) by performing central cumulative dose ($DL^{'}(0)$) measurements for $L^{'} = 100$ mm on clinical scans.[10] The purpose of the present study was to estimate the CT dose index for head and body PMMA phantoms and to determine the accuracy of the CT radiation dose parameter displayed on the CT scanner console.[9] The CT dose index was estimated using the American Association of Physics in Medicine (AAPM) Report 96 formalism. The study was performed on a Philips 16-slice CT scanner with a 100 mm pencil ionization chamber. The measured body and head phantom doses were compared to selected international dose reference levels and varying deviations were observed. The role of the medical physicist in this study is to track and measure the dose to patients using appropriate indicators.[11,12]

Materials and Methods

The measurements were performed on a Philips Big Bore 16-slice CT system installed at the Radiotherapy Department of the S. Chiara Hospital, Trento, Italy. The study involved the use of a standard CTDI head phantom, a standard CTDI body phantom, and a Radical 3CT pencil chamber (PC) with a length of 100 mm and a short 10 × 5 ionization chamber (SC) with a charge collection length of 20 mm. Both the chambers were coupled with a Radical 9010 electrometer (Figure 3).

The characterization of the computed tomography (CT) scanner involved preliminary measurements of the CTDI in free air, and the PC (pencil chamber) was placed at the CT center. The selected scan parameters of the series of single-rotation CT protocols were 90-120-140 kV, 100-200-400 mAs, and a slice thickness ranging from 3 mm to 24 mm.

The second series of measurements assessed the CTDIvol with head and body phantoms. These provided a direct comparison between measured CTDIvol values and the nominal value displayed on the CT scanner console and compared international dose reference levels.[4,13-15] The scan parameters for both types of phantom head and body were 120 kV, 100 mA, and a slice thickness of 24 mm.

The final dosimetric evaluations involved the measurement of the central cumulative dose $DL^{'}(0)$ of the helical head, abdomen, and thorax scans with a scan length $L^{'}$ of 100 mm and different scan parameters. In these conditions, we obtained DL (0) = CTDIvol. Therefore, we estimated equation (5). $DL^{'}(0)$ was then compared with the corresponding nominal volume CTDIvol and to the CTDIvol international reference levels. The CT dosimetric values were estimated in

Table 1. Normalized Measured CTDI in free air for Different Voltages (kV), Tube Charges (mAs), and X-Ray Slice Collimations (mm).

Voltage (kV)	Charge (mAs)	Rx (X-ray) slice thickness (mm)	PC Readings (mGy)	Normal. CTDI in free air (mGy)
90	100	24	1.53	6.4
120	100	24	3.27	13.6
140	200	24	4.76	19.8
120	100	24	3.27	13.6
120	200	24	6.54	13.6
120	400	24	13	13.5
120	100	24	3.27	13.6
120	100	12	1.86	15.5
120	100	6	1.02	17.0
120	100	3	.73	24.4

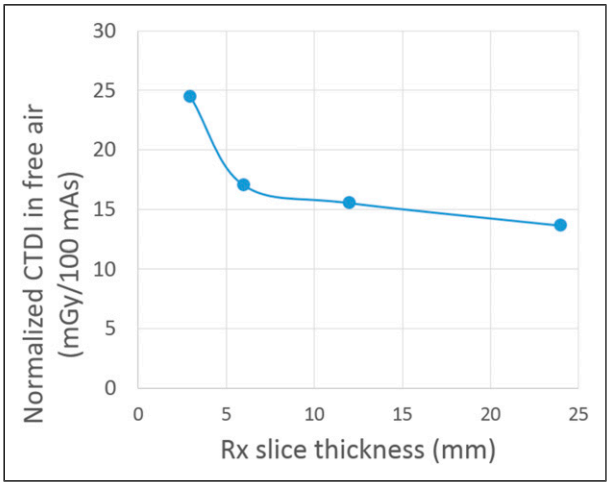

Figure 4. Normalized computed tomography dose index (CTDI) in free air (mGy) for different Rx (x-ray) slice thicknesses.

the American Association of Physics in Medicine (AAPM) report 96.[3]

Results

The result of the (CTDI for free air measurements, in particular, the experimental data, verify that the CTDI calculated in accordance with equation (2) depends on the selected voltage, with higher values corresponding to a higher voltage in as shown in Table 1. The CTDI measurements in the present study, in accordance with data in the literature, showed a linear relationship between CTDI and mAs.[16] The experimental data also verified the relationship between X-ray slice thickness and CTDI in free air. In particular, narrow slices, for example, 3 mm, see Figure 1, emphasize the rule of over beaming.[1]

This result increased CTDI values and the Rx (X-ray) slice thickness will be decrease as shown in Figure 4.

The radiation dose delivered by the head and body PMMA phantom was in good agreement with the dose displayed on the corresponding computed tomography (CT) scanner console as shown in Table 2. According to various published data, the experimental CTDIvol values demonstrate significantly high agreement between the nominal (console) CTDI value and measured CTDI values.[2,14] On the other hand, as described in the earlier sections and in the literature.[1] As explained in the previous section, the CTDI-based approach shows certain limitations in dose assessment for helical scans. The present study provided certain central cumulative dose (DL′ (0)) measurements on helical CT scans to overcome this drawback.[17] These reveal, confirming a good agreement of the data with the corresponding CT scanner console volume CTDIvol and, subsequently, the robustness of the advanced AAPM approach. In addition, CTDIvol of 11.6 and 10.6 mGy obtained for abdomen and thorax scans match the prescriptions of international standards as seen in Table 3, which specify dose reference levels of 15 mGy for body examinations. A similar result was obtained for the head scan the measured and displayed on the corresponding CT scanner console CTDIvol values (<56 mGy) which were below the reference level of 60 mGy.[4]

The comparison of the dose delivered to head and body phantoms with international publication is shown in Table 4. The present study also shows that the dose delivered to patients by the 16-slice CT scanner is below the international dose reference levels for head and body phanton.[2,4,5,10,13-15,18]

Discussion

The American Association of Physics in Medicine (AAPM) Report 96 formalism and the comprehensive methodology for the evaluation of radiation dose in the CT report of the American Association of Physics in Medicine (AAPM) task group 111 were used to evaluate CT radiation dose exposures.[3,8] The CTDI value was calculated in free air at tube potential (90.120, 140) kV, tube current (100, 200, and 400) mAs and X-ray slice thickness (3, 6, 12, and 24) mm were estimated in this study. The X-ray slice thickness increases the radiation dose for free air decrees and vice versa. The present study was to estimate the CTDI for head and body phantoms

Table 2. Percentage Disagreement Between CTDIvol Measurements And The Reported Result Of The Corresponding Dose Displayed on the console (Nominal CTDIvol on the CT Console).

	PC readings at different phantom locations (mGy)					CTDIvol (mGy)		
Body region	Center	3	6	9	12	Calculated	Displayed	CTDI disagreement (%)
Head	2.29	2.48	2.31	2.46	2.60	10.0	10.2	1.7
Body	.77	1.81	1.48	1.82	1.65	5.8	6.1	5.5

Table 3. Comparison of the Measured Central Cumulative Dose ($DL'(0)$) to the Dose Displayed on the Console.

			SC readings in different phantom locations (mGy)							
Exam	Charge (mAs/sl)	Pitch (unit less)	Center	3	6	9	12	Measured $DL'(0)$ (mGy)	Displayed CTDIvol (mGy)	$DL'(0)$-CTDIvol Disag. (%)
Abdomen	220	1.188	6.92	13.85	13.92	14.49	15.3	11.9	11.6	−2.5
Thorax	200	1.063	6.10	13.69	11.79	13.72	13.48	10.8	10.6	−2.0
Head	550	.313	52.28	57.2	53.16	57.44	61.28	55.6	55.9	0.5

Table 4. Comparison of the Dosimetric Results of the Head and Body Phantom with International Dose Reference Levels.

	CTDIvol (mGy)					
Examination	This study	Europe (2004)	UK (2003)	ACR (2008)	Norway (2018)	Sweden (2019)
Body	5.8	15	14	25	13	12
Head	10.0	60	65	75	60	60

and to determine the accuracy of the CT radiation dose parameter displayed on the CT scanner console using a 16-slice CT scanner, short ionization chamber, and pencil ionization chamber. The result of the CTDI in the present study was a good agreement for the corresponding CT scanner console value and also the selected international does reference level and varying deviations were observed. The measured CT radiation dose for head and body phantoms was less than the international dose reference level. We advised radiologists to utilize there must be carefully selection of technical parameter of CT scanner that control exposure of patient radiation dose and regular checking of scanner performance with measurement of the CT dose index parameter. The purpose of the present study was computed tomography. The CT dose measurement is a very important measurement in the acceptance of any CT scanner after installation. The CT radiation dose parameter is accepted.

Conclusions

Computed tomography (CT) is a highly effective tool used by radiologists to detect illness inside the human body and deliver a high dose to patients compared with other imaging modalities. The CT radiation dose reported by the computed tomography console during a CT scan examination is based on the CTDI stated in reports by the American Association of Physics in Medicine (AAPM). The CTDI is a standardized measure of the dose output of the CT system. The present study showed a deviation of 1.7 % and 5.5 % using the American Association of Physics in Medicine's (AAPM) report 96 dose estimation formalism. The measured computed tomography (CT) radiation dose or dosimetric values of certain clinical CT scans are less than the international diagnostic reference levels (DRLs). In particular, this work is in agreement with other studies when it shows that a series of clinical CT scans match the prescriptions of international standards concerning patient exposure.[5] In general, the present study describes the most important examinations and activities of specialists in medical physics working on computed tomography (CT) radiation dose measurements.

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Declaration Conflict of Interest

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Ethical Approval

This article does not report any studies performed on animals.

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