International Journal of Scientific Research in Science and Technology
Print ISSN: 2395-6011 | Online ISSN: 2395-602X (www.ijsrst.com)
doi : https://doi.org/10.32628/IJSRST

Comparison of Water-Equivalent Diameter Measured from CT Localizer Radiograph Based on Two phantoms of the Step-Wedge and Computed Tomography Dose Index

Sitti M. Rif'ah[1], Choirul Anam[1*], Heri Sutanto[1], Heryani Cholid[2]

[1]Department of Physics, Faculty of Science and Mathematics, Diponegoro University, Jl. Prof. Soedarto SH, Tembalang, Semarang 50275, Central Java, Indonesia.

[2] Installation of Radiology, Rumah Sakit Umum Daerah (RSUD) Kraton Pekalongan, Jl.Veteran No. 31, Padukuhan Kraton, Pekalongan City, 51116, Central Java , Indonesia

*Corresponding author: anam@fisika.fsm.undip.ac.id

Article Info

Volume 9, Issue 6

Page Number : 445-452

Publication Issue

November-December-2022

Article History

Accepted : 01 Dec 2022

Published : 12 Dec 2022

ABSTRACT

The purpose of this study is to compare the water-equivalent diameter (D_w) and size-specific dose estimate (SSDE) obtained from CT localizer radiograph based on the step-wedge and computed tomography dose index (CTDI) phantoms. The two phantoms were scanned using a 64-slice SIEMENS Somatom CT Scanner with tube currents of 100 mA and 120 kV. The CT localizer radiographs of two phantoms were obtained. Subsequently, relationships between pixel values (PV) and water-equivalent thickness (t_w) were developed. Based on those relationships, the D_w and SSDE of twenty patients were calculated from the CT localizer radiographs. The results of the D_w and SSDE measured using CT localizer radiographs based on the two phantoms were compared. The relationships between PV and t_w obtained from both CT localizer radiographs of the phantoms of step-wedge and CTDI are established. The D_w and SSDE values from the CT localizer radiograph calibrated with the CTDI phantom and step-wedge phantom also have linear relationship with $R^2 > 0.99$. The statistical test value with p-value > 0.05 indicating that the two measurements of D_w and SSDE based on two phantoms are not statistically different. The results from the step-wedge phantom are comparable with those from the CTDI phantom. The relationship PV and t_w with CT localizer radiograph from the step-wedge phantom can produce accurate calibration results. The results of the calibration of the step-wedge phantom can then determine the value of D_w and SSDE.

Keywords: CT, CTDI, step-wedge, water-equivalent diameter, SSDE

I. INTRODUCTION

Dosimetry of computed tomography (CT) has evolved over the years [1,2]. Previously, computed tomography dose index volume ($CTDI_{vol}$) [3] and dose-length product (DLP) were the standard quantities for CT radiation dose [4-6]. However, these two quantities have limitations, because they only provide information about output dose from CT and do not account for patient radiation dose [7-9]. Size-specific dose estimate (SSDE) was subsequently introduced to estimate patient dose based on specific patient physical characteristics [10,11]. At beginning, SSDE was calculated based on effective diameter (D_{eff}) [12]. However, the calculation of patient dose with D_{eff} is less accurate because it only considers the patient's physical size [13,14]. Subsequently, a more accurate approach based on water-equivalent diameter (D_w) was proposed [15].

Theoretically, the D_w can be calculated using CT localizer radiograph and CT axial images [16,17]. However, the attenuation value at CT localizer radiograph has not been standardized and normalized for water attenuation. This causes the determination of D_w from pixel values (PV) of CT localizer radiographs is complicated. In contrast to axial CT images, the obtained PV have been normalized with water attenuation so that the pixel values are following the standard of Hounsfield unit (HU) [16]. Although fairly easy to do, in some cases, the axial images are truncated, making the D_w and SSDE calculations are less accurate. Meanwhile, if using a CT localizer radiograph the truncation can be avoided [18].

Anam et al. (2018) [19] have proposed a method for calibration of PV and water-equivalent thickness (t_w) of CT localizer radiographs. The measurements used a CTDI phantom made of polymethyl methacrylate (PMMA) with a diameter of 32 cm and a length of 15 cm. Zhang et al (2018) [20] also reported that the calculation of the D_w value proves that the PV and t_w have a strong correlation. They used ACR CT accreditation phantom, CTDI phantom, and several variations of water containers. However, the availability of these phantoms is still limited.

One of the alternative phantoms that can be used for the same purpose is the step-wedge phantom mad from acrylic. Acrylic material is widely used materials because it has more advantages than other materials in terms of its density value which resembles water [21]. This makes acrylic a better option as the base material for step-wedge phantom to facilitate calibration of PV with t_w for CT localizer radiograph measurements. The phantom can be developed in hospital. However, an accuracy of implementation of the step-wedge phantom for D_w and SSDE measurements has not been investigated. In this study, we aimed at compare the step-wedge with the CTDI phantom in terms of determining calibration accuracy for the D_w and SSDE measurements.

II. METHODS AND MATERIAL

A. Step-wedge and CTDI phantom scan

This study used a 64-slice SIEMENS Somatom CT Scanner (Siemens Medical Systems, Erlangen, Germany) which was installed in the Radiology Installation of the Rumah Sakit Umum Daerah (RSUD) Pekalongan Regency. The two phantoms were scanned on the patient's table to provide the phantom image, as seen in Figure 1. The CTDI and step-wedge were scanned with several scanning parameters as shown in Table 1.

Table 1. Scan parameters.

Parameters	**Input**
Image type	*CT localizer radiograph*
Projection	AP
Tube voltage (kV)	120
Tube current (mA)	100

All images generated from the scanning process were saved in the Digital Imaging and Communications in Medicine (DICOM) format. The CTDI and step-wedge phantom images were used to obtain the relationship between the pixel value and the water equivalent-thickness of the CT localizer radiograph for determining D_w and SSDE.

B. Patients

The CT localizer radiographs of the patients were obtained from the hospital based on the standard protocol in the form of a CT localizer radiograph. The patient's image consisted of 20 patients for abdominal examination. The input parameters of patients are listed in Table 2.

Table 2. Input parameters of patients.

Parameters	Value
Number of patient	20
Image type	CT localizer radiograph
Tube voltage (kV)	120
Tube current (mA)	35
Exposure time (s)	5.17

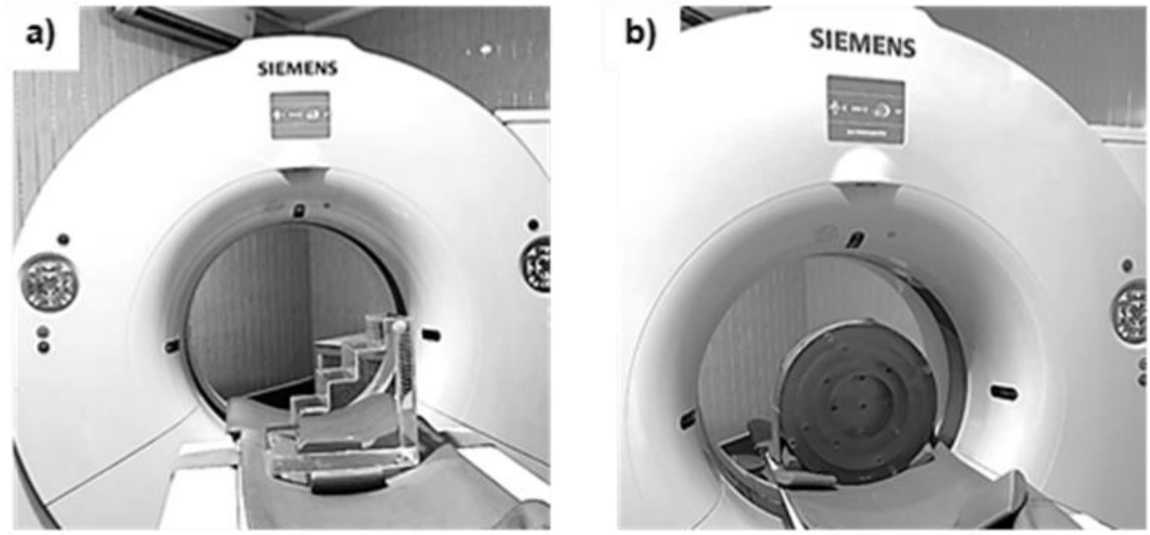

Figure 1. Two phantoms were scanned with a 64-slice SIEMENS Somatom CT Scanner. (a) Step-wedge phantom, and (b) CTDI phantom.

C. Calculation of D_w based on CTDI phantom

The relationship between PV and t_w in D_w and SSDE calculations using CT localizer radiographs was the first step must be done. In this study, the pixel value on the CTDI phantom (diameter of 32 cm) was determined using the Matlab R2015a software (Figure 2). The center position of this phantom was considered as the zero position and the distance along the axis was converted from the number of pixels to mm (or cm). The pixel value profile is set from -160 to +160 mm, as shown in Figure 3.

Figure 2. CT localizer of CTDI phantom.

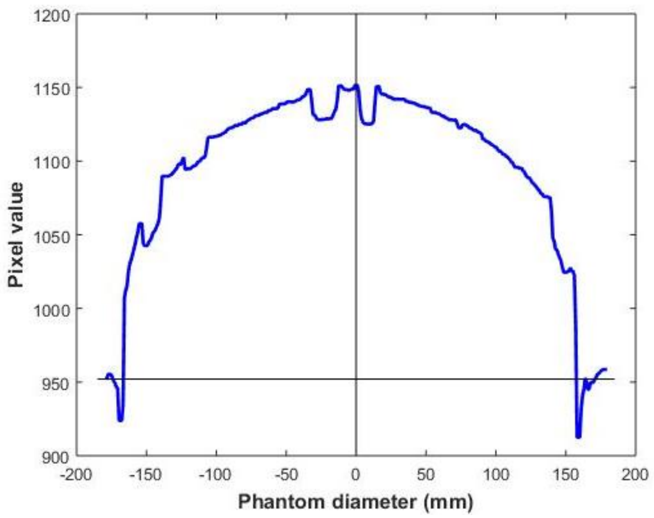

Figure 3. CTDI phantom pixel value profile.

In Figure 3, each x-position was a position on the CTDI phantom which does not represent the phantom thickness (t_p). The tp value can be obtained from every 30 mm interval in the pixel value profile, and it can be calculated using the circle equation. Each x-position had a value of 2y where the minimum was 0 mm and the maximum was 2r (320 mm or phantom diameter). For each t_p obtained, it had to be converted into t_w by using equation (1).

$$t_w = t_p \times k \qquad (1)$$

k is the conversion factor from PMMA thickness to t_w, with a value of 1.058 [15]. After obtaining the relationship between the PV and t_w, both were calculated using equation (2).

$$t_w = a \times PV \pm b \qquad (2)$$

where a is the slope and b is the intercept. This relationship was described in the form of a curve and its value was to calculate the D_w from the CT localizer radiograph of the patient. The equation was then applied to calculate D_w from patient CT localizer radiograph using equation (3).

$$D_w = 2 \times \sqrt{\frac{\sum_{i=1}^{n} t_w \times d}{\pi}} \qquad (3)$$

where d is pixel dimension in mm (taken from DICOM header) and n is number of pixels within patient border in the localizer radiograph along x-axis. Border of patient image was manually segmented.

D. Calculation of D_w based on step-wedge phantom

The pixel value of the step-wedge phantom was determined by placing the data cursor at each step using Matlab R2015a software, as shown in Figure 4.

Figure 4. The identification of pixel value on step-wedge phantom images.

The PV of each step in the homogeneous section and the t_w can be determined by using equation (2). This process was iterated along with each step in the phantom to get 5 data for developing the correlation.

E. SSDE calculation

SSDE was calculated using equation (4) by considering the value of D_w, as follows.

$$SSDE = CTDI_{vol} \times f_{D_w} \qquad (4)$$

$CTDI_{vol}$ is the CT output dose and f_{D_w} be the conversion factor of patient thickness. This conversion factor is obtained based on the AAPM report no. 24 of 2011, and has been evaluated by previous study [22].

III. RESULTS AND DISCUSSION

A. The relationship between PV and t_w

The relationships between PV and t_w of the step-wedge and the CTDI phantoms are shown in Figure 5. It shows that the PV and t_w have linear correlations with $R^2 > 0.99$ for both phantoms. This indicates that the results obtained are correlated. The pixel values calibrated by the two phantoms increase as the t_w value increases.

B. Water-equivalent diameter (D_w)

The relationship between D_w values obtained from patients CT localizer radiographs calibrated with the step-wedge and CTDI phantoms is shown in Figure 6. It is found that there is relationship between D_w values from the CT localizer radiograph calibrated with the CTDI phantom and step-wedge phantom with $R^2 = 0.9929$. The statistical test value with p-value of 0.996. This indicates that the two measurements are not statistically different.

C. Size-specific dose estimate (SSDE)

The relationship between SSDE values calculated using CT localizer radiographs based on the CT localizer radiographs calibrated using the CTDI phantom and the step-wedge phantom is shown in Figure 7. It indicates that the value of $R^2 = 0.9901$ and p-value > 0.05.

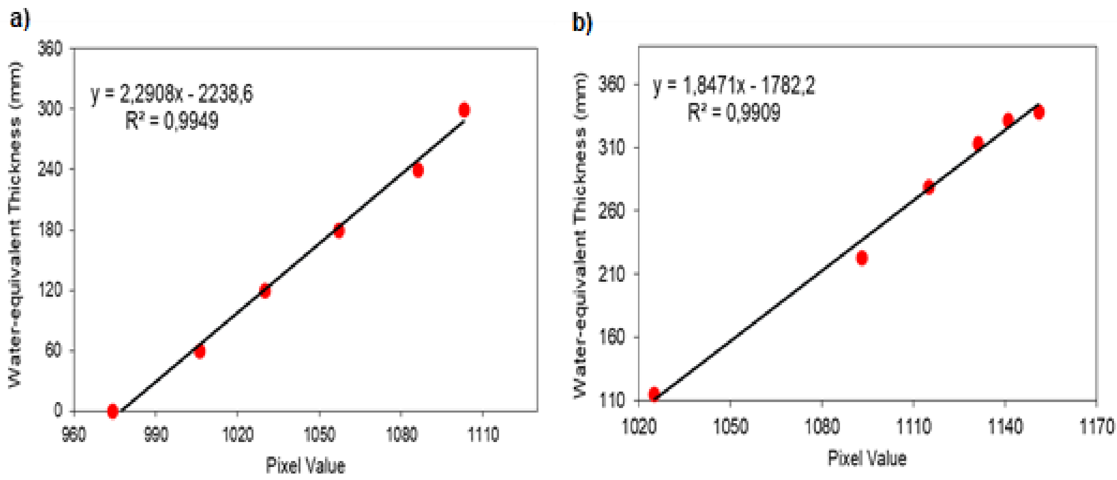

Figure 5. Relationships between pixel value and water-equivalent thickness from two phantoms. (a) step-wedge phantom, and (b) CTDI phantom.

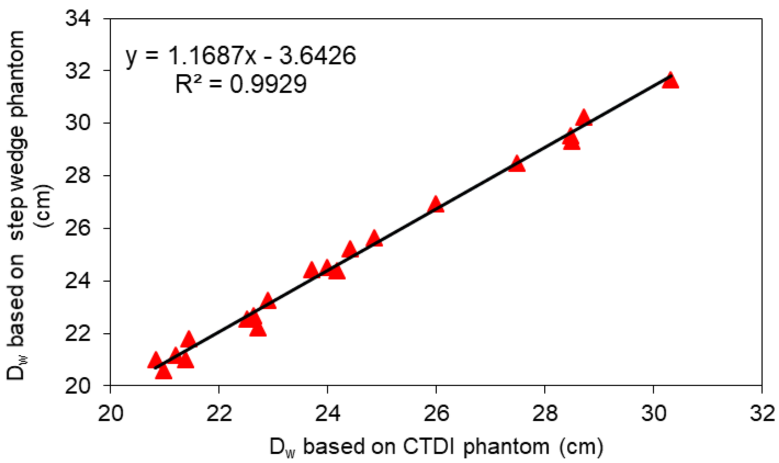

Figure 6. The relationship between D_w values calculated based on the CT localizer radiographs calibrated using the CTDI phantom and the step-wedge phantom.

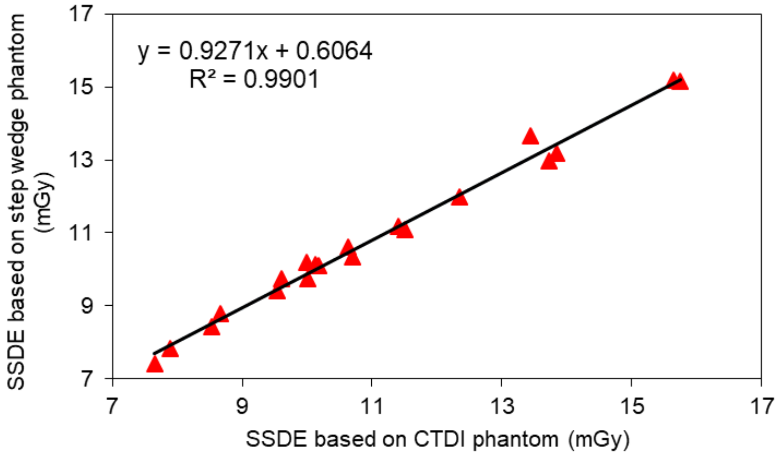

Figure 7. The relationship between SSDE values calculated based on the CT localizer radiographs calibrated using the CTDI phantom and the step-wedge phantom.

The relationship between pixel values (PV) and water-equivalent thickness (t_w) in a CT localizer radiograph is very important, hence D_w can be measured from the CT localizer radiograph. The relationships between PV and t_w obtained from phantoms of ACR CT and CTDI phantom had been previously developed [20]. However, the availability of two phantoms are still limited in some CT centers. One alternative phantom is the step-wedge phantom which can be developed in hospital. In this study, we demonstrate that the step-wedge phantom can be used as a tool to calculate the values of D_w and SSDE using a CT localizer radiograph.

Anam et al. (2018) [19] reported that the calculation of D_w and SSDE using a CT localizer radiograph based on a CTDI phantom is accurate. In their study, the D_w and SSDE obtained from CT localizer radiograph were compared with those from the axial CT images. They obtained comparable results.

In this study, we compare the results of D_w from the step-wedge phantom with those from the CTDI phantom. Figure 5 shows that the relationship between D_w values from the step-wedge phantom with those from the CTDI phantom are very similar. The relationship between both has $R^2 > 0.990$. Previously, phantoms for establishing relationship between pixel value and water-equivalent thickness for measuring D_w has been proposed by Terashima et al (2019) [23]. However, the phantoms have only two thicknesses. Our step-wedge phantom has five different thickness, hence it is more accurately to establish the relationship between pixel value and t_w.

This study has shown one simple method to calculate D_w and SSDE based on CT localizer radiograph with the step-wedge phantom. Although we have compared to those from the CTDI phantom, in this study we only used fixed tube voltage and current and only one type of scanners and may not be representative of other types of scanners.

IV. CONCLUSION

The relationships between PV and t_w obtained from CT localizer radiographs of the phantoms of step-wedge and CTDI are established. The D_w values from the CT localizer radiograph calibrated with the CTDI phantom and step-wedge phantom also have linear relationship with $R^2 > 0.99$. The statistical test value with p-value > 0.05 indicating that the two measurements of D_w based on two phantoms are not statistically different. The similar trend has been obtained for SSDE values. Hence, the results of the calibration of the step-wedge phantom can be used to determine the D_w and SSDE.

V. ACKNOWLEDGEMENTS

This work was funded by the Riset Publikasi International Bereputasi Tinggi (RPIBT), Diponegoro University, No. 569-187/UN7.D2/PP/VII/2022.

VI. REFERENCES

[1] McNitt-Gray MF. AAPM/RSNA Physics Tutorial for Residents: Topics in CT. Radiation dose in CT. *Radiographics*. 2002;22(6):1541-1553.

[2] Abuhaimed A & Martin CJ. Estimation of Size-Specific Dose Estimates (SSDE) for pediatric and adults patients based on a single slice. *Physica Medica*. 2020;74:30–39.

[3] Moore BM, Brady SL, Mirro AE, Kaufman RA. Size-specific dose estimate (SSDE) provides a simple method to calculate organ dose for pediatric CT examinations. *Med Phys*. 2014;41(7):071917.

[4] Bankier AA, Kressel HY. Through the Looking Glass revisited: the need for more meaning and less drama in the reporting of dose and dose reduction in CT. *Radiology*. 2012;265(1):4-8.

[5] Kalender WA. Dose in x-ray computed tomography. *Phys Med Biol*. 2014;59(3):R129-R150.

[6] Xu J, He X, Xiao H, Xu J. Comparative Study of Volume Computed Tomography Dose Index and Size-Specific Dose Estimate Head in Computed Tomography Examination for Adult Patients Based on the Mode of Automatic Tube Current Modulation. *Med Sci Monit*. 2019;25:71-76.

[7] McCollough CH, Leng S, Yu L, Cody DD, Boone JM, McNitt-Gray MF. CT dose index and patient dose: they are not the same thing. *Radiology*. 2011;259(2):311-316.

[8] Huda W, Mettler FA. Volume CT dose index and dose-length product displayed during CT: what good are they?. *Radiology*. 2011;258(1):236-242.

[9] Anam C, Mahdani FR, Dewi WK, et al. An improved method for automated calculation of the water-equivalent diameter for estimating size-specific dose in CT. *J Appl Clin Med Phys*. 2021;22(9):313-323.

[10] AAPM. Size-specific Dose Estimates (SSDE) in Pediatric and Adult Body CT Examinations. in *AAPM Report No. 204*. 2011.

[11] Hu X, Gou J, Lin W, Zou C, Li W. Size-specific dose estimates of adult, chest computed tomography examinations: Comparison of Chinese and updated 2017 American College of Radiology diagnostic reference levels based on the water-equivalent diameter. *PLoS One*. 2021;16(9):e0257294.

[12] AAPM. AAPM TG 220: Use of Water Equivalent Diameter for Calculating Patient Size and Size-Specific Dose Estimates (SSDE) in CT. in *AAPM Report 220*. 2014.

[13] Cheng PM. Automated estimation of abdominal effective diameter for body size normalization of CT dose. *J Digit Imaging*. 2013;26(3):406-411.

[14] Juszczyk J, Badura P, Czajkowska J, et al. Automated size-specific dose estimates using deep learning image processing. *Medical Image Analysis*. 2021;68:101898.

[15] Wang J, Christner JA, Duan X, Leng S, Yu L, McCollough CH. Attenuation-based estimation of patient size for the purpose of size specific dose estimation in CT. Part II. Implementation on abdomen and thorax phantoms using cross sectional CT images and scanned projection radiograph images. *Med Phys*. 2012;39(11):6772-6778.

[16] Anam C, Haryanto F, Widita R, Arif I, Dougherty G. Automated Calculation of Water-equivalent Diameter (DW) Based on AAPM

Task Group 220. *J Appl Clin Med Phys*. 2016;17(4):320-333.

[17] Mihailidis D, Tsapaki V, Tomara P. A simple manual method to estimate water-equivalent diameter for calculating size-specific dose estimate in chest computed tomography. *Br J Radiol*. 2021;94(1117):20200473.

[18] Christianson O, Li X, Frush D, Samei E. Automated size-specific CT dose monitoring program: assessing variability in CT dose. *Med Phys*. 2012;39(11):7131-7139.

[19] Anam C, Fujibuchi T, Toyoda T, et al. A simple method for calibrating pixel values of the CT localizer radiograph for calculating water-equivalent diameter and size-specific dose estimate. *Radiat Prot Dosimetry*. 2018;179(2):158-168.

[20] Zhang D, Mihai G, Barbaras LG, Brook OR, Palmer MR. A new method for CT dose estimation by determining patient water equivalent diameter from localizer radiographs: Geometric transformation and calibration methods using readily available phantoms. *Med Phys*. 2018;45(7):3371-3378.

[21] Wu RY, Liu AY, Wisdom P, et al. Characterization of a new physical phantom for testing rigid and deformable image registration. *J Appl Clin Med Phys*. 2019;20(1):145-153.

[22] Nasir M, Pratama D, Anam C. Calculation of size specific dose estimates (SSDE) value at cylindrical phantom from CBCT Varian OBI v1.4 X-ray tube EGSnrc Monte Carlo simulation based. *J Phys: Conf Ser*. 2016;694:012040.

[23] Terashima M, Mizonobe K, Date H. Determination of appropriate conversion factors for calculating size-specific dose estimates based on X-ray CT scout images after miscentering correction. *Radiol Phys Technol*. 2019;12(3):283-289.

Cite this article as :

Sitti M. Rif'ah, Choirul Anam, Heri Sutanto, Heryani Cholid, "Comparison of Water-Equivalent Diameter Measured from CT Localizer Radiograph Based on Two phantoms of the Step-Wedge and Computed Tomography Dose Index", International Journal of Scientific Research in Science and Technology (IJSRST), Online ISSN : 2395-602X, Print ISSN : 2395-6011, Volume 9 Issue 6, pp. 445-452, November-December 2022. Available at doi : https://doi.org/10.32628/IJSRST229661

Journal URL : https://ijsrst.com/IJSRST229661