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Radiation Dose and Image Quality of Bladder Cancer Patients Analysis on Abdominal CT-Scan Examinations

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ABSTRACT

The bladder is a subperitoneal, hollow muscular organ that acts as areservoir for urine and located in the lower abdomen. Bladder cancer is one of health issues that can affect many people each year. Bladder cancer ranks as the 10th most common cancer worldwide. Early management includes cancer screening using abdominal CT-Scan. The objective of this study was to analyze the radiation dose received by patients and the image quality of patients underwent abdominal CT scans based on the Signal to Noise Ratio (SNR) and Contrast to Noise Ratio (CNR) values obtained. Data analysis management, specifically using quantitative analysis techniques, involved observing 20 bladder cancer patients with a total of 2,653 images. The IndoseCT software was used for analyzing the radiation dose to patients, while the IndoQCT software was used for analyzing image quality in CT-Abdomen examinations based on Signal to Noise Ratio (SNR) and Contrast to Noise Ratio (CNR) values. The results showed that the radiation dose received by patients during CT-Abdomen examinations was higher than the dose output by the device. The maximum dose output by the device (CTDIvol) was 50.10 mGy, and the minimum was 6.70 mGy, while the maximum dose received by patients (SSDE) was 53.34 mGy, and the minimum was 9.34 mGy. The image quality results for CT-Abdomen examinations based on SNR and CNR values indicated that the image quality obtained was adequate for diagnostic purposes.

INTRODUCTION

Bladder cancer ranks as the 10th most common cancer worldwide. According to GLOBOCAN 2020 data, there were 573,000 new cases and 213,000 deaths attributed to this type of cancer. The majority of bladder cancers are urothelial carcinomas, with less common types including squamous cell carcinoma, adenocarcinoma, small cell carcinoma, and sarcoma. Based on the staging classification from the World Health Organization (WHO), bladder cancer is classified into non-muscle-invasive bladder cancer (NMIBC) and muscle-invasive bladder cancer (MIBC). The treatment for NMIBC typically involves transurethral resection of the bladder tumor (TURBT) and chemotherapy to prevent recurrence, using agents such as Mitomycin-C and Epirubicin [1].

CT-Abdomen examination is one of the commonly used diagnostic methods to evaluate the condition of organs within the abdominal cavity. Over time, CT-Scan has become a diagnostic tool that provides highly accurate information. However, attention must also be given to radiation protection for patients as well as the significant costs involved in this examination. Awareness of the potential increase in radiation dose during CT-Scan examinations has led to efforts to reduce radiation exposure. However, reducing the CT-Scan dose can result in decreased image quality with increased noise levels. In other words, a high radiation dose is required to achieve good image quality [2].

In the CT-Scan process, to create an image of the object, radiation beams from the source pass through the object's plane from various angles. The radiation that successfully penetrates the object is then detected by the detector, recorded, and collected as input data. This data are subsequently processed by a computer using a method called reconstruction to generate the image of the object [3].

Diagnostic Reference Levels (DRLs) are typically determined by collecting patient dose data at

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the 75th percentile of the dose distribution or the median CTDIvol and DLP obtained from surveys across a wide user base. Since 25 % of the population will exceed the DRLs, these should be viewed as indicators rather than signs of excessive radiation exposure. DRLs can be established at the local, hospital, or center level [4].

To accurately estimate the dose in CT-Scan patients, reference can be made to an optimization index known as the DRLs. Currently, the DRLs for CT-Scans is expressed in terms of CTDIvol (Computed Tomography Dose Index Volume) and DLP (Dose Length Product), where CTDIvol represents the dose output indicator from the CT-Scan for a single slice, and DLP represents the total dose during the examination. The values of CTDIvol and DLP are displayed on the CT-Scan workstation [5]. The DRLs is generally designed for patients with standard body dimensions. The systematic dosing in CT-Scans using automatic registration has been regulated by considering parameters such as the lateral head thickness and Water Equivalent Diameter (Dw) [6].

CTDIvol does not specifically reflect the dose for each patient because it is only measured on phantoms with diameters of 16 cm and 32 cm. Therefore, the American Association of Physicists in Medicine (AAPM) introduced a dose parameter that accounts for patient dimensions, known as the Size-Specific Dose Estimate (SSDE) [7]. SSDE is the product of the conversion factor (f) and the CTDIvol value. It represents the dose value that accounts for the patient's body size (mGy), with f being the conversion factor [8].

Research on calculating DRL values using the SSDE method is considered to better represent the dose received by patients. In addition to manual calculations, SSDE values can now be automatically computed using software such as IndoseCT. IndoseCT is software developed to calculate radiation dose values for patients undergoing CT-Scan examinations by [9]. This software functions to calculate and record the radiation dose for patients undergoing CT examinations. IndoseCT not only calculates the radiation dose from the CT device using CTDIvol, but also considers the individual dose received by each patient using the SSDE method [10].

CT-Scan uses X-rays to produce images with adequate diagnostic detail. Tissue reactions (such as infertility, cataracts, erythema, hair loss, etc.) and stochastic consequences (such as cancer and genetic impacts) are associated with high-dose ionizing radiation exposure. As a result of patients' exposure to higher CT doses, there is an increased likelihood of developing cancer. After the examination, this becomes one of the greatest sources of anxiety for patients. Consequently, its clinical use requires careful examination of the conditions, as well as optimization of patient dose and image quality [11].

Optimal image quality is indicated by a high signal-to-noise ratio (SNR). SNR is the ratio of signal strength to noise strength; the less noise in the image, the higher the resulting SNR [12]. Low contrast resolution differentiates the density of an object from its background. The Contrast to Noise Ratio (CNR) parameter measures how well the signal intensity can be distinguished from the background [13]. Image processing in CT-Scan aims to enhance image quality by reducing noise, increasing spatial resolution, and improving contrast resolution [14].

Image noise is an important factor in evaluating image quality and determining system performance. Noise in CT refers to the level of uncertainty in measuring the attenuation of X-rays passing through the patient. CT noise depends on the number of X-ray photons reaching the detector, known as quantum noise, which is the most significant factor affecting image quality [15].

Research by Missinychrista et al. [16] compared the dose emitted by CT-Scans with the dose received by patients, finding that the dose emitted by the machine tends to be lower than the dose received by patients. In addition, the research reported in Diartama et al. [17] to determine the DRL values for adult non-contrast MSCT Thorax at X General Hospital in Denpasar and compare them with the standards recommended by BAPETEN/IDRL 2021. The results showed that the third quartile value (75th percentile) of CTDIvol and DLP received by patients was 5.77 mGy for CTDIvol and 232.73 mGy.cm for DLP. These values are still below the standards recommended by BAPETEN/IDRL 2021, indicating that the amount of radiation used is within normal limits and considered safe.

Research by Irsal and Winarno [18] analyzed image quality and radiation dose in pediatric head CT-Scans, with a linear regression test showing an R2 = 0.045 between mAs and CNR, and an R2 = 0.704 between mAs and CTDI. Based on the estimated radiation dose limits, the examination was deemed safe for use. However, the use of mAs values should be carefully considered as part of an optimization effort to reduce radiation dose while still providing optimal image quality.

Therefore, this study aimed to analyze the radiation dose received by bladder cancer patients and to evaluate the image quality of bladder cancer patients during CT-Abdomen examinations based on the SNR and CNR values obtained. This research provided a better understanding of the radiation dose risks faced by patients during CT-Abdomen examinations while ensuring that the image quality is sufficiently high for diagnosis, adhering to the principle of As Low as Diagnostically Acceptable being Indication-oriented and Patient-specific (ALADAIP). Consequently, this study is expected to make a positive contribution to the development of safety and effectiveness in CT-Abdomen examinations.

METHODOLOGY

This study was designed to analyze the radiation dose and image quality of 20 bladder cancer patients during CT-Abdomen examinations. The research data included image data from patients aged 40 and above, both male and female, and the patients' images used are from diagnostic examinations using CT-Scan equipment. Data collection for this study was conducted by downloading CT-Abdomen examination images from the official website of the "National Cancer Institute (NCI)" at https://www.cancerimagingarchive.net/collection/tcga-blca/ [19].

The first step involved downloading the imaging data from the website and calculating the radiation dose values, including CTDIvol, DLP, D_w, and SSDE, using the IndoseCT software. the software is equipped with features that allow for calculation of CTDIvol, DLP, D_w, and SSDE values. The second step is classified the data based on parameters, such as CTDIvol, DLP, D_w, and SSDE values. Each variable was described by providing the mean and the 75th percentile values (or the 3rd quartile). To assess image quality, SNR and CNR were measured for one image from each patient. The Region of Interest (RoI) was determined in both the signal area and the background area to calculate the average signal and compute the SNR and CNR values, using the IndoQCT software.

The establishment of the DRL for specific examination data is set at the third quartile (Q3) in the data distribution. The Q3 can be calculated using Eq. (1).

$$n_{q3} = \frac{3(n+1)}{4} \tag{1}$$

where n_{q3} is the position of the third quartile and n is the total number of data points [20].

The CTDIvol value is calculated using the following Eq. (2).

$$CTDI_{vol} = \frac{CTDI_W}{pitch} \tag{2}$$

where pitch characterizes the speed of the table feed per 360° rotation and CTDIw represents the CTDI that accounts for the difference in dose values between the surface and the center of the phantom (measured in mGy).

DLP is the total absorbed dose from the entire scan series, calculated from the CTDIvol and the scan length (L). Mathematically, DLP is expressed as follows Eq. (3).

$$DLP = CTDI_{vol} \times L \tag{3}$$

SSDE is the product of the conversion factor (f) and the CTDIvol value. Mathematically, SSDE is expressed as follows Eq. (4).

$$SSDE = f_{size}^{32x} . CTDI_{vol}^{32} \tag{4}$$

where SSDE represents the dose value that accounts for the patient's body size (measured in mGy), and f is the conversion factor. For the f_{size}^{32x}, this conversion factor is based on the diameter of 32 cm PMMA phantom for a specific CTDIvol value with a given Dw, calculated using the following Eq. (5).

$$f_{size}^{32x} = 4{,}3781 \; x \; e^{-0{,}0433 \, D_w} \tag{5}$$

Dw is determined for each patient by defining the RoI and averaging the Hounsfield Unit (HU) within the RoI. The area of the RoI is recorded, and the Dw value is calculated using the following Eq. (6).

$$D_w = \sqrt[2]{\left(1 + \frac{HU_{ROI}}{1000}\right) \frac{Area_{ROI}}{\pi}} \tag{6}$$

Tables 1 and 2 below present the DRL threshold values for CT-Abdomen examinations [21] and the conversion factors based on 32 cm AAPM phantom [22].

Table 1. DRL threshold values for CT-Abdomen examinations [21].

Kategory	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)
Contrast Abdominal CT	20	1.360
Non-Contrast Abdominal CT	17	885

Table 2. The conversion factors based on 32 cm AAPM phantom [22].

D_w (cm)	f
24	1,53
25	1,48
26	1,43
27	1,37
28	1,32
29	1,28
30	1,23
31	1,19
32	1,14
33	1,10
34	1,06
35	1,02
36	0,99
37	0,95
38	0,92
39	0,88
40	0,85
41	0,82

RESULTS AND DISCUSSION

The data analyzed in this study consists of imaging data from 20 bladder cancer patients who underwent CT-Abdomen examinations. These images were downloaded from the official website of the "National Cancer Institute (NCI)" at https://www.cancerimagingarchive.net/collection/tcga-blca/, with the downloaded images in DICOM format. Table 3 presents the results of the DRL and SSDE examination for bladder cancer patients.

The average values for DRLs and SSDE were calculated by averaging the CTDIvol, DRLs, and SSDE values. To find the third quartile for DRLs and SSDE, the parameters CTDIvol, DLP, and SSDE were sorted. The third quartile values were then determined using Eq. (1). The mean and third quartile (75th percentile) values for DRLs and SSDE in bladder cancer patients are presented in Table 4.

Table 3. Results of DRLs and SSDE examination for bladder cancer patients.

Patient	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	D_w (cm)	SSDE (mGy)
1	18.20	600.60	24.40	27.85
2	9.22	384.61	26.03	13.19
3	6.70	584.70	26.15	9.58
4	12.00	190.81	26.69	17.16
5	8.16	420.00	26.85	11.66
6	18.46	941.65	26.86	26.40
7	11.63	554.59	27.69	15.93
8	27.60	1,255.80	28.01	36.43
9	14.00	770.24	28.35	18.49
10	21.30	575.10	28.92	28.12
11	21.10	569.70	29.32	27.01
12	16.07	226.60	29.50	20.57
13	10.30	358.44	29.66	13.18
14	14.34	675.37	30.71	17.64
15	13.49	573.41	30.73	16.60
16	50.10	1,818.63	33.86	55.11
17	25.06	701.54	33.99	27.56
18	33.90	1,088.19	34.22	35.93
19	40.40	234.33	36.00	40.00
20	24.70	1,469.65	40.21	21.00

CTDIvol = Computed Tomography Dose Index Volume (mGy)
DLP = Dose Length Product (mGy.cm)
Dw = Water Equivalent Diameter (cm)
SSDE = Size-Specific Dose Estimate (mGy)

Table 4. Average and 75th percentile values of DRL and SSDE for bladder cancer patients.

D_w (cm)	Patient	Mean			75th Percentile		
		$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	SSDE (mGy)	$CTDI_{vol}$ (mGy)	DLP (mGy.cm)	SSDE (mGy)
24-41	20	19.84	699.70	23.97	25.06	941.65	28.12

Dw = Water Equivalent Diameter (cm)
CTDIvol = Computed Tomography Dose Index Volume (mGy)
DLP = Dose Length Product (mGy.cm)
SSDE = Size-Specific Dose Estimate (mGy)

Figure 1 shows the CTDIvol graph for 20 bladder cancer patients. From the collected images, the maximum CTDIvol value obtained was 50.10 mGy, while the minimum CTDIvol value was 6.70 mGy. Figure 2 displays the SSDE graph for 20 bladder cancer patients. The maximum SSDE value obtained was 55.11 mGy, while the minimum SSDE value was 9.58 mGy. In this case, the SSDE values for CT-Abdomen examinations were compared with the CTDIvol values, which represent the radiation dose for each patient's examination.

The doses for 20 patients undergoing CT-Abdomen examinations exceed the DRLs limits set by BAPETEN, as shown by the average and 75th percentile values in Table 4. This indicates that the radiation doses surpass the recommended threshold, raising concerns about excessive radiation exposure. It is not only increases the risk of radiation-related side effects for patients, but also suggests a need for reevaluation of the CT protocols and procedures used. However, it also depends on the patients' body size and the physician's goal to achieve an accurate diagnosis. One study that found DRL values exceeding the established limits was conducted by Ginting et al. [23], which reported that DRLs values for abdominal contrast examinations at RSUD Bali Mandara exceeded BAPETEN's limits. It was influenced by the CT-Scan process, which was performed three times-on the arteries, veins, and delay. Additionally, high current levels also affect the DRLs and CTDIvol values, although obese patients may require higher exposure factors. Therefore, CT-Scan examinations at RSUD Bali Mandara require a review of the Standard Operating Procedures (SOP) and exposure factors used. Contrast-enhanced abdominal examinations should focus more on the specific areas that need to be scanned to avoid exceeding BAPETEN's established limits.

Based on the mean and 75th percentile values obtained, it can be seen that the dose received by patients is higher than the dose emitted by the equipment. This discrepancy is due to the SSDE values, which depend on the patients' diameter affecting the conversion factors and the emitted dose. The conversion factor accounts for the patients' body size to provide a more accurate dose estimate, so although the equipment's dose output is certain, the actual dose received by the patient can be higher or lower depending on the patient's body diameter. This aligns with the study by Putri et al. [24], which found that the dose received by patients was greater than the dose emitted by the equipment due to the SSDE values depending on conversion factors influenced by the patient's body diameter and the emitted dose.

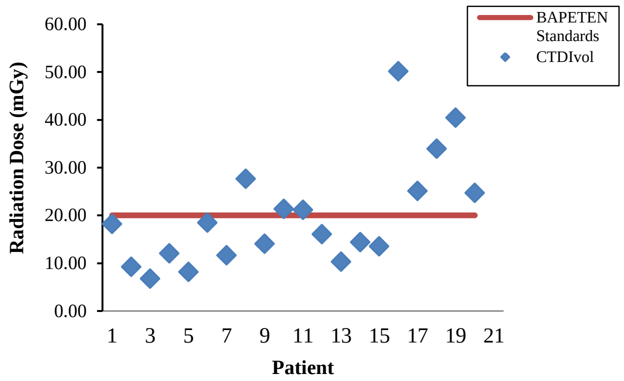

Fig. 1. CTDIvol graph for bladder cancer patients.

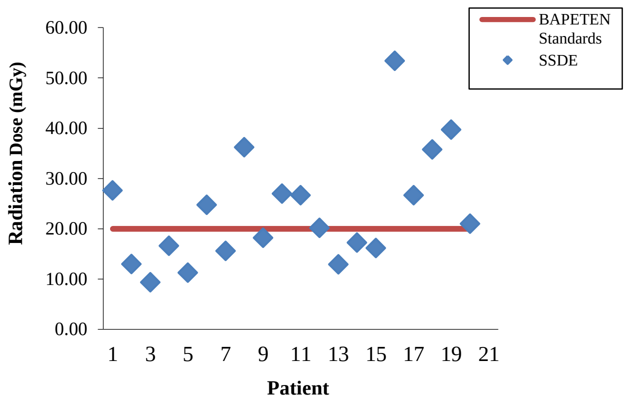

Fig. 2. SSDE graph for bladder cancer patients.

Images of patients with varying voltages, i.e., 100 kV, 120 kV, and 140 kV, and different tube current settings were used. Figure 3 illustrates the process of determining the RoI for Signal and Background in patient images to assess the average signal for each. One image per patient was selected to calculate the SNR and CNR values. Table 5 presents the image quality results based on SNR and CNR values. For SNR, the values were calculated for both the Signal area and the Background area. The CNR was determined by calculating the contrast, which is the difference between the RoI for the Signal and the Background areas, and then dividing this contrast by the noise.

The SNR value in the Signal area indicates how well the signal is captured compared to the noise. A maximum value signifies that some images have good quality with minimal noise, while a minimum value indicates images with poor quality due to high noise levels. The SNR value in the Background area generally shows lower SNR compared to the Signal area, indicating higher noise levels. The maximum value suggests that imaging still maintains relatively good quality in some cases, while the minimum value indicates parts of the Background with high noise, which can affect image quality and make clinical interpretation difficult.

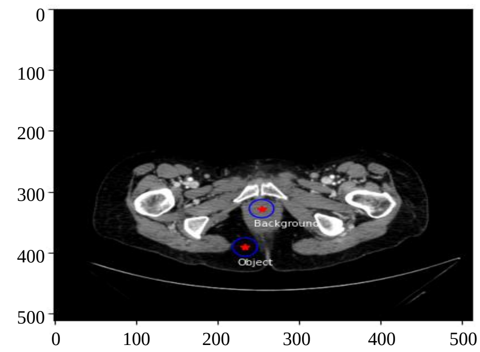

Fig. 3. The determination of region of interest (ROI) for signal and background on patient 1.

Table 5. Image quality based on SNR and CNR values.

Patient	SNR Signal	SNR Background	CNR
1	8.43	2.16	10.16
2	10.16	1.29	14.17
3	3.35	4.66	7.23
4	4.36	3.07	7.21
5	7.84	2.50	10.99
6	6.88	1.85	6.78
7	6.35	1.47	1.50
8	23.20	1.20	20.72
9	14.58	4.09	20.99
10	17.62	4.54	25.68
11	9.77	2.22	1.06
12	10.99	2.72	14.77
13	12.19	11.31	20.87
14	12.81	1.20	1.63
15	7.42	2.38	8.19
16	23.41	1.02	2.17
17	10.70	3.57	15.94
18	6.58	3.67	9.64
19	11.43	1.56	15.99
20	4.53	1.70	5.15

SNR = Signal to Noise Ratio
CNR = Contrast to Noise Ratio

SNR measures how clearly the signal or information contained in the image or signal stands out compared to the noise present. Higher SNR values make it easier to distinguish between the signal and the noise [25]. The maximum CNR value obtained from the examination of 20 patients was 25.68, while the minimum CNR value was 1.06. The American College of Radiology [26] specifies that for adult CT-Abdomen examinations, the CNR should reach or exceed 1. The maximum CNR indicates that, under optimal conditions, the contrast difference between the signal and the background is very clear, which facilitates diagnosis. The minimum CNR value is still above the established threshold, showing that even under the worst conditions, the images can still be used for accurate diagnosis.

The CNR value is influenced by exposure factors, including tube voltage and slice thickness. Each increase in tube voltage results in variable changes, while variations in slice thickness lead to increased SNR and CNR values. Satwika et al. [27] stated that increasing the tube voltage can enhance the density of the image. Higher density results in a darker image. Images with high density appear darker, making them unsuitable for diagnosing diseases. If the X-ray tube voltage is too high, the resulting image density will increase, and the SNR value will decrease. Nurhayati et al. [28] also noted that the highest tube voltage variations produce the lowest CNR values. This indicates that with each increase in tube voltage, the resulting CNR value experiences irregular increases and decreases. Kusumaningsih et al. [29] stated that slice thickness variation has a 99.9 % influence on the SNR value, meaning slice thickness significantly affects the obtained SNR value, thereby influencing the quality of the resulting image. Using a thin slice thickness will result in a minimum SNR value due to the high level of noise in the image, which lowers the image quality. A high CNR value indicates less noise, leading to better contrast resolution in the image.

CONCLUSION

The radiation dose received by patients during an Abdominal CT-Scan varies, with a maximum dose of 55.11 mGy and a minimum dose of 9.58 mGy, which is higher than the dose produced by the device. This is influenced by several factors, such as the patient's weight, the type of protocol used, and the scanner settings. Although these doses remain within the safe limits for diagnostic examinations, higher doses should be considered, particularly at the maximum value and for patients requiring repeated examinations, as cumulative radiation exposure may increase the risk of long-term side effects such as cancer. Therefore, the ALADAIP principle should be applied to minimize doses without compromising image quality, utilizing the latest technology and techniques. The image quality in abdominal CT examinations, based on the SNR and CNR, indicates that the obtained image quality is sufficient for diagnostic purposes.

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AUTHOR CONTRIBUTION

R. Anthon, S. H. Intifadhah and E. R. Putri equally contributed as the main contributors of this paper. All authors read and approved the final version of the paper.

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