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Estimation of Organ Dose, Effective Dose, and Cancer Risk in Abdominal CT Scan Patients

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ABSTRACT

Computed tomography scan (CT scan) is a modality that is used to diagnose diseases inside the human body. In the scanning process, the patient will receive radiation from the CT scanner, so that it is necessary to calculate the amount of radiation dose. The purpose of this study was to determine the organ dose, effective dose, and cancer risk received by abdominal examination patients. Data taken from the results of abdominal examination patients at Radiology Installation of A.W. Sjahranie Regional Hospital Samarinda using 16-slice CT scan modality GE BRIVO type D3161T. The data collected included 150 patients, both female and male, with ages ranging from 15 to 79 years. Dosimetry parameters taken from CT scan results are the exposure factor (kV, mAs), scan length, computed tomography dosimetry indeks volume (CTDIvol), and dose length product (DLP) of the patient. CTDIvol and DLP of the patient are used to calculate the organ dose, effective dose, and cancer risk values of abdominal CT scan patients. Then the effective dose value received by the abdominal CT scan examination patient is compared with the Nuclear Energy Regulatory Agency of Indonesia (BAPETEN) standard based on the CTDIvol and DLP values of the patient, and also compared with the International Commission Radiological Protection (ICRP) standard. Based on the results of organ dose estimation calculations, the average value of the stomach is 0.82 mSv, the gonads are 0.54 mSv, and the bladder is 0.28 mSv. Meanwhile, the average value of effective dose received by abdominal examination patients is 5.28 mSv with an average cancer risk of 0.029 %. Based on the CTDIvol and DLP values of the patients, the 3rd quartile values of the patients were 8.25 mGy and 413.84 mGy.cm. This value is still below the value recommended by BAPETEN when viewed from the 2021 Diagnostic Reference Level (DRL) guidelines. The effective dose received by one patient exceeded the standard set by the ICRP. Meanwhile, the cancer risk received by patients is still in a low percentage.

INTRODUCTION

Computed Tomography (CT) scan is a tool used to diagnose diseases in the human body. Abnormalities in the human body can be identified using CT scan without the need for surgery. CT scan can be used in several examinations, such as head, thorax, and abdominal [1].

Almost all hospitals in the world use CT scans to diagnose patients who have injuries to their organs by emitting X-rays on the patient's body for diagnosis. X-ray radiation is an ionizing radiation, which forms ions by ejecting electrons from its orbit [2].

The International Atomic Energy Agency (IAEA) reports that CT scans are used for about 25 % of all radiology examinations and 60 % to 70 % of the total radiology examination dose [3]. CT is a popular diagnostic method for imaging radiology that is useful for cancer research, localization of infection, inflammatory lesions, and assessment of treatment response [4]. CT scans have had a major influence on diagnostic radiology worldwide over the past few decades. Increased radiation of CT scans gives rise to serious concerns about significant health risks [5]. Therefore,

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potential health risks arising from CT imaging are reduced. In this regard, all clinicians should perform radiation dose assessment from time to time. Since then, clinicians have used effective dose as a metric for radiation dose assessment [6].

The computed tomography dose index (CTDI) method is used to calculate the radiation dose received by the patient from the CT scan aircraft during the scanning process. In addition, CTDI is also one of the parameters used to estimate the radiation absorption dose of organ [7]. The CTDIvol and DLP are automatically provided by the CT scanner and are commonly used as radiation dose indices in CT [8]. CTDIvol is calculated from the absorbed dose measured using a 16-cm dosimetry phantom and scanner parameters, and DLP is the integral of CTDIvol over the scanning range [9].

The radiation dose received by the patient will cause changes in the biological system and increase the risk of cancer. The cancer risk associated with radiation exposure used for medical imaging is conventionally assessed using a linear no-threshold model [10]. The single parameter that describes the risk of exposure to ionizing radiation delivered to patients from the CT scan field is the effective dose [11]. Effective dose as a quantity of radiation protection is to compare different imaging modalities and to inform patients of the relative radiation risk [12]. Exposure to ionizing radiation causes and increase of cancer risk in patients proportional to the absorbed radiation dose and affects the level of organ sensitivity [13]. Some of the adverse effects that appear on the human body due to X-ray exposure are somatic effects in the form of damage to body tissue cells and genetic damage in the form of reproductive cell mutations, stochastic effects, and deterministic effects [2].

CT scans are effectively used by radiologists to detect diseases in the human body [14]. Although CT scans provide great diagnostic benefits to individual patients, the radiation dose delivered is relatively higher compared to other conventional imaging modalities [15,16]. The Health Physics Society and the American Association of Physicists state that cancer risks are small or nonexistent at exposure levels below 100 mSv. However, effective doses of 100 mSv and above are consistently considered carcinogenic [10].

A diagnostic examination of any kind must have sufficient image quality to provide the necessary diagnostic information, and the purpose of the examination must not be sacrificed. This is known as the As Low as Reasonably Achievable (ALARA) principle, which becomes As Low as Diagnostically Acceptable, being Indication-oriented and Patient specific (ALADAIP) [17], emphasizing X-ray examinations should be obtained with adequate image quality with the lowest possible radiation dose exposure [18,19].

The study by Amaoui et al., (2021) estimated the renal effective dose during abdominal CT and assessed the risk of kidney cancer and heredity per procedure in Moroccan hospitals [18]. The results obtained showed a wide variation in exposure parameters and exposure doses during abdominal CT scans from one hospital to another. However, the average effective dose was generally lower than the dose recommended by the International Commission on Radiological Protection (ICRP).

Research by Suryatika et al., (2021) had determined the effective dose of the patients' organs and assessed the potential cancer risk of abdominal examination patients with CT scan modality [11]. CT Scan patient data that can be taken are CTDIvol and DLP to determine the patients' effective dose so that it can calculate the percentage of cancer risk in each organ. The organs contained within the abdomen include the stomach, gonads, and bladder. The results showed that the stomach is a critical organ that has the highest potential cancer risk compared to other organs for abdominal CT scan examination, but the potential cancer risk is lower than that in the ICRP Publication 103.

Research by Kiani et al., (2023) showed that the cancer risk model presented in the BEIR VII report was used to estimate risk of exposure-induced cancer death (REID) values [19]. The mean REID values were 12.34 per 100,000 males and 16.77 per 100,000 females. The REID value decreased with increasing patient age in both sexes and was higher in girls than in boys. According to the results of this study, CT scans of the brain in children are associated with an increased potential risk of cancer. Therefore, it is important to minimize unnecessary radiation exposure in pediatric patients and to use alternative imaging modalities. In addition, consideration should be given to optimizing radiation parameters while maintaining diagnostic image quality in children.

The ICRP states that cancer risk depends not only on dose but also on age at exposure and, to a lesser extent, also on gender. In most cases, those exposed at an early age are more susceptible than those exposed at a later life stage, and women are slightly more susceptible than men. Since not all radiation exposed the whole body, instead only certain parts of the body, the tissue weighting factor (wT) is required [20].

Based on previous studies, there is a wide variation in exposure parameters and exposure dose during abdominal CT scanning. Abdominal examination patients on average received an effective dose that was lower than the dose recommended by the ICRP. Meanwhile, the organs that received higher doses in the abdomen were the stomach, compared to the gonads and bladder, where male patients had a higher risk of developing cancer than female patients. Based on this, the researchers aimed to examine organ dose, effective dose, and cancer risk in patients undergoing abdominal CT scans. This study aims to find out in the abdomen, what organs receive higher doses and to find out, between women and men, which patients receive effective doses and higher patient cancer risks on abdominal CT scans at Radiology Installation at A.W. Sjahranie Regional Hospital Samarinda.

METHODOLOGY

The Radiology Installation at A.W. Sjahranie Regional Hospital Samarinda was the site of this study. It uses a 16-slice CT scan modality of GE BRIVO type D3161T, which has been calibrated by PT. Mitra Tera Accuracy and is proper to use until October 14, 2024. Patient data is secondary data of 150 patients, consisting of 75 male patients and 75 female patients with ages ranging from 15 years to 79 years. The data were the result of an abdominal CT scan without contrast from January to April 2024. Dosimetric parameters taken from the CT scan results were the exposure factor (kV and mAs), scan length, CTDIvol, and DLP of the patient. Scanning parameters in this study included tube voltage, tube current, gantry rotation time, and pitch. These parameters can affect the patients' CTDIvol and DLP [21,22].

Organ dose can be calculated by multiplying CTDIvol by the tissue weighting factor [3].

$$D_{organ} = CTDI_{vol} \times w_T \tag{1}$$

In Eq. (1) D_{organ} is the organ dose in units of mSv and w_T is the tissue weigth factor, with a tissue weight factor of stomach = 0.12, gonads = 0.08, and bladder = 0.04 [22]. CTDIvol indicated the intensity of radiation emitted by the CT device in mGy. CTDIvol did not indicate the actual amount of radiation and was not related to the size of the patient [23].

Effective dose was a concept originally developed for radiation protection purposes. Effective dose provides an acceptable metric for estimation of the stochastic effects of radiation; it cannot be directly measured in vivo. However, it can only be estimated [7,10]. The effective dose was calculated by multiplying the DLP and the conversion coefficient k; the calculation is done using the following Eq. (2):

$$D_{eff} = DLP \times k \tag{2}$$

D_{eff} was the effective dose in units of mSv, DLP was the total radiation generated during the scan, which varies based on the size and age of the patient in units of mGy.cm [24], and k was the conversion coefficient. Based on ICRP Publication 103 for CT abdomen, the conversion coefficient value was 0.015 in units of mSv.mGy^{-1}.cm^{-1} [22].

The overall cancer risk per procedure was obtained by multiplying the effective dose per Sievert (Sv) by the cancer risk factor coefficient (F). Therefore, the total cancer risk for abdominal CT procedures can be calculated as follows Eq. (3).

$$Cancer\ risk = D_{eff} \times F \tag{3}$$

Cancer risk is in percent (%) and F was the cancer risk factor coefficient of 5.5 % Sv^{-1} according to ICRP Publication 103 [20].

RESULTS AND DISCUSSION

Table 1 shows the average results of a CT scan abdominal examination without contrast, where there is a difference values between female and male patient.

Table 2 shows the mean values obtained from the calculation of organ dose, effective dose, and cancer risk based on patient gender. It was known that the organ and effective doses and cancer risk are different between both sexes.

Table 1. Average CT scan examination of abdomen without contrast in both sexes.

Patient	CTDIvol (mGy)	DLP (mGy.cm)
Male	6.95	341.36
Female	6.72	366.92

Table 2. Average patient dose calculation and their cancer risk.

Patient	Organ Dose (mSv)			Effective Dose (mSv)	Cancer Risk (%)
	Stomach	Gonads	Bladder		
Male	0.83	0.56	0.28	5.50	0.030
Female	0.81	0.54	0.27	5.12	0.028

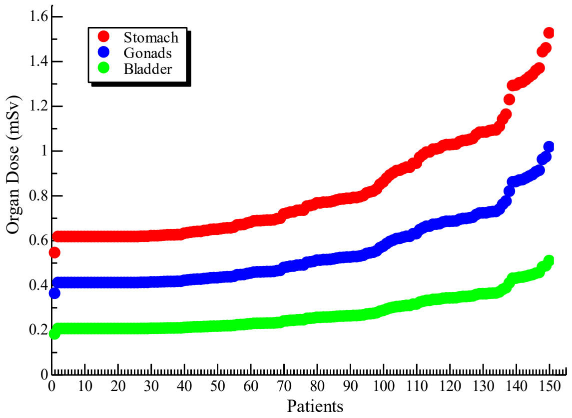

Fig. 1. Distribution of patient dose to each abdominal organ.

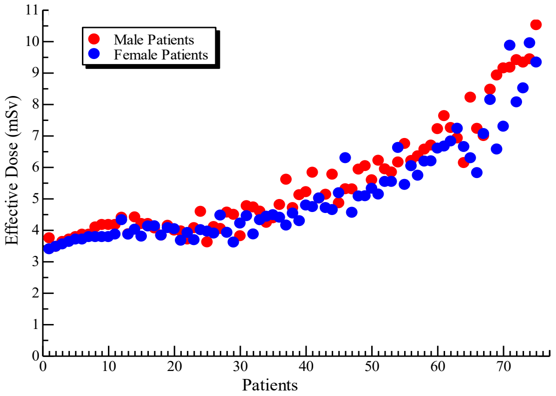

Fig. 2. Effective dose of abdominal patient for both sexes.

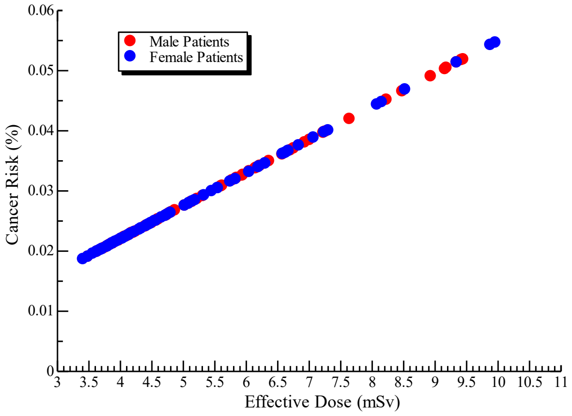

Fig. 3. Graph of the relation of effective dose to patient's cancer risk.

Table 3. CTDIvol and DLP comparison of abdominal CT examination patients between this study and BAPETEN.

Dosimetry	Samarinda Hospitals	BAPETEN
CTDIvol	8.25 mGy	17 mGy
DLP	413.85 mGy.cm	885 mGy.cm

Figure 1 shows the dose distribution of patiens according to each abdominal organ. The result of the organ dose calculation of the abdominal examination patients shows that the stomach organ receives the highest dose in the range of 0.54 mSv to 1.53 mSv. Then the gonads organs received a dose between 0.36 mSv and 1.02 mSv, and the bladder organs received a dose between 0.18 mSv and 0.51 mSv. According to BAPETEN standards, the effective radiation dose per examination is 5-50 mSv per imaged organ [25].

Figure 2 shows the distribution graph of the effective dose value of CT abdominal patients examination. Effective dose calculation: it was found that the patient received an effective dose in the range of 3.40 mSv to 10.53 mSv, with an average value of 5.28 mSv. The difference in effective dose values received by patients is influenced by several things, such as voltage (kV), tube current strength (mAs), and patient weight (kg).

Furthermore, the effective dose data that has been obtained is used to determine the patient's cancer risk using Eq. (3). Figure 3 shows a graph of the distribution of potential cancer risk against the effective dose value of patients. The results of the cancer risk of abdominal examination patients showed that patients had a potential cancer risk ranging from 0.019 % to 0.058 % with an average cancer risk of 0.029 %. The percentage of cancer risk varies due to several factors, including the radiation dose received and the patient's health condition. The potential cancer risk received by abdominal examination patients is low.

Table 3 shows the results of the calculation of the third quartile value of the CTDIvol and DLP values in abdominal examinations from Samarinda hospital.

Based on the CTDIvol and DLP values received, the patient is used as the diagnostic reference levels (DRLs) quantity. DRLs as a form of investigation level are used to help optimize protection in the medical exposure of patients for interventional procedures. Complete guidance on the practical application of DRLs is presented in ICRP 135, which emphasizes that DRLs are measurable quantities for assessing and comparing doses for specific types of examinations at various facilities and are used as a tool to optimize medical exposure [26]. CTDIvol values obtained from the examination of 75 male patients and 75 female patients with different CTDIvol values. The maximum CTDIvol and DLP values obtained from the abdominal CT scan examination were 12.72 mGy and 701.80 mGy.cm, respectively. Then, the minimum CTDIvol and DLP values obtained were 4.54 mGy and 226.92 mGy.cm, respectively. The results of the 3rd quartile data processing for abdominal examination obtained CTDIvol and DLP values of 8.25 mGy and 413.85 mGy.cm. This value is a barrier between patients who receive lower and higher radiation doses to achieve better image quality. Thus, there are 75 % patients receiving normal doses and 25 % patients receiving high doses. Patients who receive high doses from DLP and CTDIvol values are the same patients, with male patients more dominant than women. Meanwhile, BAPETEN has set the DRL standard for CTDIvol and DLP values of abdominal examination without contrast at 17 mGy and 885 mGy.cm [26]. So that the CTDIvol and DLP values in this study do not exceed BAPETEN standards without reducing image quality. CTDIvol and DLP processing results are visualized in the form of graphs displayed in Figs. 4 and 5.

In Fig. 1, it can be seen that the 150 patients are sorted from the smallest to the largest section based on the CTDIvol value. The graph shows that the stomach receives a higher radiation dose compared to the gonads and bladder. This is because the stomach has a higher tissue weight factor than the gonads and bladder, and the stomach has a significant level of sensitivity to radiation. Damage to this organ can have significant consequences on health and digestive function [22].

Based on Fig. 2, it can be seen the distribution of the effective dose of each patient, where patients are sorted by CTDIvol. The average effective dose of male patients is 5.51 mSv, and the average effective dose of female patients is 5.12 mSv. This shows that male patients receive a higher effective dose compared to female patients. The highest effective dose value in this study was received by male patients at 10.53 mSv. Meanwhile, the typical effective dose standard based on ICRP 102 for abdominal CT scan examination is 10 mSv [27]. This shows that one patient to received an effective dose that exceeds the typical ICRP effective dose value. If the effective dose is high and the exposure condition is not suitable with the standard examination, and if the doctor thinks that the patient needs a particular procedure, then the doses for organs and sensitive tissues need to be estimated carefully. It also needs to combine with other factors, such as age, gender, and risk factor, to decide a precise treatment for the patient [28]. Regardless of how high or low the radiation dose is, it can cause changes in biological systems and increase the risk of cancer in patients.

Figure 3 is a graph of the stochastic effect, i.e., the relationship of effective dose to cancer risk. The results of the graph state that the greater the dose received by the patient, the bigger the chance of the patient's cancer risk. The average cancer risk received by female patients is 0.028 %, and the average cancer risk of male patients is 0.030 %. This shows that the cancer risk of male patients is greater than that of female patients. The estimated potential of getting cancer in patients is still in a small percentage. This is because the examination carried out by the patient is only 1 time and the voltage value used is the same for each examination, i.e., 120 kV.

Based on the CTDIvol and DLP DRL results in this study, which were shown in Figs. 4 and 5 from the calculation of the 3rd quartile, the value is used as a recommendation on diagnostic and interventional radiology examinations to achieve image quality that meets clinical objectives, so that the image of the entire examination provides all the necessary diagnostic information [29]. The 3rd quartile value indicates that 25 % of the dose is above the DRL or the patient is receiving a high dose. A better clinical judgment allows the use of higher doses. The ICRP states that 25 % of patients receiving high doses are not necessarily classified as unsafe, provided the medical exposure to the patient has been justified by an appropriate dose. For medical purposes, it is not appropriate to apply dose limits. However, patients receiving high doses should be evaluated, with modality-attached dose indicators and exposure factors should be properly validated. If procedures consistently cause the relevant DRLs to be exceeded, a local review should be conducted to ascertain whether protection has been adequately optimized so that there is a low enough radiation dose to achieve an appropriate medical image [29].

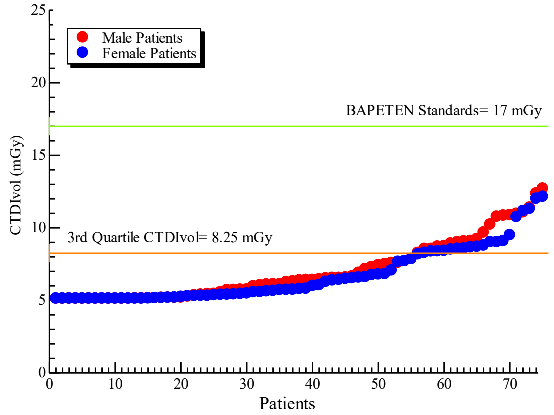

Fig. 4. Distribution of CTDIvol values based on gender.

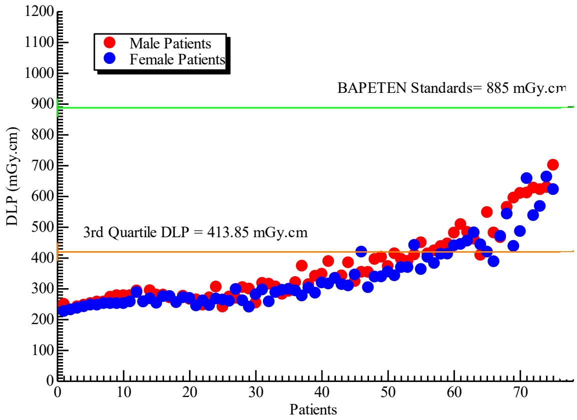

Fig. 5. DLP distribution of abdominal CT examination patients non-contrast for both sex.

CONCLUSION

It can be concluded that the organ dose in the abdomen is 0.82 mSv for the stomach, 0.54 mSv for the gonads, and 0.27 mSv for the bladder, showing that the stomach receives a higher dose. The estimated average effective dose received by male patients is 5.50 mSv, with a cancer risk of 0.030 %, and the effective dose received by female patients is 5.12 mSv, with a cancer risk of 0.028 %. Therefore, on average, men receive higher dose than women.

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AUTHOR CONTRIBUTION

S. S. Putri, 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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