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Estimation of Radiation Dose and Organs at Risk (OAR) on Abdominal CT-Scan Using Size-Specific Dose Estimates (SSDE) Method

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Abstract

A study has been carried out on the estimation of radiation dose and Organs at Risk (OAR) on abdominal CT-Scan examination using the SSDE method. The data used in this study were secondary data from medical records such as $CTDI_{Vol}$, DLP, and abdominal images of patients. This study aims to determine the size of SSDE, DE, and DE_{OAR} and to determine whether DE is still within tolerance limits to ensure the feasibility of using CT-Scans in these installations. The SSDE value is obtained by multiplying the converted d_{ef} value (f) and the $CTDI_{Vol}$, while the DE value is obtained by multiplying the DLP value and the conversion factor (k), finally, the DE_{OAR} value is obtained by multiplying the $CTDI_{Vol}$ and the organ/tissue weight factor. The results showed that the patient's average SSDE score was 12.04 ± 1.06 mGy, with a male SSDE value of 12.55 ± 1.30 mGy and a female SSDE value of 12.38 ± 2.47 mGy. While the average patient DE_{OAR} value obtained was 7.57 ± 0.72 mGy and the patient's average DE_{OAR} value for skin and bone surface was 0.09 ± 0.01 mGy and red bone marrow and large intestine was 1.06 ± 0.13 mGy. The DE value of this study is still below the tolerance value set by BAPETEN, which is less than 17.46 mGy.

Introduction

Radiation refers to the release of energy from an energy source in the form of heat, particles, or electromagnetic waves (photons). This energy emission is categorized into two main types: ionizing radiation and non-ionizing radiation. Ionizing radiation has the capability to cause an ionizing effect when it comes into contact with a substance, whereas non-ionizing radiation lacks the ability to do so [1]. Each time the process of ionization or excitation occurs, the radiation will lose some of its energy [2]. The International Commission on Radiological Protection (ICRP) classifies the impacts of ionizing radiation on the human body into two distinct categories: stochastic effects and deterministic effects [3].

The Radiology Installation serves as a medical support unit that utilizes sources of ionizing radiation to detect the presence of a disease by producing an anatomical image of the body, which is then displayed on a radiographic film [4]. There are several medical devices in radiology installations, one of which is a Computed Tomography Scan (CT-Scan) [5]. A CT-Scan uses the intensity of continuous radiation once it passes an object to create an image. [6]. Several types of CT-Scan examinations that are often carried out include examination of the head, chest cavity (Thorax), and abdominal cavity (Abdomen) [7].

The radiation used in CT-Scans is X-ray. X-rays are emitted electromagnetic waves that bear similarity to radio waves, heat, light, and ultraviolet light but with very short wavelengths [8]. X-ray radiation on a CT-Scan has a high energy. This radiation has the potential to create double-strand breaks in the DNA of the patient's cells, which, in certain instances, can result in the induction of cancer. Thus, it is crucial to ensure that patients who undertake CT-Sans are exposed to radiation doses that match the patient's immune system [9]. To reduce radiation exposure for patients undergoing CT-Scans, it's important to determine the radiation dose by employing the Computed Tomography Dose Index (CTDI) method during the scanning procedure. The resulting average CTDI value is referred to as $CTDI_{Vol}$, which serves as an indicator of output dose. Meanwhile, the total absorbed dose is represented by DLP [10]. Alongside the dose administered to the patient, medical personnel also need to pay attention to the risk to the Organs at Risk (OAR). On examination of the abdominal cavity, several organs that are sensitive to radiation are the spinal cord, kidneys, small intestine, heart, lungs, and liver. The Nuclear Energy Regulatory Agency (BAPETEN) has determined the dosage value provisions in the decision letter of the Head of BAPETEN Number: LT/STI/KN 01/P2STPFRZR1/077/2016 concerning Diagnostic Reference Level (DRL) values in examinations using a CT-Scan, namely for abdominal examinations a $CTDI_{Vol}$ of 20 mGy and a DLP of 1164 mGy.cm [11].

The high contribution of radiation originating from the use of CT-Scans raises concerns, so that many studies are focused on CT-Scan dose information. Several studies on CT-Scan doses that have been carried out include the Estimation of Patient Effective Radiation Dose Values from Asteion Multi 32 Slice CT-Scan Medical Image of the Abdomen section which shows the large difference in doses received by male patients and female patients [9]. Research on Estimating Effective Doses in Multi Slice Ct-scan Examination of the Head and Abdomen Based on ICRP 103 Recommendations shows that there is an effect of organ volume on the dose received by patients [12]. One method for estimating the radiation dose received by a patient is the Size-specific Dose Estimates (SSDE) method. SSDE is a new parameter that incorporates a patient size factor or conversion factor as a geometric function of patient size in its calculations. The conversion factor serves to translate $CTDI_{Vol}$ to patient dose at the center of the scan volume.

From the description above, it is necessary to calculate the patient's effective dose and the risk of OAR in order to minimize the negative effects of X-rays on CT-Scans. The aim of this study was to determine the estimated dose using the SSDE method and to determine whether the patient's effective dose was within the tolerance limit recommended by BAPETEN or not. As well as to determine the size of the OAR on an abdominal CT-Scan.

Theory

Size-Specific Dose Estimates (SSDE)

The SSDE, measured in mGy, serves as an estimate of the patient's radiation dose. It incorporates corrections that account for the patient's body size, utilizing linear dimensions derived from patient measurements or images. SSDE allows calculation of absorbed dose and effective dose received by patients to be more accurate. The SSDE value is obtained by multiplying the $CTDI_{Vol}$ value which has units of mGy with the patient thickness conversion factor *f*. SSDE is mathematically expressed by equation (1) below: [9].

$$SSDE = CTDI_{Vol} \times f \quad (1)$$

The *f* value is determined based on the patient's effective diameter (d_{ef}) acquired from the LAT (Lateral) and AP (anteriorposterior) calculations.

The effective diameter represents the patient diameter at a patient position along the z-axis (in the Craniocaudal dimension), assuming the patient has a circular cross-section. The following is an example of a circular section from the CT-Scan results:

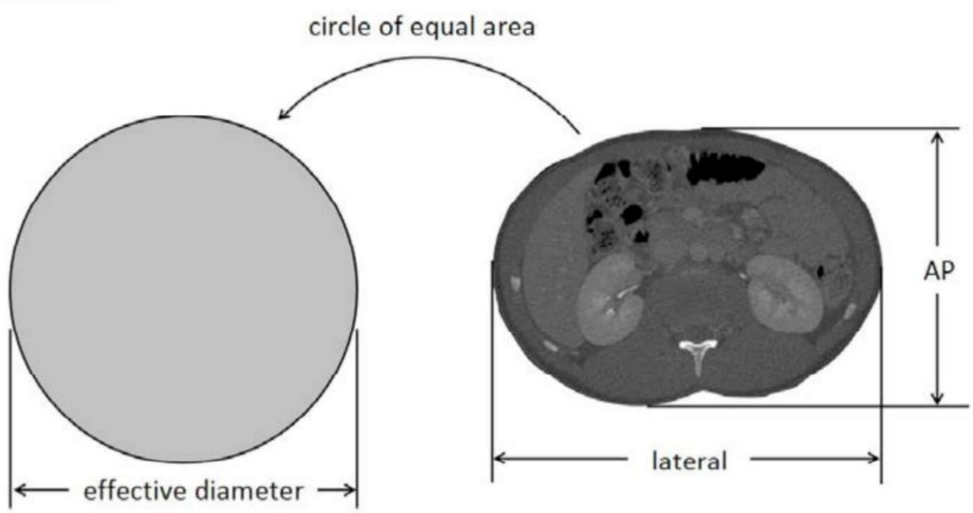

Figure 1. Effective diameter, Lateral (LAT), and Anteroposterior (AP) [13].

The LAT dimension represents the measurement from the side to side (left to right) of the scanned body part, whereas the AP dimension signifies the thickness of the patient's body part from the surface of the stomach to the surface of the back. The effective diameter is calculated using Equation (2) [13].

$$effective\ diameter\ (d_{ef}) = \sqrt{AP \times LAT} \quad (2)$$

Where d_{ef} is the effective diameter (cm), AP is anteroposterior (cm), and LAT is lateral (cm).

Effective Dose (DE)

The effective dose (DE) is the absorbed dose that factors the radiation quality and tissue sensitivity. Effective dose has units of mSv or mGy. For X-ray radiation, which is the type of radiation used in CT-Scans, 1 mSv equals 1 mGy [14]. The effective dose on a CT-Scan is acquired by multiplying the Dose Length Product (DLP) by the coefficient k. DLP represents the cumulative dose administered during the examination, with the coefficient 'k' being based on the patient's age and the specific body part subjected to the scan. Systematically expressed by equation (3) below: [15]

$$\mathrm{DE} = \mathrm{DLP} \times k \tag{3}$$

The coefficient k by age and body part of the scanned patient is shown in Table 1.

Tabel 1. The value of the coefficient k is based on the age and body part of the scanned patient [15].

Body Part	Coefficient k (mSv/mGy.cm) by age (year)				
	0	1	5	10	Adult
Head and Neck	0.013	0.0085	0.0057	0.0042	0.0031
Head	0.011	0.0067	0.0040	0.0032	0.0021
Neck	0.017	0.012	0.011	0.0079	0.0059
Chest	0.039	0.026	0.018	0.013	0.014
Abdomen dan pelvis	0.049	0.030	0.020	0.015	0.015
Torso	0.044	0.028	0.019	0.014	0.015

Apart from the effective dose to the body, the effective dose to the OAR also needs to be considered. Calculation of the effective dose to these organs can be determined by $\mathrm{CTDI_{Vol}}$ multiplied by $\mathrm{W_T}$. $\mathrm{W_T}$ is the weight factor for organs or tissues which have different values in each body tissue. As systematically stated in the equation (4).

$$\mathrm{DE_{OAR}} = \mathrm{CTDI_{Vol}} \times \mathrm{W_T} \tag{4}$$

With $\mathrm{DE_{OAR}}$ is the effective dose of the OAR (mGy), and $\mathrm{W_T}$ is a weight factor for an organ or tissue. $\mathrm{W_T}$ values are shown in Table 2.

Tabel 2. Tissue weight factor [16].

Tissue or organ type	$\mathrm{W_T}$
Red bone marrow	0.12
Colon	0.12
Lungs	0.12
Stomach	0.12
Breast	0.12
Other Organs	0.12
Gonad	0.08
Bladder	0.04
Esophagus	0.04
Liver	0.04
Thyroid gland	0.04
Bone surface	0.01
Brain	0.01
Salivary gland	0.01
Skin	0.01
Total	1.00

Abdomen

The abdomen or stomach is the part of the torso that lies between the thorax and pelvis. The abdominal contents consist of the digestive organs, liver and biliary system, pancreas, spleen, blood vessels, nerves and lymph nodes [17]. Abdominal organ projections can be used to predict which organs are likely to be injured. The projection of the location of the abdominal organs can be seen in Figure 2.

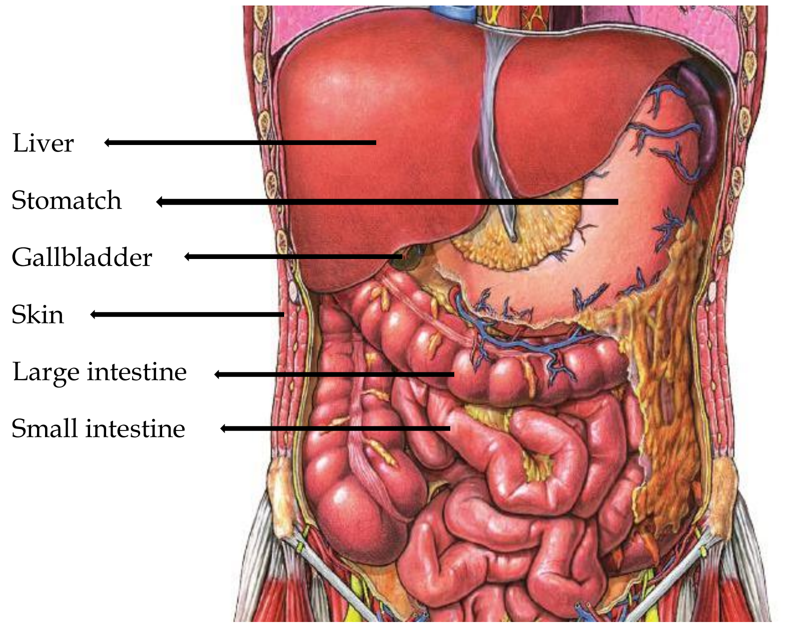

Figure 2. Organs within abdomen [18].

Experimental Method

The type of data used in this study is secondary data from medical records or CT-Scan archives. The data obtained were in the form of $CTDI_{Vol}$, DLP and abdominal images obtained from Bali Mandara General Hospital. Abdominal image data obtained from an abdominal CT-Scan is used to calculate the d_{ef}. The d_{ef} value obtained is adjusted to the d_{ef} data in AAPM report no 204 by interpolating using Equation (5) below:

$$y = y_1 + (x - x_1) \times \frac{(y_2 - y_1)}{(x_2 - x_1)} \quad (5)$$

In which y is the linear interpolation value, x is the independent variable, x_1, y_1 is the value of a function at one point and x_2, y_2 is the value of a function at another point.

The converted d_{ef} value and $CTDI_{Vol}$ are used to determine SSDE, while the DLP value is used to calculate DE. Then to calculate the average value and standard deviation, two methods are used, namely group data calculation and single data calculation.

The mean value and standard deviation of group data are shown in Equation (6) and (7):

$$\bar{x} = \frac{\sum_{i=1}^{n} f_i \, x_i}{n} \quad (6)$$

$$SD = \sqrt{\frac{\sum_{i=1}^{n} f_i\,(x_i - \bar{x})^2}{n}} \tag{7}$$

Where $\bar{x}$ is the mean value, SD is the standard deviation, x_i is the median for the i-th data range, f_i is the i-th number of data, and n is the number of all data.

The mean value and standard deviation of single data are shown in Equation (8) and (9):

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{8}$$

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}} \tag{9}$$

Where $\bar{x}$ is the mean value, SD is the standard deviation, xi is the i-th data value, and n is the number of all data.

Furthermore, the average value of DE obtained is compared and analyzed whether or not it is still in accordance with the DE issued by BAPETEN guidelines. In addition to the comparison, a statistical test was also carried out to find out whether the DE value corresponded to the DE value set by BAPETEN or not. The statistical test was carried out by one sample t-test using IBM SPSS Statistics 26 software. The test was carried out with a confidence level of 99% or a significance level (α) of 0.01 as follows:

$$H_0: \mu = \mu_0 \qquad H_1: \mu \neq \mu_0 \tag{10}$$

Where μ is the measured data and μ_0 is the value set by BAPETEN

The hypothesis taken is as follows:

H_0 : The DE value is the same as the one set by BAPETEN.

H_1 : The DE value is smaller than the one set by BAPETEN.

The basis for decision making is H_0 is rejected if: $t_{count} < -t_{table}$, $t_{count} > t_{table}$, or Sig.(2-tailed) value < α.

From these results, it can be seen that the patient's DE value on an abdominal CT-Scan at Bali Mandara General Hospital is in accordance with H_0 or H_1.

To obtain the completeness of the results of the study, the DE_{OAR} in the abdomen was also calculated. The DE_{OAR} calculation results are then tabulated and analyzed in the graph of the relationship between the patient's sex and the DE_{OAR} of each patient.

Result and Discussion

From the research that has been carried out, 30 patient data was obtained on abdominal CT-Scans at the Bali Mandara General Hospital as shown in Table 3.

Tabel 3. Research Data.

No	Patient Initials	Patient Data		Dose Description		Patient Images	
		Age (Year)	Sex (M/F)	CTDIvol (mGy)	DLP (mGy.cm)	AP (cm)	LAT (cm)
1	IMA	51	M	11.81	752.58	25.11	34.80
2	IMS	62	M	8.17	482.20	19.71	31.00
3	TOA	22	F	10.73	552.16	22.79	32.69
4	KRA	50	F	9.91	528.01	22.34	33.48
5	IKD	68	M	9.58	548.85	23.96	35.42
6	IND	48	M	8.83	510.12	20.55	30.85
7	NWS	37	F	9.41	518.55	19.60	32.48
8	INM	58	F	5.78	287.20	19.97	28.06
9	IGA	40	M	10.32	603.67	25.14	35.54
10	NPN	20	F	10.07	518.18	23.04	34.27
11	SST	29	M	10.15	575.74	21.48	31.81
12	PYS	31	M	11.97	723.60	27.54	35.14
13	MWS	58	M	11.97	708.04	24.49	35.87
14	IMG	60	M	9.82	604.66	26.37	33.88
15	IGM	63	F	4.79	236.29	13.83	24.13
16	IDK	58	M	11.06	688.62	23.90	35.10
17	IGK	78	M	6.60	333.85	20.18	27.59
18	IAS	30	F	12.63	685.85	23.37	33.97
19	AAP	58	F	7.93	418.84	20.07	30.75
20	NMO	59	M	8.17	444.60	18.50	30.30
21	IBN	32	M	8.50	471.49	23.51	30.54
22	IWS	53	M	9.58	537.23	24.54	32.93
23	INS	50	M	9.41	574.55	25.75	37.02
24	IBM	57	M	10.48	608.09	22.46	38.04
25	INR	61	M	8.83	508.35	24.56	32.74
26	IWA	59	M	7.51	427.83	19.06	31.17
27	IWM	62	M	8.50	451.09	23.81	32.29
28	ABP	41	M	7.51	401.91	21.34	31.33
29	IWR	44	M	9.16	522.32	22.67	34.01
30	SAP	31	F	7.51	375.62	22.80	34.03

Furthermore, calculations were carried out to obtain the SSDE value and DE value for each patient. Calculations were also carried out to obtain the average values of $CTDI_{Vol}$, DLP, d_{ef}, SSDE and DE which can be viewed in Table 4.

Tabel 4. Mean value and standard deviation $CTDI_{Vol}$, DLP, d_{ef}, SSDE dan DE.

$CTDI_{Vol}$ (mGy.cm)	DLP (mGy.cm)	d_{ef} (cm)	SSDE (mGy)	DE (mGy)
8.84 ± 1.07	499.19 ± 54.42	26.68 ± 1.51	12.04 ± 1.06	7.49 ± 0.82

To see the differences in the mean values of $CTDI_{Vol}$, DLP, d_{ef}, SSDE and DE in male and female patients, calculations were also carried out by looking at the sex of the patient. The mean value of $CTDI_{Vol}$, DLP, d_{ef}, SSDE and DE in male and female patients can be seen in Table 5.

Tabel 5. Mean values and standard deviations of $CTDI_{Vol}$, DLP, d_{ef}, SSDE and DE in male and female patients.

Sex	Mean Values				
	$CTDI_{Vol}$ (mGy.cm)	**DLP (mGy.cm)**	**d_{ef} (cm)**	**SSDE (mGy)**	**DE (mGy)**
Male	9.43 ± 1.46	546.64 ± 108.04	27.66 ± 2.30	12.55 ± 1.30	8.20 ± 1.62
Female	8.75 ± 2.34	457.86 ± 133.17	25.64 ± 3.02	12.38 ± 2.47	6.87 ± 2.00

From the calculation results, it can be seen in Table 4 that the patient's average SSDE value is 12.04 ± 1.06 mGy. In Table 5 it can be seen the difference in the SSDE value of male patients and female patients. The SSDE value of male patients was 12.55 ± 1.30 mGy and the SSDE value of female patients was 12.38 ± 2.47 mGy, these values indicated that the dose received by male patients was greater than the dose received by female patients. The results acquired aligned with the results of previous studies which indicated that the average SSDE value and effective dose in male patients were greater when compared to female patients [9]. The difference in SSDE values obtained by male patients and female patients occurs because the volume of male organs tends to be larger than the volume of female organs. From a study conducted by Sofiana in 2013 shows that the volume of male organs is larger than that of women. In Table 5 it can be seen that the d_{ef} of male patients was 27.66 ± 2.30 cm and the d_{ef} of female patients was 25.64 ± 3.02 cm. Thus, that it can be said that the diameter of male patients is larger than the diameter of female patients. The results obtained were the same as the results of a study conducted by Yuana in 2011 which showed that the diameter of male patients was on average larger than that of female patients. The $CTDI_{Vol}$ and DLP that patients receive are also influenced by organ volume, where the more the patient's organ volume increases, the greater the $CTDI_{Vol}$ and DLP values that patients receive. This is indicated by the $CTDI_{Vol}$ and DLP values of male patients greater than the $CTDI_{Vol}$ and DLP values of female patients. [10]

The mean value of DE in abdominal CT-Scan examination patients at Bali Mandara General Hospital was 7.49 ± 0.82 mGy, where this value is still below the value specified in the decision of the Head of BAPETEN No. Rek: LT/STI/KN01/P2STPFRZR1/077/2016 regarding the DRL value on examination using an abdominal CT-Scan which is less than 17.46 mGy, so that it can be said that the CT-Scan in the Radiology Installation of Bali Mandara General Hospital is still suitable for use for abdominal CT-Scan.

The results of the patient's DE calculations were then analyzed using a statistical test, namely the t test (one-sample test) using the IBM SPSS Statistics 26 application. The test of normality was carried out first before carrying out the one-sample test. The results of the test of normality and one-sample test can be seen in Figure 3 and Figure 4.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DE	.097	30	.200*	.981	30	.846

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Figure 2. The results of the patient DE's test of normality.

One-Sample Test

	Test Value = 17.46					
					99% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
DE	-28.175	29	.000	-9.66000	-10.6051	-8.7149

Figure 3. The results of the patient DE's one-sample test. The t_{table} value is obtained by adjusting the df results on the one sample test and the α used and the t_{table} is -2.46.

The results of the test of normality can be seen in Figure 2 which shows the data is normally distributed because the p-value (Sig.) > α is 0.846 > 0.01. Figure 3 shows the results of the patient DE's one-sample test. The basis for decision making is to compare the value of t_{table} with t_{count}. From the results of the analysis in Figure 3, the t_{count} for DE is -28.175, while the t_{table} value is -2.46. Because the value of $t_{count} < -t_{table}$, the decision obtained is that H_0 is rejected. So that the results of the t test analysis showed that the patient DE's was smaller than the BAPETEN decision DE.

Some of the OAR in the abdomen that will be calculated for the DE_{OAR} are; skin, bone surfaces, red bone marrow and large intestine. The DE_{OAR} calculation will be influenced by the W_T of each organ or tissue, where the W_T value of the skin and bone surface is 0.01 while the W_T value of red bone marrow and large intestine is 0.12. Then the DE_{OAR} value will be calculated as a mean value. The results of calculating the mean DE_{OAR} value can be seen in Table 6.

Table 6. Mean Value and standard deviation DE_{OAR}.

Skin (mGy)	Bone Surface (mGy)	Red Bone Marrow (mGy)	Large Intestine (mGy)
0.09 ± 0.01	0.09 ± 0.01	1.06 ± 0.13	1.06 ± 0.13

The DE_{OAR} calculation was also performed by looking at the sex of the patient. The mean value of DE_{OAR} in both male and female patients can be seen in Table 7.

Table 7. Mean Value and standard deviation DE_{OAR} on male and female patients.

Sex	DE_{OAR}			
	Skin (mGy)	**Bone Surface (mGy)**	**Red Bone Marrow (mGy)**	**Large Intestine (mGy)**
Male	0.10 ± 0.01	0.10 ± 0.01	1.13 ± 0.18	1.13 ± 0.18
Female	0.09 ± 0.02	0.09 ± 0.02	1.05 ± 0.28	1.05 ± 0.28

The graph between the sexes of the patients and the DE_{OAR} of each patient is shown in Figure 4.

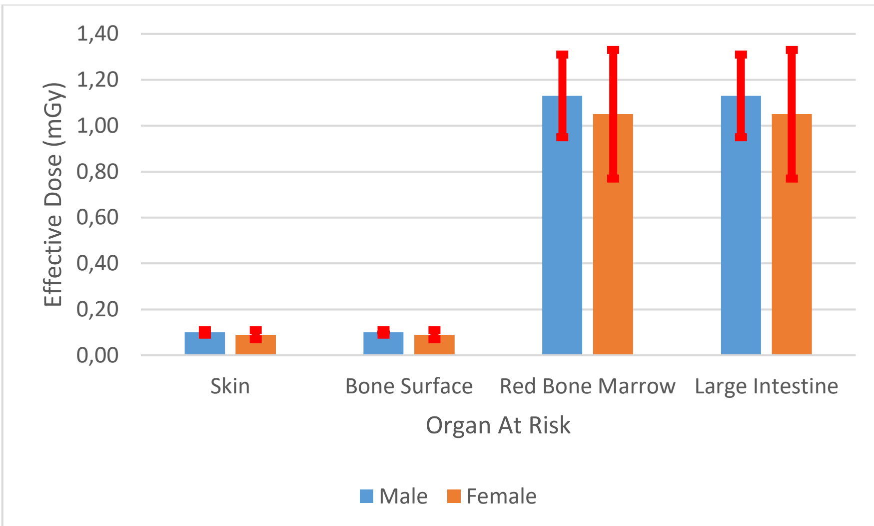

Figure 4. DE_{OAR} on the sexes of the patients.

The mean value of DE_{OAR} in patients who underwent an abdominal CT-Scan at Bali Mandara General Hospital, namely for the skin and bone surface, was 0.09 ± 0.01 mGy, while for red bone marrow and large intestine, it was 1.06 ± 0.13 mGy. The results of the analysis in Figure 4 show that the male DE_{OAR} value is greater than the female DE_{OAR} value, differences in DE_{OAR} in male patients and female patients can occur because in this study the radiation dose received by male patients was more than the radiation dose received by patients Woman. Thus, that it can be said that the greater the radiation dose received by the patient, the greater the patient's DE_{OAR} value. This is in accordance with the principle of radiation, namely the greater the radiation that an organ receives, the greater the risk factor that organ will receive.

Conclusion

The average dose of patients on an abdominal CT-Scan at Bali Mandara General Hospital using the SSDE method was 12.04 ± 1.06 mGy. Where the SSDE value of male patients was 12.55 ± 1.30 mGy while the SSDE value of female patients was 12.38 ± 2.47 mGy. The mean value of DE in patients who underwent an abdominal CT-Scan at Bali Mandara General Hospital was 7.57 ± 0.72 mGy and the mean value of DE_{OAR} in patients who underwent an abdominal CT-Scan for skin and bone surfaces was 0.09 ± 0.01 mGy, while for red bone marrow and large intestine it was 1.06 ± 0.13 mGy. In this study, the DE_{OAR} of male patients was greater than that of female patients, the difference in DE_{OAR} could occur because the radiation dose received by male patients was greater than the radiation dose received by female patients. DE and DE_{OAR} values are still below the tolerance value set by BAPETEN, which is less than 17.46 mGy.

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