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STUDY OF THE DOSE CURVE TO DETERMINE THE DOSE RECEIVED BY A PATIENT ON THE DIAGNOSTIC RADIOLOGY

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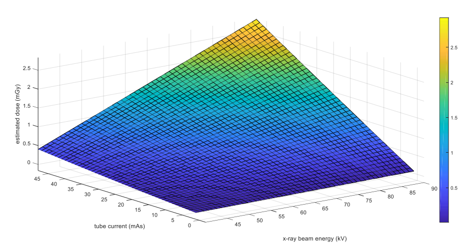
Graphical abstract



Abstract

A study of the dose curve to determine the dose received by a patient on the diagnostic radiology was carried out. One of the efforts to apply radiation dose optimization in diagnostic radiology is using the Diagnostic Reference Level (DRL), the dose value used as a reference for each radiological examination. The primary purpose of this study is to develop a method for determining the dose curve as a function of two variables: x-ray tube current and x-ray beam energy. Furthermore, the dose curve that has been developed can be used to estimate the value of the patient dose for each exposure factor arranged. In this study, the dose curve is determined using the polynomial model compiled using MATLAB software, and then validation is carried out using calibrated dosimeter. It shows that at a focus-to-detector distance (FDD) of 100 cm, the deviation factor is 4.89%. It meets the acceptance criteria determined, which is less than 5%. Furthermore, another validation result at FFD 50 cm shows that the average deviation value is 0.43%. In addition, the estimated dose still met the DRL criteria, where the estimated dose obtained for thorax AP and abdominal examinations are 0.26 mGy and 1.5 mGy, respectively. These values were still below the Indonesian Diagnostic Reference Level (IDRL) criteria determined by the Nuclear Energy Regulatory Agency of Indonesia (BAPETEN), which are 0.4 mGy and 10 mGy for thorax AP and abdominal, respectively.

Keywords: Dose Curve, Polynomial, Diagnostic Reference Level, Diagnostic Radiology, X-Ray Beam

1.0 INTRODUCTION

The use of ionizing radiation in human life has developed widely, especially in the health sector. One of the uses of ionizing radiation in the health sector is x-ray beam in diagnostic radiology. Besides providing considerable benefits, the use of x-ray beam also providing radiation effects for patients caused by the interaction of x-ray beam with human body cells [1]–[6]. Therefore, the use of x-ray beam must be carried out in accordance with regulations to guarantee patient safety [7]. In addition, applying the radiation protection principles in the use of x-ray beam in the health sector is a mandatory requirement that must be met [8]–[10]. In Indonesia, the use of an x-ray beam machine must have a permit from the Nuclear Energy Regulatory Agency of Indonesia (BAPETEN) and meet the As Low as Reasonably Achievable (ALARA) principle[7], [11]–[14]. One of the efforts to apply radiation dose optimization in diagnostic radiology is using the Diagnostic Reference Level (DRL) [15]–[19].

DRL is the dose value used as a reference for each radiological examination determined by Regulatory Body [19], [20]. DRL is determined from the distribution of dose indicator data that is easy to measure and directly relates to the patient's dose. In diagnostic radiology, DRL is determined based on the dose area product (DAP), incident air-kerma (INAK), or entrance surface dose (ESD). In a diagnostic radiology examination, if the obtained dose is above the DRL, it is necessary to carry out a special investigation to see if there is a radiation worker error, an x-ray beam machine discrepancy, or the procedure that needs to be updated. Therefore, that dose information becomes essential to know in diagnostic radiology [21].

In some x-ray beam machines, the patient dose cannot be directly obtained. Therefore, one method to obtain patient dose information is by using a dose curve. The dose curve for each x-ray beam machine has different characteristics. Based on TRS 437, the patient dose can be calculated by determining the curve that provide correlation between the radiation dose to the x-ray tube current (mGy/mAs) for several different x-ray beam energies [22], [23]. However, this method requires some equations for different x-ray beam energy. In addition, this method can only estimate the dose value for the x-ray beam energy discrete [24]–[26]. Therefore, it is necessary to develop a dose estimation method to estimate the dose value for the continuous x-ray beam energy and easy-to-use. In addition, this method should have a relatively small deviation between the estimations value and measurements value.

The primary purpose of this study is to develop a method for determining the dose curve as a function of two variables: x-ray tube current and x-ray beam energy. Furthermore, the dose curve that has been developed can be used to estimate the value for the continuous x-ray beam energy. The dose curve is determined using the polynomial model compiled using MATLAB software, and then validation is carried out using calibrated dosimeter. The stationary x-ray beam machine was used to obtain the preliminary data then the dose curve equation as a function of two variables was compiled using MATLAB software. The validation was performed by comparing the calculated value from the dose curve equation with the measured value to obtain the deviation factor. Based on the criteria established by the Nuclear Energy Regulatory Agency of Indonesia (BAPETEN), the maximum acceptable deviation is 10% [27]. However, the acceptance criteria were determined in this study, where the average deviation factor should be less than 5% for the conservative approach.

2.0 METHODOLOGY

2.1 Acceptance Test

An acceptance test was carried out to ensure that the used x-ray beam machine was in proper condition. This acceptance test uses several parameters: x-ray beam voltage accuracy, radiation dose linearity, and reproducibility. This test was performed by setting the X-ray meter detector 100 cm from the focus perpendicular to the beam collimator.

X-ray beam voltage accuracy test is carried out to ensure the suitability of the generator's voltage with the value set at the control panel. In this test, several voltage variations are used from 50 kV to 90 kV with an interval of 10 kV, and then the deviation value is calculated using Equation (1). A linearity test verifies the linearity between the x-ray tube current and the radiation dose output. Then, the linearity coefficient (CL) can be obtained from Equation (2). The reproducibility test is performed to ensure the stability of the x-ray beam machine by determining the coefficient of variation (CV). The coefficient of variation for the x-ray beam voltage, exposure time, and radiation dose is obtained from Equations (3) to (5), respectively [23], [27].

$$Error = \frac{Vp_{set} - Vp_{measured}}{Vp_{set}} \times 100\% \tag{1}$$

$$CL = \left| \frac{\left(\frac{D_i}{I_i}\right)_{max} - \left(\frac{D_i}{I_i}\right)_{min}}{\left(\frac{D_i}{I_i}\right)_{max} + \left(\frac{D_i}{I_i}\right)_{min}} \right| \tag{2}$$

$$CV_{vp} = \frac{\sigma_{Vp}}{\overline{Vp}} \tag{3}$$

$$CV_t = \frac{\sigma_t}{\bar{t}} \tag{4}$$

$$CV_D = \frac{\sigma_D}{\bar{D}} \tag{5}$$

where,

Vp_{set}	:	x-ray voltage set at control panel
$Vp_{measured}$	:	measured x-ray voltage
D_i	:	radiation dose output
I_i	:	x-ray tube current
σ_{Vp}	:	standard deviation of x-ray Voltage
σ_t	:	standard deviation of exposure time
σ_D	:	standard deviation dose output

2.2 Dose Curve Development

The dose curve was determined using multivariable polynomial equations [28], [29]. This polynomial equation was chosen because it has a simple solution form and suitable characteristics, where the dose curve $P(x)$ is arranged as a function of x-ray tube current (x_1) in mAs units and x-ray beam energy (x_2) in kV units. The general model of multivariate polynomial equations is expressed in Equation (6).

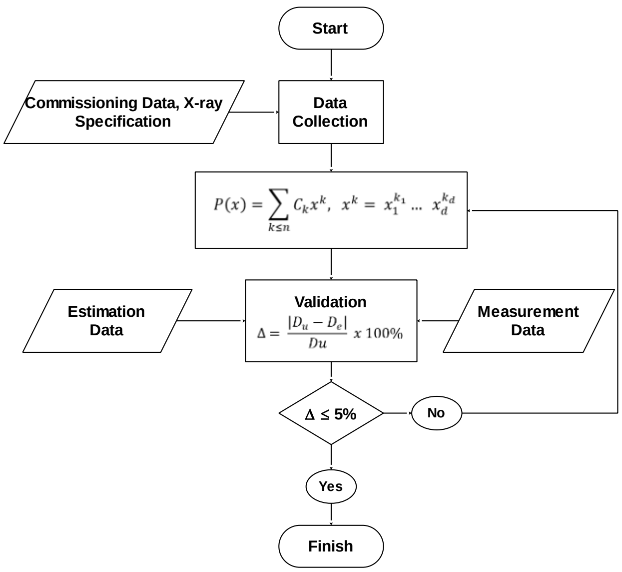


Figure 1 Flowchart to develop dose curve equation using multivariable polynomial model

$$P(x) = \sum_{k \le n} C_k x^k,\ x^k = x_1^{k_1} \dots x_d^{k_d} \qquad (6)$$

with coefficients $c_k \in R$ and $c_n \neq 0$.

The dose curve equation was formulated using MATLAB software using initial data obtained from the commissioning results of the x-ray beam machine. This study used a stationary x-ray beam machine with a maximum tube current and maximum x-ray beam energy is 550 mA and 135 kV, respectively. Then, the estimated dose was validated by comparing it to the measured dose from calibrated "Raysafe" dosimeter. The iteration process was carried out to obtain the optimum polynomial coefficient, where the deviation factor between the calculation and measurement results is less than 5%. The deviation factor is calculated using Equation (7). The steps to obtain an optimum dose curve equation are described in Figure 1.

$$\Delta = \frac{|D_u - D_e|}{D_u} \times 100\% \qquad (7)$$

Where Δ is deviation factor, D_u is measured dose, and D_e is estimated dose using dose curve equation that been developed.

3.0 RESULTS AND DISCUSSION

One of the optimization fulfillment in the use of ionizing radiation for medical purposes is the implementation of the DRL [19], where the radiation dose received by patient should not be higher than DRL value. In fact, for several x-ray beam machines, the radiation dose cannot be directly displayed. Therefore, the method to estimate the radiation dose received by the patient was developed to know the patient's dose directly. One of the methods that can be used is dose curve as a function of x-ray tube current and x-ray beam energy.

The first step to develop a dose curve model is by performing an acceptance test. This test was conducted to ensure the used x-ray beam machine was in good condition. The acceptance criteria for the voltage accuracy test is that the highest error should be less than 10%. Meanwhile, the linearity coefficient (CL) and the variation coefficient (CV) should be less than 0.1 and 0.05, respectively [23], [27]. From the test result, it was found that the highest error value for the voltage accuracy test is 1.3%. The radiation dose linearity value still meets the acceptance criteria, where the linearity coefficient is 0.0015. In addition, the reproducibility test results show that the variation coefficient (CV) for x-ray beam voltage, radiation dose, and exposure time is 0.002; 0.001; and 0.0005, respectively. These variation coefficient values still meet the acceptance criteria. Therefore, it shows that the x-ray beam machine used in this study performed well.

In the previous study, the radiation dose received by the patient can be estimated as a function of the x-ray tube current for the specific x-ray beam energy, as described in Figure 2. The radiation dose received by the patient during the diagnostic examination can be estimated by entering the x-ray tube current value used. However, this method requires several equations for different x-ray beam energy. In addition, this method can only estimate the dose value at a specific x-ray beam energy plotted [24]–[26]. Therefore, a dose estimation method is developed to estimate the dose value for the continuous x-ray beam energy.

The radiation dose estimation is performed by developing a multivariate polynomial equation with two independent variables among other x-ray tube current and x-ray beam energy. Then it can be used to calculate the dose received by the patient for all exposure factors that have been determined. This equation is arranged using initial data obtained from the commissioning results of the x-ray beam machine. This polynomial curve is arranged as shown in Equation 8:

$$P(x,y) = p0 + p10\,(x) + p01\,(y) + p11(x)(y) + p02(y^2) \qquad (8)$$

where $P(x,y)$ is estimated dose value, x is x-ray beam energy, and y is x-ray tube current.

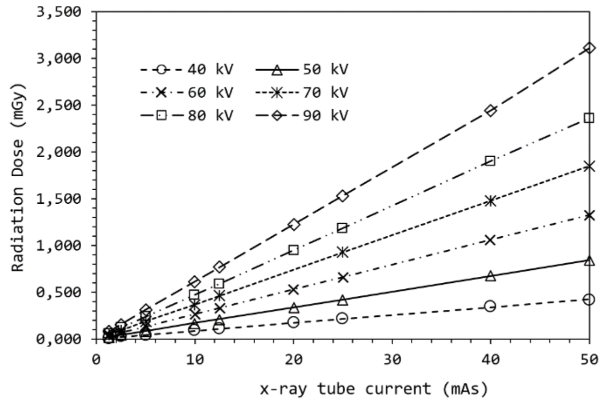


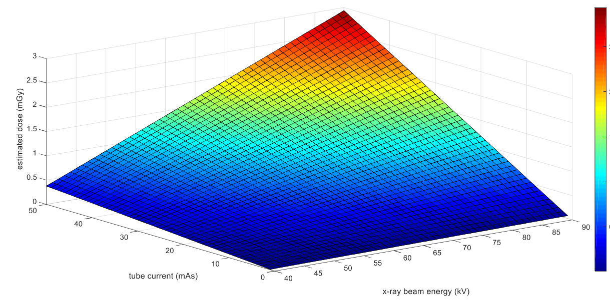
Figure 2 The dose curve for several x-ray beam energy

The radiation dose curves were arranged following the polynomial model as described in Equation 8. Two dose curve models, (a) and (b), are obtained from the iteration results for further validation. Validation is performed by comparing the estimated results from the dose curve equation with the measured value using a calibrated Raysafe x-ray meter. Furthermore, the deviation factor is calculated using equation (7). This study determines the acceptance criteria, where the deviation between the measurement and estimated results should be less than 5%. The constants of dose curves (a) and (b) are presented in Table 1 and Figure 3.

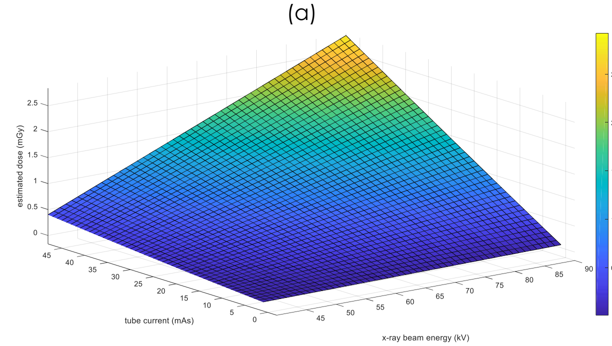
Table 1 The Dose Curve Equation Constant for Several Models

Constant	Model (a)	Model (b)
p0	0.000547	0.00188
p10	5.39 x 10^{-6}	- 9.00 x 10^{-8}
p01	- 0.0334	-0.03315
p11	0.001023	0.001
p02	492 x 10^{-7}	3.00 x 10^{-5}
Deviation (Δ) factor in %	5.24	4.89

Figure 3 shows the dose curve as a function of the x-ray tube current and x-ray beam energy, where the deviation factor for the dose curve (a) model is 5.24% and for the dose curve (b) model is less than 5% which is 4.89%. Therefore, the dose curve (b) model meets the determined acceptance criteria. Meanwhile, the dose curve (a) model does not meet this criterion. The comparison between the estimated dose from (a) and (b) models with the measured data is depicted in Figure 4. It shows that the (b) model is closer to the measured data than the (a) model.



(a)



(b)

Figure 3 The dose curve: (a) and (b) model

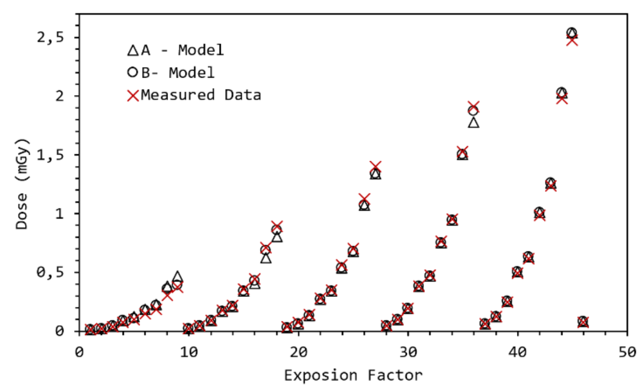


Figure 4 Comparison between (a) and (b) dose curve model with the measured data

Another validation step is also carried out in this study, which is validating the estimation results for different measurement distances by applying the inverse square law. Furthermore, (b) model is validated using the measurement results for focus to detector distance (FFD) of 50 cm, as shown in Table 2. The deviation factor for FFD 50 cm is 0.432 %. This result shows that this dose curve model can estimate the dose value at different FFD where the deviation factor is less than 5%.

Table 2 The Dose Curve Equation Constant for Several Models

Energy (kV)	Current (mAs)	Estimated Dose (mGy)	Measured Dose (mGy)	Deviation Factor (%)
40.00	1.25	0.045	0.044	2.170
40.00	2.50	0.0889	0.089	0.079
40.00	5.00	0.178	0.181	1.570
40.00	10.00	0.355	0.355	0.103
40.00	12.50	0.444	0.444	0.051
40.00	20.00	0.710	0.709	0.093
40.00	25.00	0.887	0.886	0.124
40.00	40.00	1.420	1.420	0.185
40.00	50.00	1.770	1.786	0.902
50.00	1.25	0.088	0.087	0.723
50.00	2.50	0.176	0.177	0.559
50.00	5.00	0.351	0.351	0.023
50.00	10.00	0.702	0.700	0.411
50.00	12.50	0.878	0.878	0.038
50.00	20.00	1.400	1.407	0.237
50.00	25.00	1.750	1.760	0.280
50.00	40.00	2.810	2.800	0.191
50.00	50.00	3.510	3.507	0.045
Average deviation factor				0.432

The estimated dose was also compared with the diagnostic reference level (DRL) value determined for specific examinations. For the thorax AP examination and the abdominal examination, the DRL values are 0.4 mGy and 2.0 mGy, respectively [19]. For the thorax AP examination, the x-ray tube current and x-ray beam energy used are 10 mAs and 70 kV, respectively. The estimated dose obtained is 0.29 mGy. Furthermore, the x-ray tube current and x-ray beam energy used for abdominal examination are 25 mAs and 85 kV, respectively. The estimated dose obtained is 1.50 mGy. These results show that the estimated dose from the developed dose curve model still meets the DRL determined by the Nuclear Energy Regulatory Agency of Indonesia (BAPETEN).

4.0 CONCLUSION

The dose curve was developed as a function of the x-ray tube current and x-ray beam energy. Based on the validation results shows that the deviation factor obtained is 4.89%. It meets the acceptance criteria, which is less than 5%. Another validation step is to compare the estimated dose with the measured dose at FDD 50 cm, where the deviation factor obtained is 0.432%. These results indicate that the dose curve can be used to estimate the dose value for various FFD. Furthermore, the estimated dose also still meets the Indonesian-diagnostic reference level (IDRL) value issued by the Nuclear Energy Regulatory Agency of Indonesia (BAPETEN). The estimated dose for the thorax AP and abdominal examination is 0.29 mGy and 1.5 mGy, respectively. These estimated doses are still below the IDRL for the thorax AP and abdominal examination, which are 0.4 mGy and 10 mGy, respectively.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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