International Journal of Health Sciences

Available online at www.sciencescholar.us
Vol. 7 No. 3, December 2023, pages: 147-153
e-ISSN: 2550-696X, p-ISSN: 2550-6978
https://doi.org/10.53730/ijhs.v7n3.14645

Application of Anode Heel Effect (AHE) with Stepwedge and Variation of X-Ray Tube Voltage to Contrast to Noise Ratio (CNR) in Computed Radiography (CR)

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Manuscript submitted: 27 August 2023, Manuscript revised: 09 October 2023, Accepted for publication: 18 November 2023

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Keywords

AHE;
CNR;
computed radiography (CR);
stepwedge;
X-ray tube voltage;

Abstract

A study has been carried out on the application of anode heel effect (AHE) with stepwedge to variations in X-ray tube voltage in contrast to noise ratio (CNR) on computed radiography (CR) images. Stepwedge used with 21 steps with the addition of a thickness of 1.5 mm each step. X-ray tube voltage variations are 40kV, 50 kV, 60 kV, 70 kV, 80 kV, and 90 kV. Analysis of the variation of the X-ray tube voltage on the CNR value was determined using IMB SPSS Statistics 26 with a simple regression test. The results of these tests indicate that the variation of the X-ray tube voltage affects the CNR value, where the greater the variation of the X-ray tube voltage, the lower the CNR value. The CNR value at a thickness of 27.0 mm is the optimal CNR value of 71.113.

Contents

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1 Introduction

X-rays in various fields have been widely applied, one of which is in the medical field. The quality of X-rays is the ability of X-rays to be measured by their penetrating power to objects they pass through (Sudin et al., 2015). The intensity of X-rays emitted from the anode has different strengths (Carlton & Adler, 1992). The difference in the X-ray intensity distribution is caused by the tilt angle formed by the anode in the diode tube called the anode heel effect (Carlton & Adler, 1992).

Anode Heel Effect (AHE) is defined as a form of uneven distribution of X-ray intensity from the anode to the cathode side caused by the slope of the anode surface so that the X-ray intensity towards the anode is less than the X-ray intensity going towards the anode (Mraity et al., 2017; Miles et al., 2023). Cathode direction (Kenneth, 2014). Therefore, the position of the object to be given X-rays is very important to get an even intensity of X-rays (Alfiati, 2013). At the time of irradiation such as the body parts, namely the pedis (leg bones) and femur (thigh bones) which have different thicknesses, the object with the thickest part should be placed in the cathode direction while the thinnest part should be placed in the anode direction (Bourne, 2010).

Image quality can be seen based on the density, contrast, sharpness, and detail of the resulting image. The better the image quality, the easier it will be to diagnose a disease. With the digitization of images using computed radiography (CR), image quality can be measured through signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) (Dewi et al, 2022; Allen et al., 2013; Taylor, 2015). SNR describes the level of difference between the measured signal and the noise which is also included in the measurement results. The larger the SNR value, the easier the signal and noise to distinguish. The SNR value on the application of heel effect anodes with stepwedge images has a significant and very strong influence on CR (Ratini et al., 2020). CNR is a measure of how far the signal can be distinguished from the background. The greater the CNR value, the more easily the signal will be distinguished from the background (Louk & Suparta, 2014).

The process of image formation is also influenced by the exposure factor. X-ray tube voltage (kV) is one of the exposure factors. The greater the voltage of the X-ray tube used, the greater the penetrating power obtained (Litasova et al., 2018). Variations in X-ray tube voltage can affect the resulting intensity. X-ray tube voltages commonly used for radiodiagnostics range from 30 kV to 150 kVp. At voltages below 70 kV emit bremsstrahlung X-ray radiation (100%) while at voltages above 70 kV emit bremsstrahlung X-ray radiation (85%) and characteristic X-rays (15%) (Fauber, 2012).

The irradiation process using X-rays to produce digital images must pay attention to the voltage of the X-ray tube used, to be able to produce optimal digital images (Satwika et al., 2021). The X-ray tube voltage is too high or too low, so the resulting image cannot show the organs of the body properly. In describing the organs of the body, a digital image with the appropriate density and contrast is needed. The contrast in digital images is indicated by the CNR value (Paul et al., 2011; Funama et al., 2013). Based on this background, the authors are interested in conducting research with the title: "Application of Anode Heel Effect (AHE) with Stepwedge and Variation of X-Ray Tube Voltage on Contrast to Noise Ratio (CNR) in Computed Radiography (CR)".

2 Materials and Methods

This research was conducted at the ATRO Radiodiagnostic Laboratory in Bali. Tools The research used in this research is an X-ray machine, CR, Imaging Plate (IP), CR scanner, 21-step stepwedge with an additional 1.5 mm thickness for each step, and software program RadiAnt DICOM VIEWER 2020.1 (64 bit). Before conducting the research, the X-ray machine was turned on and a warm-up procedure was carried out with the collimator facing the examination table (Afifi et al., 2020; Campillo-Rivera et al., 2021). The stepwedge is positioned in the middle of the CR cassette by adjusting the collimation to the size of the stepwedge, where the thickest part is placed in the cathode direction and the thinnest part is placed in the anode direction for AHE application (Dahlan, 2011). Central ray or the direction of the rays perpendicular to the middle of the step wedge. The collimator is set with an FFD of 100 cm. The exposure factor is regulated by an X-ray tube voltage

(kV) of 40 kV, time of 0.05 seconds and current of 100 mA. Expose and process image reader on CR. The next step is carried out on other voltage variations, namely 50 kV, 60 kV, 70 kV, 80 kV, and 90 kV. From the resulting image, the values of I_s, I_b, and σ_b are read. The reading of the value in the Region of Interest (ROI) is carried out with 3 repetitions as shown in Figure 1.

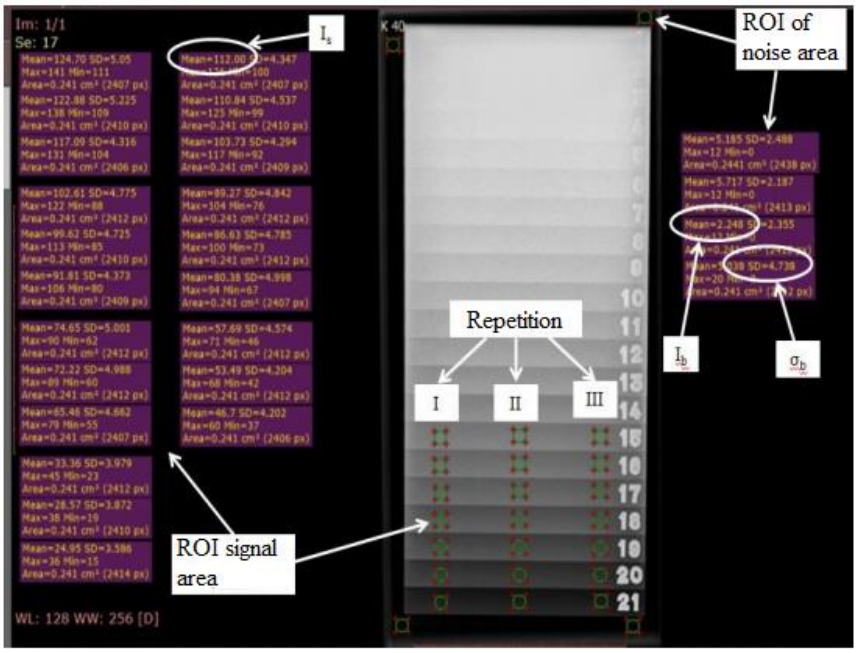

Figure 1. The process of reading the values of I_s, I_b, and σ_b

Analysis of the effect of variations in X-ray tube voltage on the CNR value can be determined using IMB SPSS Statistics 26 with a simple regression test (Wibowo et al., 2016).

3 Results and Discussions

From the image, the values of Is Ib and b are read, at each step with a total of 21 steps using an ROI area of 0.241 cm2. The calculation determines the CNR value using the following formula (Louk & Suparta, 2014):

$$CNR = \frac{I_s - I_b}{\sigma_b}$$

Where I_s is the average value of the signal, I_b is the average value of the signal from the noise area (background), and σ_b is the standard deviation value of the noise area. Furthermore, the calculation is carried out to obtain the CNR value with variations in the voltage of the X-ray tube: 40 kV, 50 kV, 60 kV, 70 kV, 80 kV, and 90 kV. The calculation results are shown in Table 1 below. From the results of a simple regression test, the correlation coefficient (R) is 0.967 and the coefficient of determination (R^2) is 0.935, meaning that variations in the X-ray tube voltage will affect the CNR value of 93.5%. Furthermore, the regression equation y = 70.864 – 0.613x with y as the CNR value, and x as the X-ray tube voltage. The regression coefficient is negative, meaning that the greater the variation of the X-ray tube voltage, the smaller the CNR value, this is also shown by the graph in Figure 2.

Table 1
Result of calculation of CNR value

Step	Thickness (mm)	CNR					
		40 kV	50 kV	60 kV	70 kV	80 kV	90 kV
1	31,5	67,959	53,291	54,661	46,216	34,883	28,092
2	30,0	70,860	51,027	50,434	43,548	32,201	26,263
3	28,5	71,006	49,919	48,728	42,039	31,056	25,217
4	27,0	71,113	48,974	47,552	41,057	30,360	24,493
5	25,5	70,246	47,667	46,230	39,735	29,434	23,829
6	24,0	68,740	46,498	44,871	38,159	28,143	22,821
7	22,5	67,318	45,219	43,059	36,821	27,007	21,693
8	21,0	65,485	43,596	40,916	35,507	25,930	20,745
9	19,5	63,300	41,320	39,159	33,774	24,813	19,862
10	18,0	60,050	39,066	37,324	31,543	23,086	18,631
11	16,5	56,728	36,848	35,116	29,770	21,516	17,253
12	15,0	52,868	34,769	32,575	28,128	20,313	16,240
13	13,5	48,996	31,932	30,458	26,384	19,137	15,394
14	12,0	44,238	29,163	28,177	24,270	17,801	14,442
15	10,5	39,772	27,338	26,486	22,235	16,046	13,164
16	9,0	35,455	25,358	23,988	20,508	14,705	11,996
17	7,5	31,770	23,628	21,794	18,831	13,512	11,008
18	6,0	27,491	21,132	19,569	16,551	12,310	9,892
19	4,5	22,512	18,143	16,377	13,512	9,883	8,173
20	3,0	16,343	14,688	12,612	9,744	7,249	5,815
21	1,5	8,298	9,267	6,030	4,912	3,351	2,817
Average		50,502	35,183	33,625	28,726	21,083	17,040

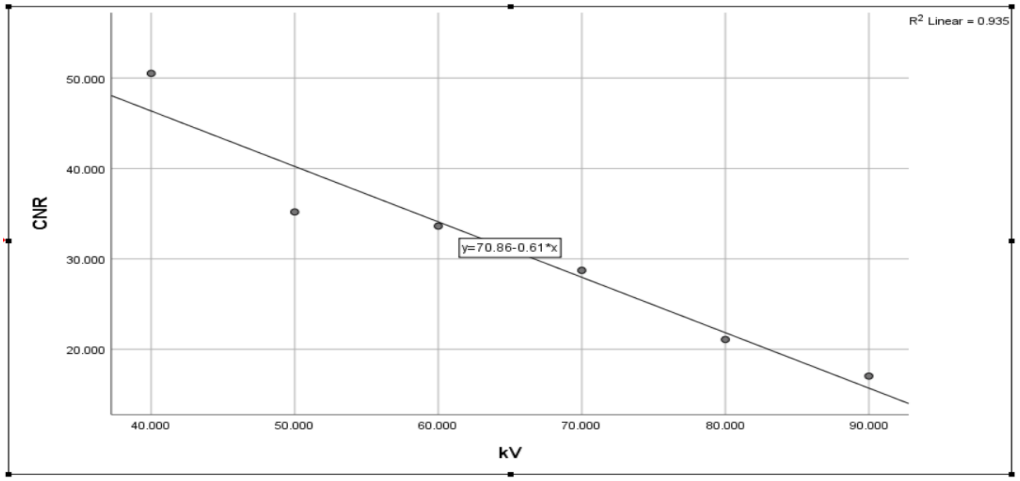

Figure 2. Graph of X-ray tube voltage variation (x) with CNR (y) value

Based on Table 1, then it is poured in a graph of the variation of the thickness of the stepwedge against the CNR value shown in Figure 3.

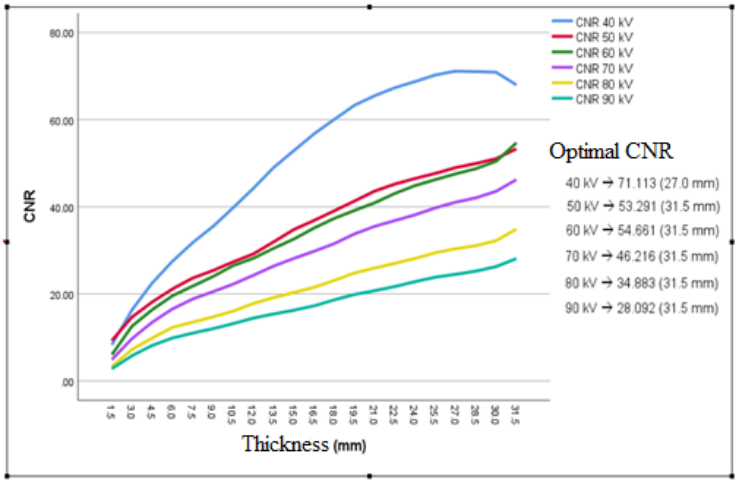

Figure 3. Graph of the relationship between variations in the thickness of the stepwedge with the CNR value for each X-ray tube voltage

Figure 3 shows that the greater the thickness of the stepwedge, the greater the CNR value. Then also shows the maximum CNR value of each X-ray tube voltage. The CNR value at 40 kV X-ray tube voltage increased from 1.5 mm thickness to a peak of 27.0 mm thickness. However, the CNR value decreased at 28.5 mm thickness. The CNR value at a thickness of 27.0 mm is the optimal CNR value of 71.113. At X-ray tube voltages of 50 kV, 60 kV, 70 kV, 80 kV, and 90 kV, the CNR value increased from 1.5 mm to 31.5 mm thickness and tended to continue to increase if thickness variations were added. The greater the voltage of the X-ray tube used causes an increase in the value of CNR. However, the stepwedge used is limited to a maximum thickness of 31.5 mm, so the optimal CNR value has not been obtained at this voltage (Gu et al., 2006; Pickering et al., 2015).

4 Conclusion

From the results of the research that has been done, it can be concluded that: variations in X-ray tube voltage affect the CNR value, where the greater the X-ray tube voltage variation, the CNR value will be smaller. The CNR value at a thickness of 27.0 mm is the optimal CNR value of 71.113.

Acknowledgements
The author expresses high gratitude for funding support on this research from the DIPA PNBP Universitas Udayana for the 2022 Fiscal Year.

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