Evaluation of Image Quality Using Step Wedge and Parameters of Tube Current and Exposure Time at Constant Tube Voltage

Salihu A. Yusuf[1*]; Abdulmumini K. Yusuf[2]; Halilu, S. Daniel[3]

[1,2,3] Department of Radiology, Abubakar Tafawa Balewa University Teaching Hospital (ATBUTH), Bauchi, Nigeria

*Corresponding Author: Salihu A. Yusuf

Publication Date: 2026/01/20

Abstract: This study investigates how tube current (mA) and exposure time (s) influence radiographic image quality, using a three-step aluminum step wedge at a constant tube voltage of 60 kV. We measured radiographic densities across varying exposure parameters to evaluate contrast and resolution. Our findings show that increasing tube current and exposure time improves image density and contrast. However, excessive exposure can lead to saturation. We observed optimal image quality at mAs values between 10 and 15.

Keywords: *Step Wedge, Image Quality, Optical Density, Tube Current, Exposure Time, mAs.*

How to Cite: Salihu A. Yusuf; Abdulmumini K. Yusuf; Halilu, S. Daniel (2026) Evaluation of Image Quality Using Step Wedge and Parameters of Tube Current and Exposure Time at Constant Tube Voltage. *International Journal of Innovative Science and Research Technology*, 11(1), 1089-1093. https://doi.org/10.38124/ijisrt/26jan081

I. INTRODUCTION

Image quality in radiographic imaging is fundamentally influenced by exposure parameters such as tube voltage (kV), tube current (mA), and exposure time (s). Among these, tube current and time determine the quantity of X-ray photons reaching the image receptor, directly affecting optical density (Bushong, 2020). The product of mA and time, known as milliampere-seconds (mAs), is a primary factor in determining radiographic density (Seeram, 2019).

While much research has focused on the role of tube voltage in controlling image contrast, fewer studies have investigated the influence of tube current and exposure time under constant voltage conditions. Step wedges, which simulate varying tissue thickness, are widely recognized as practical tools for image quality evaluation and quality assurance in radiology departments (Martin & Sutton, 2015).

This study explores the impact of varying tube current and exposure time at a fixed tube voltage of 60 kV, using a three-step aluminum wedge to simulate soft tissue variation. We conducted this study to guide exposure parameter optimization in radiographic procedures at Abubakar Tafawa Balewa University Teaching Hospital (ATBUTH), a resource-limited clinical setting in Northeast Nigeria.

II. MATERIALS AND METHODS

- *Equipment and Setup*

Our experimental setup utilized a standard general-purpose X-ray machine with the tube voltage fixed at 60 kV. We used a three-step aluminum step wedge (thicknesses: 1 mm, 2 mm, and 3 mm) to evaluate image quality variation. A standard radiographic film and a densitometer were employed to measure optical densities across the wedge. The films were developed under standard conditions, which included using an automatic film processor maintained at 34°C with a total processing time of 90 seconds.

➢ *Exposure Conditions*

We made ten exposures by varying tube current and exposure time, while maintaining a constant 60 kV. The resulting mAs values ranged from 2.5 to 20. Table 1 details the specific exposure combinations used.

Table 1: Exposure Parameters and Resulting mAs Values at 60 kV

Exposure	Tube Current (mA)	Exposure Time (s)	mAs
1	50	0.05	2.5
2	50	0.10	5
3	100	0.05	5
4	100	0.10	10
5	150	0.05	7.5
6	150	0.10	15
7	200	0.05	10
8	200	0.10	20
9	100	0.15	15
10	100	0.20	20

Note: All exposures were performed at a constant tube voltage of 60 kV.

➢ *Optical Density Measurements*

After exposure, the films were developed under the standard conditions mentioned above. Then the optical densities for each step of the wedge were measured using a densitometer (Victoreen 07-424 Densitometer). Table 2 presents the measured values, corresponding to each exposure setting.

Table 2: Optical Density Measurements for Each Step of the Aluminum Wedge Across Varying Exposures

Exposure	Step 1 Density (1 mm Al)	Step 2 Density (2 mm Al)	Step 3 Density (3 mm Al)
1	0.40	0.28	0.15
2	0.72	0.54	0.30
3	0.76	0.55	0.31
4	1.10	0.83	0.50
5	0.98	0.72	0.44
6	1.42	1.08	0.64
7	1.15	0.89	0.54
8	1.82	1.41	0.80
9	1.44	1.12	0.65
10	1.85	1.43	0.81

Optical densities represent the amount of light absorbed by the film at each step thickness of the aluminum wedge.

III. RESULTS

A graphical representation of the optical densities against mAs values for each step of the wedge reveals a clear linear trend, as depicted in Figure 1. As shown in Table 2, Step 1 (1 mm aluminum) consistently demonstrated the highest density response, suggesting that thinner structures are more susceptible to saturation at high exposure levels. In contrast, Step 3 (3 mm aluminum), which simulates denser tissue, had the lowest optical densities but responded steadily to increasing mAs without reaching saturation within the tested range.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26jan081

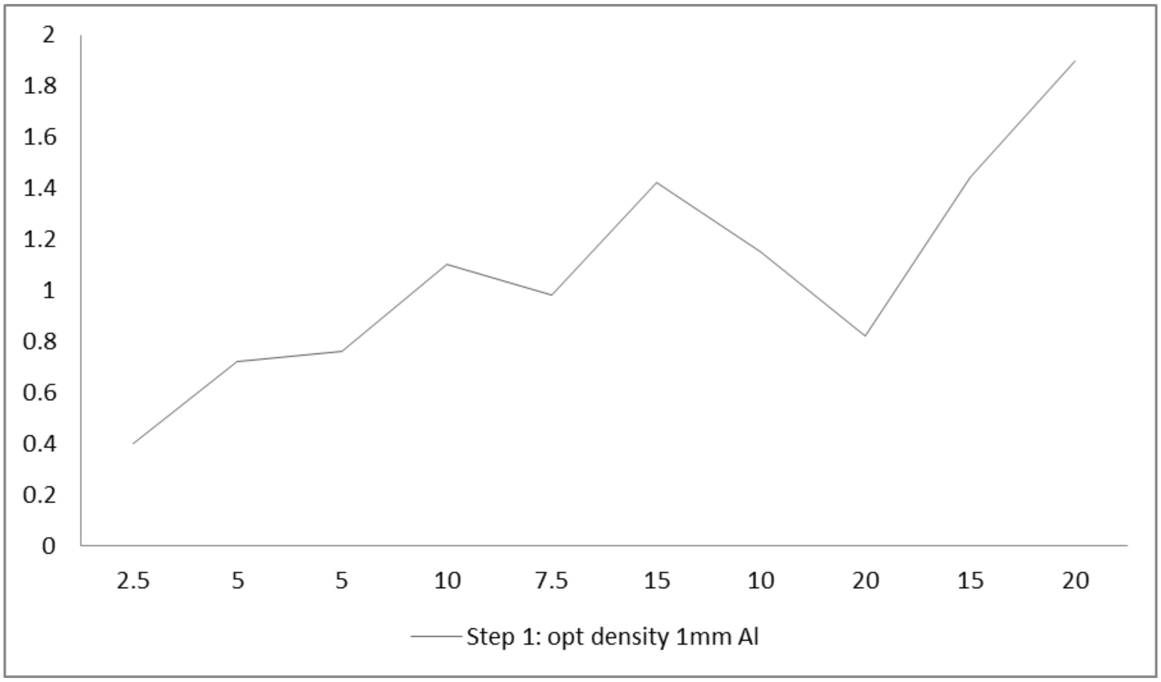

Fig 1: Relationship Between Optical Density and mAs for Step 1 (1 mm) of the Step Wedge.

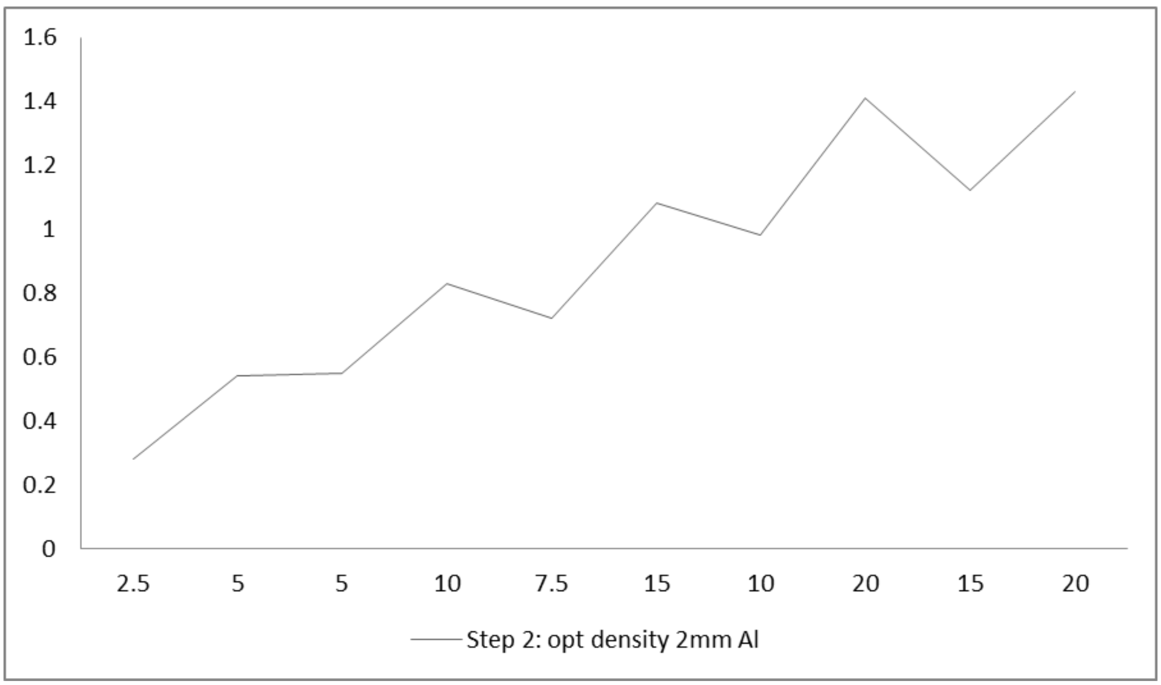

Fig 2: Relationship Between Optical Density and mAs for Step 2 (2 mm) of the Step Wedge.

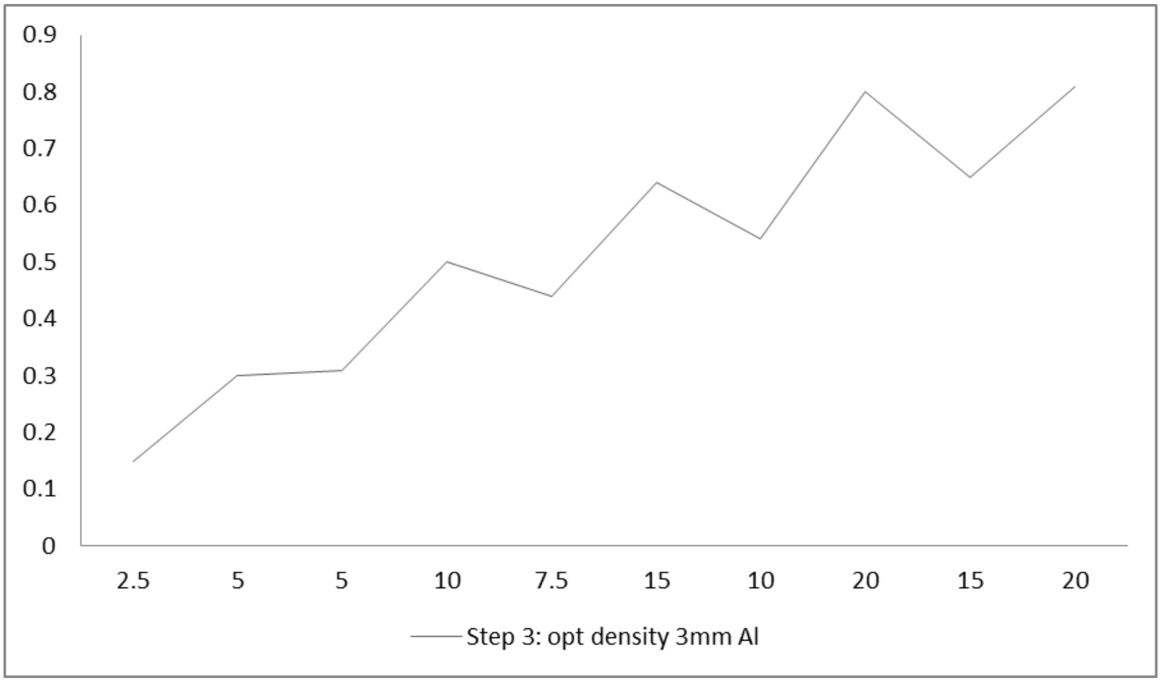

Fig 3: Relationship Between Optical Density and mAs for Step 3 (3 mm) of the Step Wedge.

Contrast resolution, evaluated by the difference in optical density between adjacent wedge steps (e.g., Step 1 vs. Step 2, Step 2 vs. Step 3, as seen in Table 2), generally increased with mAs up to 15. For instance, the difference between Step 1 and Step 2 densities at 5 mAs (Exposure 2) was 0.18 (0.72-0.54), whereas at 15 mAs (Exposure 6) it was 0.34 (1.42-1.08). Beyond 15 mAs, gains in contrast became marginal, and overexposure was evident at higher mAs values, particularly for the thinner Step 1, where the density plateaued.

IV. DISCUSSION

Our results affirm that radiographic image density increases with mAs at constant kV, due to the greater number of photons reaching the film (Seeram, 2019; Bushong, 2020). The quantitative data presented in Table 2 clearly illustrates this relationship, with higher mAs values consistently yielding higher optical densities across all three steps of the wedge. The use of a step wedge was instrumental in visualizing density differences across varying thicknesses, effectively simulating real anatomical variability in a controlled environment.

The improved contrast observed between 5 and 15 mAs (as derived from the density differences in Table 2) suggests that this range is optimal for general imaging at 60 kV in similar clinical conditions. At 20 mAs, specifically for Step 1 (1 mm Al), the optical density reached 1.85, indicating saturation. This demonstrates that thinner body parts may be overexposed at such levels, potentially reducing their diagnostic value due to a loss of differentiation (Martin & Sutton, 2015). This saturation effect is evident in the diminishing returns of density increase at higher mAs for Step 1, compared to the more linear increase for the thicker steps.

These findings are consistent with quality assurance standards that recommend regular step wedge analysis for system calibration and exposure optimization (IAEA, 2014). The detailed data in Table 1 and Table 2 provide a practical basis for establishing such protocols in clinical settings like ATBUTH.

Limitations: This study was conducted at a single tube voltage (60 kV) and utilized conventional radiographic film. Future research should explore the effects across a wider range of kV settings and investigate the response of digital detectors, which have different characteristic curves and wider dynamic ranges.

V. CONCLUSION

This study demonstrates that varying tube current and exposure time at a constant voltage significantly influences radiographic image quality. We found that the optimal range for achieving diagnostic density and contrast without overexposure was between 10 and 15 mAs at 60 kV. The use of a step wedge proved to be a valuable tool for conducting this analysis and is essential for ongoing image quality assurance and exposure standardization in radiographic practice.

RECOMMENDATIONS

Radiologic technologists should aim to maintain exposures between 10–15 mAs at 60 kV for standard imaging protocols, particularly for areas of the body comparable to the aluminum thicknesses tested.

Step wedge analysis should be incorporated into routine quality assurance procedures within radiology departments to ensure consistent image quality and equipment calibration.

Further research involving digital detectors and variable kV settings is recommended to provide a more comprehensive understanding of exposure parameter optimization across different imaging modalities and clinical scenarios.

ACKNOWLEDGMENT

The authors express sincere gratitude to the Radiology Department of Abubakar Tafawa Balewa University Teaching Hospital (ATBUTH) for providing the equipment and resources for this study.

- *Conflict of Interest*

The authors declare no conflict of interest regarding the publication of this paper.

REFERENCES

[1]. Bushong, S. C. (2020). Radiologic Science for Technologists: Physics, Biology, and Protection (11th ed.). Elsevier.
[2]. Chesney, D. N., & Chesney, M. (2019). Radiographic imaging: A guide for producing quality radiographs. Springer.
[3]. Fauber, T. L. (2020). Radiographic imaging and exposure (6th ed.). Elsevier.
[4]. IAEA. (2014). Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. Vienna: International Atomic Energy Agency.
[5]. International Atomic Energy Agency. (2014). Radiation protection and safety of radiation sources: International basic safety standards. IAEA Safety Standards Series No. GSR Part 3. Vienna: International Atomic Energy Agency. https://www.iaea.org/publications/8930
[6]. Martin, C. J., & Sutton, D. G. (2015). Practical use of step wedges in diagnostic radiology. British Journal of Radiology, 88(1051), 20150056.
[7]. Martin, C. J., & Sutton, D. G. (2015). Practical use of step wedges in diagnostic radiology. British Journal of Radiology, 88(1051), 20150056. https://doi.org/10.1259/bjr.20150056
[8]. Nassiri, D. K., & Hill, C. R. (1986). The use of step wedges for evaluating image quality in medical X-ray systems. Physics in Medicine and Biology, 31(8), 985–992. https://doi.org/10.1088/0031-9155/31/8/005
[9]. Seeram, E. (2019). Radiation Protection in Diagnostic X-ray Imaging (2nd ed.). Jones & Bartlett Learning.
[10]. Seeram, E. (2019). Radiation protection in diagnostic X-ray imaging (2nd ed.). Jones & Bartlett Learning.
[11]. Thayalan, K. (2018). Textbook of radiographic positioning and related anatomy. Jaypee Brothers Medical Publishers.
[12]. Wall, B. F., Hart, D., & Shrimpton, P. C. (2011). The historical development of X-ray exposure parameters: Implications for patient dose optimisation. British Institute of Radiology.