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Compliance test of field area conformity and beam straightness on x-ray machines in radiological installation

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Abstract

Compliance testing of diagnostic X-ray equipment is an essential part of quality control to ensure image accuracy and patient safety. This study evaluated the conformity of collimator illumination, collimation accuracy, and X-ray beam alignment in a hospital radiology unit. Measurements were carried out using a collimator and beam alignment test tool at a source-to-image distance (SID) of 100 cm. Illumination was measured five times in four quadrants. Collimation deviation was determined by comparing the X-ray and light field edges along the X and Y axes, expressed as % SID. Beam straightness was evaluated using the steel ball superposition method, and the deviation angle was calculated based on geometric displacement. Illumination values exceeded 100 lux in all quadrants. Collimation deviation was 1.5 ± 0.05 % SID, within the permissible tolerance of ≤ 2% SID as specified by BAPETEN Regulation No. 2 of 2022. Beam straightness deviation was 1.20 ± 0.05°, within the permissible limit of ≤ 3°. The tested X-ray unit met national compliance standards for illumination, collimation, and beam alignment. These findings highlight the importance of periodic quality control testing to maintain patient safety, minimize unnecessary radiation exposure, and ensure high-quality diagnostic images

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INTRODUCTION

X-rays were first discovered by Wilhelm Conrad Roentgen in 1895 while experimenting with cathode rays, forming the basis for modern medical imaging techniques. X-ray examination is a medical imaging technique that uses electromagnetic radiation to visualize internal structures of the body. X-rays are commonly used to examine bones, soft tissues, joints, and internal organs, but sometimes are also applied to detect other health problems [1].

X-ray equipment must guarantee both accuracy and safety to produce high-quality diagnostic results. Therefore, X-ray machines must undergo quality control (QC) [2,3]. QC is the activity of checking whether the product meets the required standards. One important aspect is testing the accuracy of the X-ray irradiation area. Compliance Testing ensures that X-ray equipment meets radiation safety requirements and provides reliable diagnostic information. It forms the foundation of a diagnostic radiology quality assurance programme, especially for parameters concerning radiation safety [4].

A collimator is an X-ray field limiting device designed to control the size and shape of useful X-rays directed at the patient. The extent of the X-ray field can be adjusted by regulating the collimator shutter according to the shape of the object to be irradiated. collimators are also useful for reducing

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the amount of scattering radiation that reaches the image receptor. Testing of the collimator is necessary to determine the conformity of the collimator beam with the direction of the X-ray beam. The collimator is one of the main key parameters that must be tested, as its suitability directly affects both the patient's radiation dose and the quality of the resulting image [5].

The deviation or mismatch between the collimator field and the X-ray beam field area is evaluated by analyzing the boundary line formed along by the X and Y-axis, then determining the midpoint between the boundary line and the scattered radiation limit. Parameters that directly affect the patient's radiation dose include light beam collimation, X-ray beam quality (HVL) and reproducibility. Reproducibility refers to the ability of an X-ray unit to produce consistent radiation output when the same exposure parameters (kV, mA, and exposure time) are used repeatedly. This consistency ensures image quality remains stable and prevents unnecessary variation in patient dose. According to international and national standards, variation in reproducibility should not exceed ±5% of the average value. According to regulatory standards, collimation parameters include illumination ≥ 100 lux, the difference between the collimator field and X-ray field ≤ 2% SID, and beam straightness ≤ 3° [5,6]

Based on this background, it is important to evaluate the conformity of collimation and straightness of X-ray beams in diagnostic radiology facilities. The aim of this study was to assess the level of collimation and beam alignment on X-ray equipment at the Radiology unit in Hospital, as part of efforts to improve patient safety and the quality of radiodiagnostic services.

MATERIALS & METHODS

This study uses quantitative experimental approach by testing the X-ray collimator at the Radiology unit in Hospital. The experiment was conducted using collimator field size of 24 x 30 cm with a source-to-image distance (SID) of 100cm. The equipment used in this study was Stationary Digital Radiography (DR) X-ray machine, brand Allengers, with a capacity of 200 kV, 100 mA, 100 s. The study used The Collimator and Beam Alignment Test Tool, part of the RADIQ Phantom, (polymethyl methacrylate/PMMA, density 1.18 g/cm^3). The main plate dimensions were 250 × 250 × 10 mm without coating, or 250 × 250 × 20 mm when covered with mica/acrylic.

The testing procedure for collimator conformity and beam alignment consisted of three stages: (1) illumination test of the collimator lamp, (2) evaluation of the collimator shutter, and (3) assessment of the similarity and accuracy of the collimator light field. The procedure began by centering the X-ray tube on the image plate (IP), placing the beam alignment test tool at the center of the illuminated area, and setting the SID at 100 cm, 55kV and 5 mAs. The waterpass was used to ensure that the X-ray tube was not tilted

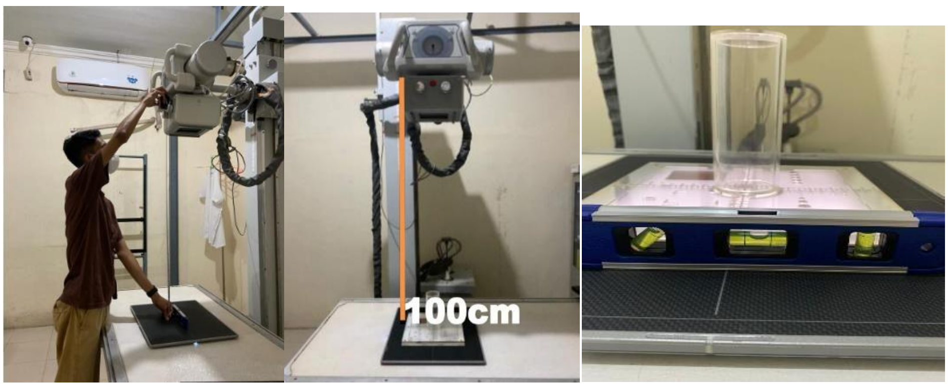

Figure 1. Setting the X-ray tube with SID 100 cm

Figure 1 shows the setup for the illumination test of the collimator light at a source-to-image distance (SID) of 100 cm. The luxmeter was positioned within the light field area to record illumination values.

The collimator test tool and beam alignment test tool were then irradiated, with the collimator light adjusted to the boundaries of the collimator test tool field area to obtain a clear image. The resulting image was analyzed to determine the difference between the collimation field and the X-ray beam, using the following equations:

$$\Delta X = \frac{|X_1 - X_2|}{SID} \; x \; 100\% \qquad (1)$$

$$\Delta Y = \frac{|Y_1 - y_2|}{SID} \; x \; 100\% \qquad (2)$$

The deviations along the X-axis (ΔX) and Y-axis (ΔY) were used to calculate the angular deviation of the X-ray beam. The deviation angle (θ) was determined using Equation (3), as illustrated in Figure 2.

$$\theta = \tan^{-1}\left[\frac{r\,(FFD-h+x)}{FFD\,(h+x)}\right] \qquad (3)$$

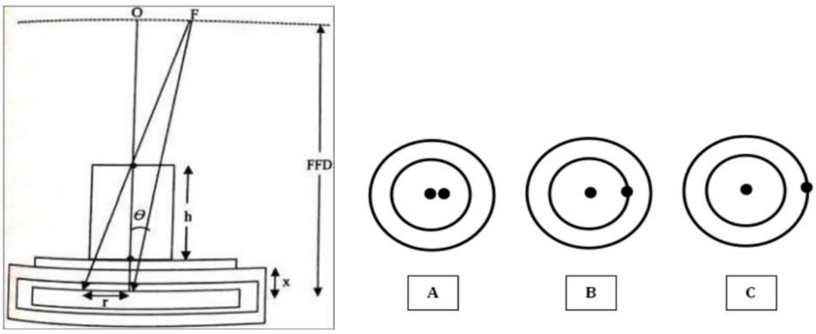

Figure 2 Illustration of X-ray beam Deviation A. 0.50^0, B $1,50^0$ and C. 30^0

The conformity limits for collimation testing are specified in BAPETEN Regulation No. 2 of 2022. The illumination must be ≥ $100 lux$. The difference between the collimation field and the X-ray beams must be ≤ 2% SID, and the beam alignment deviation must be ≤ 3° [8].

RESULTS AND DISCUSSION

1. Illumination of the Collimator

The illumination measurements were performed four times in each region. The reported values in Table 1 represent the mean ± standard deviation (SD) of these repeated measurements. All regions consistently exceeded the minimum requirement of ≥ 100 lux as regulated by BAPETEN (2022). Adequate illumination is crucial for ensuring that the irradiation field can be clearly visualized. Insufficient illumination may cause parts of the image to be truncated, leading to incomplete diagnostic information and requiring repeated exposures that unnecessarily increase patient dose.

Table 1. Measured illumination value compared with minimum standard limits

Region	Illumination (lux)	Limit Value (lux)
1	224.7 ± 0.03	
2	244.3 ± 0.03	≥ 100 lux
3	237.3 ± 0.02	
4	248.9 ± 0.03	

The use of mean ± SD highlights that the illumination values were not only above the compliance threshold but also consistent across repeated measurements. Although background illumination was not separately recorded, the test was performed in a dimly lit radiology room, minimizing the influence of ambient light on the results. The resulting images are shown in Figure 3. illustrating the alignment of the light field and the X-ray field boundaries. The figure highlights the presence of slight deviations along the X- and Y-axes, which were subsequently measured to evaluate collimation conformity.

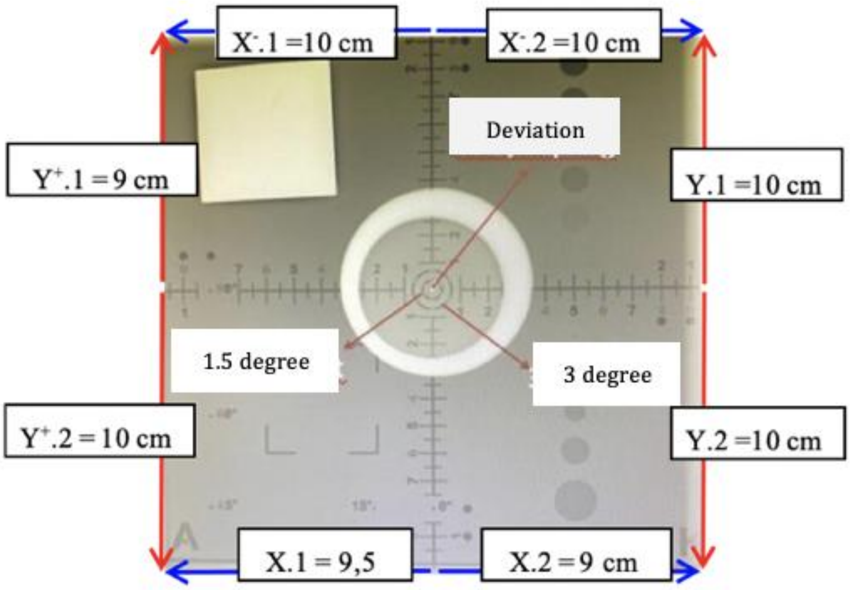

Figure 3. Test results of measuring the accuracy and straightness of the X-ray beam

After irradiation of the collimator test tool and beam alignment test tool, the resulting image was analyzed to assess the conformity of the collimation field with the X-ray beam. The deviations along the X- and Y-axes are summarized in Table 2.

Table 2. The difference between the collimation field and the X-ray beam.

Axis	*Light Field Edge (cm)*	*X-ray Field Edge (cm)*	*Deviation (% SID, mean ± SD)*	*Tolerance (BAPETEN, 2022)*
X1	10.0	9.5	0.5 ± 0.05	≤ 2% SID
X2	10.0	9.0	1.0 ± 0.05	≤ 2% SID
Y1	10.0	9.0	1.0 ± 0.05	≤ 2% SID
Y2	10.0	10.0	0.0 ± 0.00	≤ 2% SID

The total deviation (|ΔX| + |ΔY|) was 1.5± 0.05 %, which within the tolerance limit of ≤ 2% SID specified by BAPETEN Regulation No. 2 of 2022, and also complies with the permissible limit of ≤ 3% SID defined by the Indonesian Ministry of Health (2009). While small deviations may be acceptable in practice, continuous monitoring is important since larger deviations could expose patients to unnecessary radiation and reduce diagnostic accuracy.

The straightness test was performed to evaluate the angular alignment of the X-ray beam with respect to the central axis of the collimator light field (see Methods, Eq. 3). In Figure 2, the steel ball images at the top and bottom of the beam alignment test tool were not perfectly superimposed, indicating a small angular deviation. The measured displacement between the X-ray beam centre and the reference circle on the Collimator Test Tool was r = 4.0 mm, with FFD 100 cm and h 15 cm and x 1 cm. Subtituting these values into Equation (3):

$$\theta = \tan^{-1}\left[\frac{0.4\ (100 - 16.0)}{100\ (16.0)}\right] \approx 1.20°$$

The mean deviation angle from repeated measurements was θ=1.20±0.05^0 (n = 5). This complies with the permissible limit of ≤ 3° defined by BAPETEN Regulation No. 2 of 2022, confirming acceptable beam straightness for clinical use. ensuring that the X-ray beam is well aligned with the light field. Proper beam alignment is essential to maintain image quality and reduce unintended radiation exposure to non-target areas.

Overall, the findings demonstrate that illumination, collimation conformity, and beam straightness all complied with the required standards established by BAPETEN (2022) and the Indonesian Ministry of Health (2009). These results emphasize the importance of routine compliance testing as part of quality control in diagnostic radiology, ensuring both patient safety and the reliability of radiodiagnostic services

CONCLUSION

The compliance testing of the X-ray machine at the Radiology Hospital Unit showed that collimator illumination exceeded the minimum requirement of ≥ 100 lux, collimation field deviation was 1.5% SID (within the tolerance limit of ≤ 2% SID), and beam straightness was 1.20° (within the permissible limit of ≤ 3°) as specified by BAPETEN Regulation No. 2 of 2022. While these findings indicate that the unit complies with national requirements, small deviations may arise from collimator positioning or mechanical stability, and this study did not account for factors such as long-term reproducibility or variations across different exposure settings. Future evaluations should therefore include repeated measurements under varied clinical conditions to better characterize equipment performance. Importantly, periodic quality control testing remains essential, as it directly supports patient safety by minimizing unnecessary radiation exposure and ensures optimal image quality for accurate diagnosis.

AUTHOR CONTRIBUTIONS

All authors contributed to the conceptualization, methodology, investigation, data analysis, and manuscript preparation. All authors reviewed and approved the final version of the manuscript.

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