Journal of Associated Medical Sciences 2026; 59(3): 85-91

JAMS
Journal of Associated Medical Sciences

Scopus Indexed & Thai-Journal Citation Index Centre (TCI)

Journal of Associated Medical Sciences

Journal homepage: https://www.tci-thaijo.org/index.php/bulletinAMS/index



Comparison of radiation and light field congruence between a developed collimator test tool and a standard collimator test tool in the general X-ray units of Lamphun Province hospitals

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ARTICLE INFO

Article history:
Received 8 December 2025
Accepted as revised 18 May 2026
Available online 25 May 2026

Keywords:
Radiation and light field congruence, collimator, collimator test tool

ABSTRACT

Background: Assessment of radiation and light-field congruence is a key quality-control procedure for general X-ray machines. This process typically requires a standard collimator test tool, which can be costly. Therefore, the author developed an innovative collimator test tool as a cost-effective alternative for evaluating the congruence between the radiation field and the collimator light field.

Objectives: The present study aims to evaluate and compare radiation and light-field congruence measured using the developed collimator test tool and a standard tool on general X-ray units across eight hospitals in Lamphun Province.

Materials and methods: The developed collimator test tool was constructed from an etched stainless-steel plate measuring 20×25 cm, with scale resolutions of 2.5 mm and 5 mm. The standard collimator test tool (GAMMEX, Model 161B) is made from a brass plate of the same dimensions with a scale resolution of 5 mm. Measurements followed the 2023 diagnostic X-ray quality standards established by the Department of Medical Sciences, Ministry of Public Health. Radiation and light field borders were measured three times on each of four sides, yielding a total of 96 measurements. Error and percentage error were calculated, and a paired-sample t-test analysis was performed.

Results: Comparison of radiation and light-field congruence between the developed collimator and the standard collimator test tools revealed a maximum error of 0.5 mm, corresponding to a percentage error of 3%, which is below the acceptable limits of 1 mm or 5%. Statistical analysis using a paired-sample t-test ($p<0.05$) indicated no significant difference between measurements obtained from the two test tools ($p\geq0.05$).

Conclusion: The developed collimator test tool can be used as an alternative to the standard tool for radiation and light field congruence testing in general X-ray units. It offers a cost-effective option for self-quality control and monitoring in radiology departments while maintaining the same measurement accuracy.

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doi: 10.66285/JAMS.2026.081
E-ISSN: 2539-6056

Introduction

Radiological diagnostic technology has been rapidly and continuously evolving to support medical diagnosis. Diagnostic X-rays are now an essential tool that helps doctors diagnose diseases and detect abnormalities in patients' organs more accurately and quickly. International and national radiation safety organizations regulate and supervise the use

of radiation to ensure compliance with international standards for radiation hazard prevention. To maximize the benefits of radiation in diagnosis while minimizing exposure, it is essential to implement appropriate protective measures. Awareness of radiation protection for patients can be achieved by establishing a quality management system to supervise operations and maintain equipment. Improving the quality of work and services, as well as controlling the radiation dose received by patients, ensures that exposure does not exceed necessary levels, thereby reducing the risk to both patients and radiation workers.[1-4]

In Thailand, the Department of Medical Sciences has a policy to enhance the quality and capabilities of diagnostic radiology laboratories by focusing on developing and supporting quality systems and standards in accordance with the Ministry of Public Health's regulations. To support public health, quality control of medical diagnostic X-ray machines is implemented, providing hospital radiology personnel with guidelines for their work. Efforts are made to improve the quality of the service system to ensure efficient services for the public. Additionally, the quality of services in diagnostic radiology laboratories is enhanced to maintain radiation safety and security in accordance with nationwide standards.[7]

Quality control of medical diagnostic X-ray machines, digital imaging equipment, and other accessories is essential to ensure that diagnostic radiology laboratories produce high-quality X-rays that are safe for both patients and operators. X-ray images are a critical component of medical diagnosis, helping doctors ensure accuracy and precision in treatment planning. High-quality imaging benefits practitioners by reducing the time required to obtain X-rays and supports the development of efficient diagnostic radiology services within hospitals, ultimately contributing to an effective public healthcare system.[9]

The Annual Reports from 2017 to 2024 of the Regional Medical Sciences Center 1, Chiang Mai, reported that up to 12.7 percent of general diagnostic X-ray machines failed to meet quality standards each year. One of the main causes was the misalignment between the radiation beam and the collimator light. Similarly, the Annual Report 2023 of the Bureau of Radiation and Medical Devices, Department of Medical Sciences, showed that out of 4,262 general diagnostic X-ray machines tested nationwide, 258 units (6.1 percent) did not meet the standards, primarily due to a mismatch between the X-ray beam and the collimator light.[10,11]

Quality standards for radiation and light-field congruence in medical diagnostic X-ray machines specify that the alignment error should not exceed 2 centimeters at a source-to-image distance (SID) of 100 centimeters, and that testing should be conducted every 6 months.[8,9] ICRP Publication 154 emphasizes the importance of proper collimation to reduce the total patient dose as part of a consistent quality control program. Misalignment between the radiation beam and the collimator light can increase the patient's radiation dose, resulting in unnecessary exposure.[2]

X-ray machine quality control standards are important for ensuring patient safety, minimizing radiation dose, and identifying test items that do not meet quality requirements. Problems related to the adjustment of X-ray machines have been observed during radiation and light-field congruence testing of general X-ray machines in Health Region 1. To deal with these issues, the author developed an innovative collimator test tool for assessing radiation and light field congruence, in collaboration with The Brick Fabrication Lab (THE BRICK FABLAB) at the Northern Sciences and Technology Park (STeP), Chiang Mai University.[12] This developed tool serves as an alternative for testing the congruence of general X-ray machines and can be used to monitor and adjust collimators in diagnostic radiology laboratories in Lamphun Province, other provinces in Health Region 1, or nationwide.

Therefore, the purpose of this study was to evaluate and compare radiation and light-field congruence measurements obtained with the developed collimator test tool against those obtained with the standard collimator test tool.

Materials and methods

Development of a collimator test tool

A collimator test tool was developed using an etched stainless-steel plate measuring 20×25 cm, with scale resolutions of 2.5 and 5 mm, as shown in Figure 1.

Standard collimator test tool

The standard tool (GAMMEX 161B) used a brass plate measuring 20×25 cm with a 5 mm scale resolution (Figure 1).

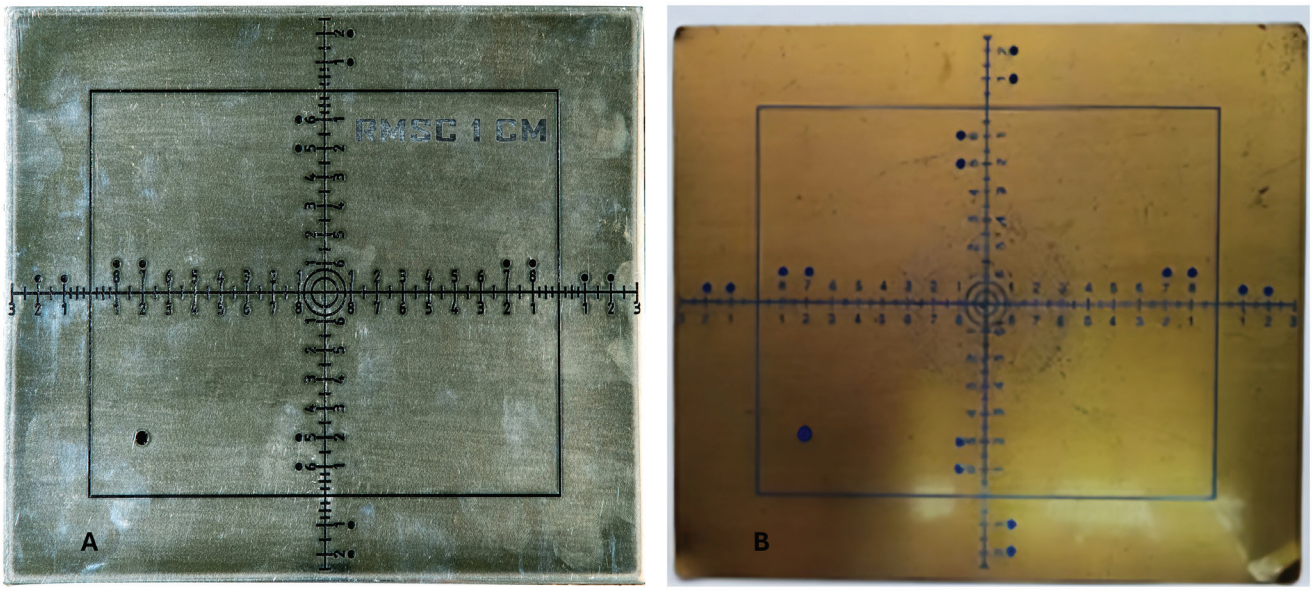


Figure 1. *The collimator test tool images. A: The developed collimator test tool, B: The standard collimator test tool.*

Test method

Radiation and light-field congruence testing between the developed collimator test tool and the standard collimator test tool on general X-ray machines was conducted at eight hospitals.[1,6,7] A total of 96 measurements was collected from eight general X-ray units in this preliminary investigation. The radiation and light field congruence test began by aligning the X-ray tube with the examination table. A digital X-ray image detector plate was then positioned at the center of the table, after which the developed collimator test tool was placed on top of it. The collimator light field was adjusted so that the central crosshair aligned precisely with the center point of the test tool. The X-ray tube was positioned at a source-to-image distance (SID) of 100 cm, and the collimator light was adjusted to match the 14×18 cm rectangular field of the test tool (Figure 2). Room lighting was dimmed or turned off to ensure that the collimator light borders were clearly visible (Figure 3). The X-ray technique was set at approximately 50-55 kV, 100 mA, and 0.30-0.50 s (3-5 mAs), after which an exposure was taken and the resulting image analyzed. The radiation and light field congruence distances on each of the four sides (left, right, top, and bottom) were measured three times using a medical digital radiography viewer (MicroDicom Viewer 2024), and the values were recorded (Figure 3). The entire procedure was repeated using the standard collimator test tool for comparison.

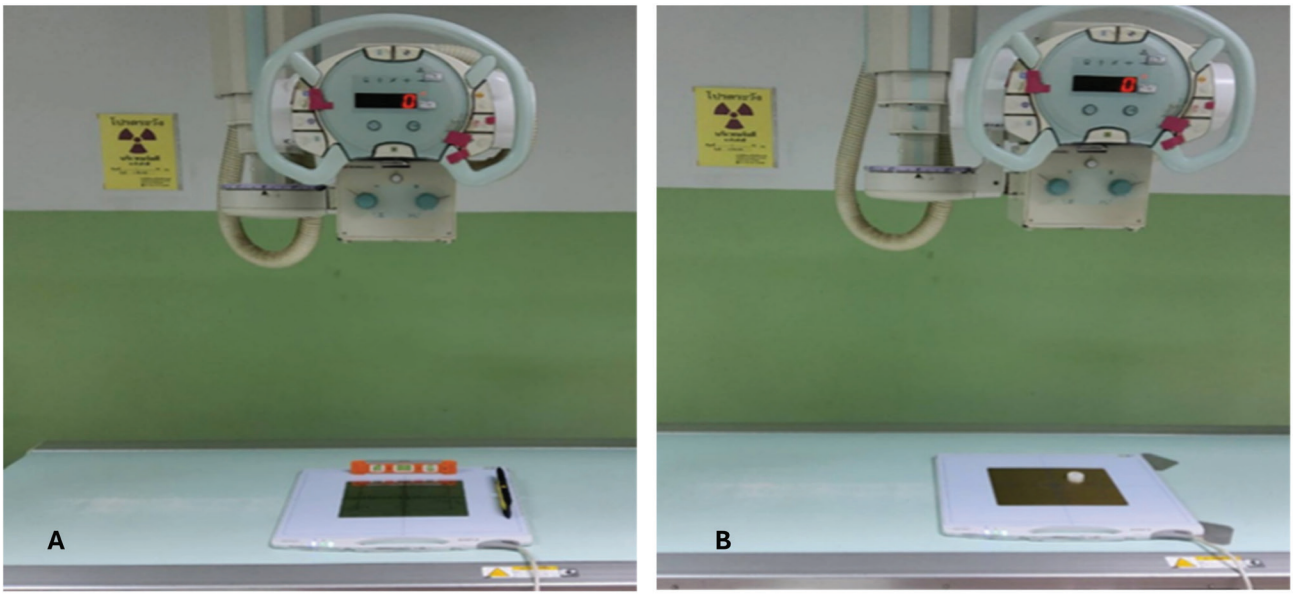


Figure 2. *Setting for the radiation and light field congruence testing images. A: The developed collimator test tool, B: The standard collimator test tool.*

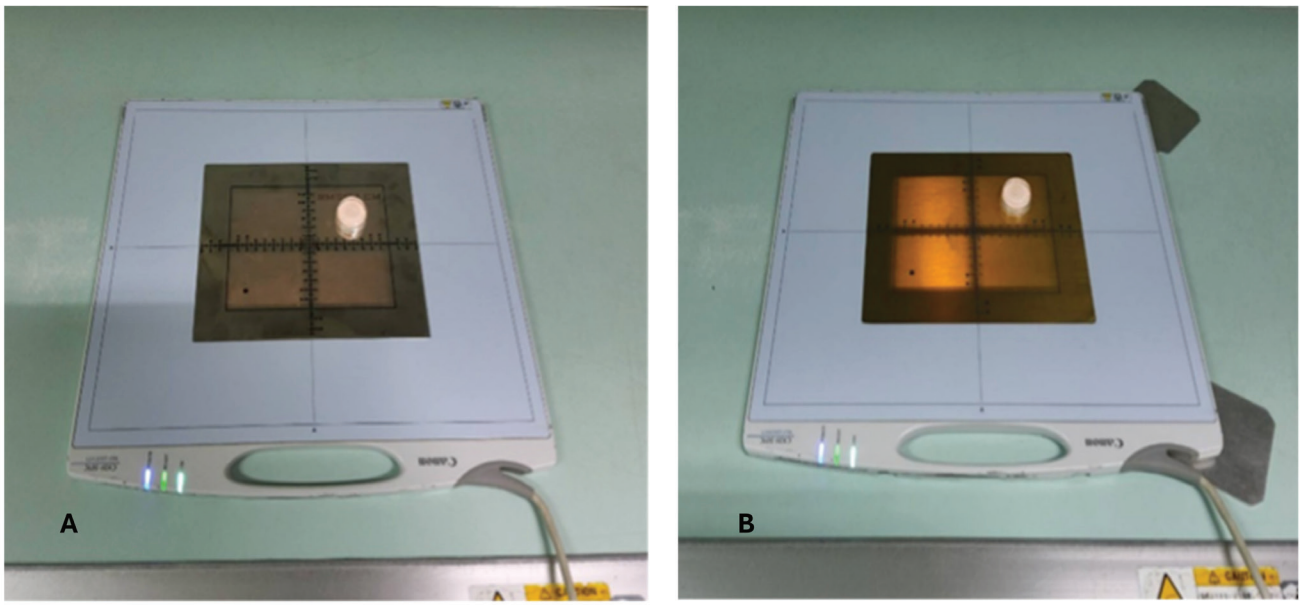


Figure 3. *The light field and markings on the collimator test tool.*
A: The developed collimator test tool, B: The standard collimator test tool.

Analysis method

The error analysis was performed by subtracting the radiation and light field congruence values of the developed collimator (E1) from the beam and light disparity values of the eight standard collimators (E2). Using the average of measurements taken on each side (left, right, top, bottom) 3 times and the sum of the average of all sides from each X-ray machine, totaling eight machines (Figure 4).

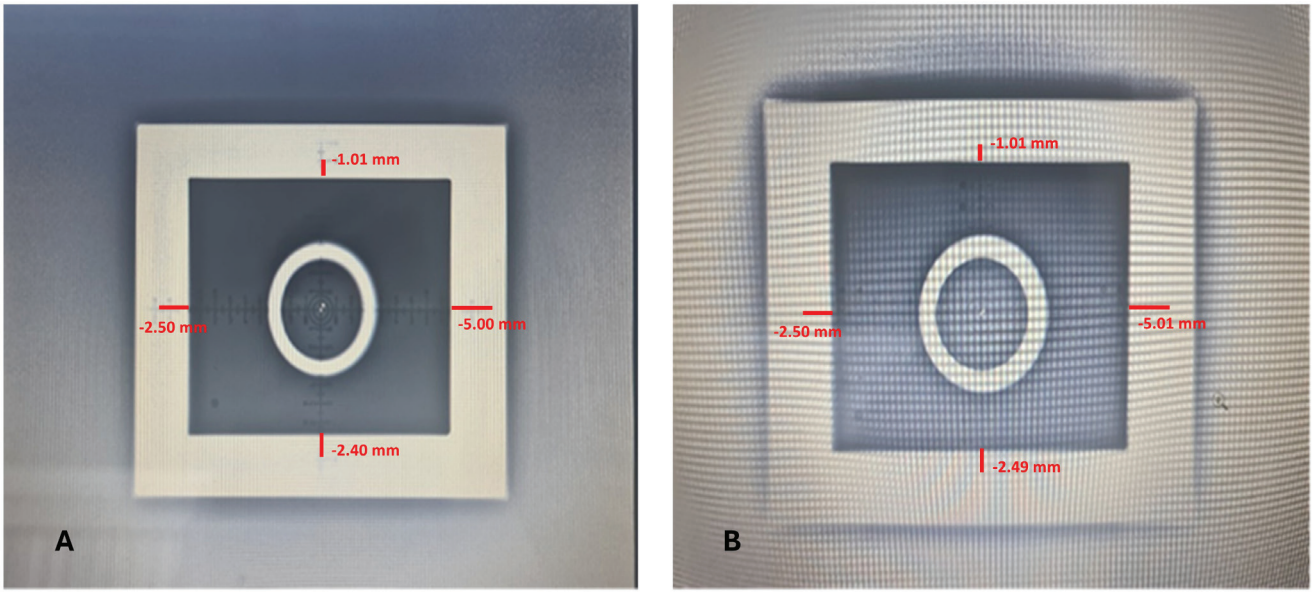


Figure 4. *Example of the measurement of the radiation and light field congruence distance images.*
A: The developed collimator test tool, B: The standard collimator test tool.

Statistical analysis

Comparison of the radiation and light field congruence values of the developed collimator test tool with the standard collimator test tool. The average of the three measurements taken for each side (left, right, top, bottom) and the sum of the averages from each X-ray machine (8 in total) were analyzed using a paired-sample t-test at the 95% confidence level (p<0.05) to determine whether there were any differences.

Results

The results of the present study were divides into two parts, including the mean (mean±SD), error and percentage error (%Error) of the results of the measurement of the radiation and light field congruence on each side between the developed collimator test tool and the standard collimator test tool and the summary of the comparative results of the radiation and light field congruence between the developed collimator test tool and the standard collimator test tool. The details of the results are shown in Table 1 and Table 2.

Discussion

The study results showed that the maximum error of radiation and light field congruence measured using the developed collimator test tool compared to the standard collimator test tool on each side (left, right, top, and bottom), as well as the overall average from a total of 8 X-ray machines, was 0.5 mm or 3%. This value is well below the acceptable limit of 1 mm or 5% and falls within the resolution scale.

Comparison of beam alignment with the collimator light between the developed and standard collimator test plates using a paired-sample t-test at 95% confidence (p<0.05) showed no statistically significant difference (p≥0.05), which is consistent with the established hypothesis.

Although the observed differences were statistically non-significant and below acceptable limits, they confirm that beam-light field misalignment does not compromise patient safety in terms of radiation dose and field coverage, helping to avoid both overexposure and under-coverage. Practically, the developed tool demonstrates comparable performance to the standard tool and can be effectively used for routine quality control, particularly in resource-limited settings.

Table 1. Mean±SD, error, and percentage error (%Error) of the results of the measurement of the radiation and light field congruence on each side between the developed collimator test tool and the standard collimator test tool.

The radiation and light field congruence (Measuring side)	**Average measurement results of the developed collimator test tool** (mm) Mean±SD	**Average measurement results of the standard collimator test tool** (mm) Mean±SD	**Error value** (mm) Mean±SD	**Percentage of error (%Error)** Mean±SD
Left side (N=24)	4.007±2.76	4.07±2.75	0.00±5.52	0.02
Right side (N=24	3.62±1.85	3.69±1.85	0.01 ± 3.70	- 0.28
Top side (N=24)	3.16±1.87	3.15±1.88	0.01 ± 3.74	- 0.20
Bottom side (N=24)	6.13±3.16	6.12±3.19	- 0.02 ± 6.35	0.24
Total of all aspects (N=96)	4.24±2.69	4.24±2.69	0.00 ± 5.39	- 0.01

Table 2. Summary of the comparative results of the radiation and light field congruence between the developed collimator test tool and the standard collimator test tool using a paired-sample t-test (p<0.05) statistic.

The radiation and light field congruence (measuring side)	**Average measurement results of the developed collimator test tool** (mm) Mean±SD	**Average measurement results of the standard collimator test tool** (mm) Mean±SD	***p* value**	**Summary of results**
Left side (N=24)	4.07±2.76	4.07±2.75	0.93	Not significantly different (p≥0.05)
Right side (N=24)	3.62±1.85	3.69±1.85	0.08	Not significantly different (p≥0.05)
Top side (N=24)	3.16±1.87	3.15±1.88	0.26	Not significantly different (p≥0.05)
Bottom side (N=24)	6.13±3.16	6.12±3.19	0.25	Not significantly different (p≥ 0.05)
Total of all aspects (N=96)	4.24±2.69	4.24±2.69	0.96	Not significantly different (p≥0.05)

its comparable accuracy and significantly lower cost, the developed tool is suitable for production and for testing the radiation and light-field congruence of X-ray machines in hospitals. The developed collimator test tool offers several practical advantages over the standard commercial device. These include lower cost, ease of fabrication, and suitability for routine and frequent quality control use. The thin, flat stainless-steel design facilitates straightforward positioning on the image receptor and reduces setup complexity. Additionally, the tool's durability allows repeated use without significant degradation, supporting long-term implementation in clinical QA/QC programs.

Overall, the developed tool provides performance comparable to that of the standard collimator test tool while offering improved accessibility and practicality for routine self-quality control, aligning with quality optimization principles and the ALARA concept.

Limitations

This study was limited to evaluating beam–light field congruence in general radiographic X-ray units, excluding mobile X-ray systems, which were excluded due to their continuous clinical use and limited accessibility for standardized testing. In addition, the study was conducted by a single observer, which precludes assessment of inter-observer and intra-observer variability. As a result, it is not possible to fully distinguish whether the observed variability arises from the measurement process or from observer-related factors.

Although standardized measurement procedures and repeated measurements were implemented to minimize potential bias, some degree of observer-dependent variability may persist. This limitation is particularly relevant for applications involving routine self-quality control, where consistency across different users is essential. Therefore, future studies should incorporate multiple observers and repeated measurement designs to evaluate measurement reproducibility using appropriate statistical methods.

Conclusion

The results of measuring radiation and light field congruence between the developed collimator test tool and the standard tool on eight general X-ray machines in eight hospitals in Lamphun Province showed that the maximum error was 0.5 mm, corresponding to a percent error of 3%, which is well below the acceptable limit of 1 mm or 5%. Statistical analysis using a paired-sample t-test ($p<0.05$) indicated no significant difference between measurements obtained from the two tools ($p\geq0.05$). Therefore, it can be concluded that the developed collimator test tool performs equivalently to the standard tool and can be used as a substitute. Future studies should include mobile X-ray systems, as this would enhance the applicability of quality control assessments in radiographic practice.

Ethical approval

This study did not require ethical approval.

Funding

This research received no funding from any agency.

Conflict of interest

The author declares no conflict of interest.

CrediT authorship contribution statement

Kampol Taywadithep: conceptualization, methodology, writing: original draft, review, and edit.

Acknowledgements

I would like to thank the Brick Fabrication Lab (THE BRICK FABLAB) in Northern Sciences and Technology Park (STeP), Chiangmai University, for their cooperation in designing and developing the collimator test tool for the radiation and light field congruence of a general X-ray machine, as requested by the author this time.

I would like to thank the hospitals and radiologists at Lamphun Hospital, Ban Thi Hospital, Mae Tha Hospital, Ban Hong Hospital, Pa Sang Hospital, Wiang Nong Long Hospital, Thung Hua Chang Hospital, and Li Hospital in Lamphun Province. Thank you for providing the general X-ray machine and X-ray recording system, which enabled the successful completion of the radiation and light-field congruence testing.

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