Natural Resources for Human Health
eISSN: 2583-1194

Original Research

Received 05 July 2026
Revised 13 Aug 2026
Accepted 30 Aug 2026

Natural Resources for Human Health 2026, Vol. 6 (20s):335–342

KEYWORDS:
Mammography, 3D printing, Quality control, Phantom, Image loss

Evaluation of the Usefulness of a Quality Control Phantom Developed for an In-House Mammography System and Assessment of Chest Wall Image Defects According to Focal Spot Position

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ABSTRACT: In Korea, the mammography quality control (QC) criteria currently exclude the assessment of "chest wall image loss according to focal spot position," which is considered an essential item in advanced radiotherapy countries. This omission raises concerns regarding potential reductions in diagnostic accuracy. To address this issue, the present study designed and fabricated a QC phantom suitable for evaluating chest wall image loss. The phantom was modeled using Fusion 360 and manufactured with a stereolithography (SLA) 3D printer. Four holes (depth: 1 cm, diameter: 2 mm, repeated five times at each corner) were created on the lateral sides of the phantom, into which contrast medium was injected. After printing, the phantom was cleaned with isopropyl alcohol and post-cured at 60 °C. For imaging, the phantom was placed on the detector surface and fixed with a compression paddle. Exposures were performed with the focal spot fixed, using semi-automatic mode at 30, 32, and 34 kVp, as well as one exposure with automatic exposure control (AEC), for a total of four acquisitions. The images were analyzed using ImageJ software (version 1.53k, USA). Evaluation focused on whether all four contrast-filled holes near the chest wall were visualized and whether continuous visibility of at least 6 mm could be maintained throughout the image. The results showed that the mammography equipment at University S (Gyeonggi Province) achieved an average detectable length of 6 mm, whereas the mammography system at Hospital H (Namyangju) demonstrated an average length of less than 6 mm. Quality control review confirmed that the University S system met the Japanese mammography QC standards, while the Hospital H system did not. This study provides empirical evidence supporting the necessity of including the "verification of chest wall image loss" in domestic QC protocols, a criterion already established abroad. Furthermore, these findings offer foundational data for future policy improvements and are expected to contribute positively to enhancing mammographic image quality, promoting early detection of breast cancer, and ultimately improving patient survival rates.

I. INTRODUCTION

Breast cancer incidence has been increasing rapidly in South Korea, with a steady rise also observed among younger women [1]. This trend has been associated with changes in lifestyle patterns, including the adoption of Westernized dietary habits characterized by high fat and caloric intake, which may contribute to an increased risk of breast cancer [2]. Early-stage breast cancer is often asymptomatic, making timely detection challenging without appropriate screening. Delayed diagnosis may result

in disease progression, including local invasion and distant metastasis. Therefore, early detection and timely diagnosis are essential for improving treatment outcomes and survival rates, highlighting the need for continuous advancements in medical imaging technologies and examination protocols [3].

Various imaging modalities are used for breast cancer detection and evaluation, including mammography, breast ultrasonography, magnetic resonance imaging (MRI), and nuclear medicine imaging. Among these modalities, mammography remains the primary imaging technique for the early detection of breast cancer [4]. Mammography uses low-energy X-rays to visualize abnormalities within breast tissue, including masses and microcalcifications, and is widely recognized as an effective screening tool for detecting early-stage breast cancer [5]. However, the complex anatomical composition of the breast, consisting of adipose and fibroglandular tissues with relatively low inherent X-ray attenuation differences, makes mammographic image quality particularly sensitive to variations in imaging parameters. Even minor changes in acquisition conditions may affect image quality and compromise the visibility of subtle lesions. Accordingly, optimizing image quality while minimizing unnecessary radiation exposure remains a fundamental requirement in mammographic imaging.

Systematic quality control (QC) procedures are essential for maintaining the performance and accuracy of mammography systems and ensuring diagnostic image quality at the lowest reasonably achievable radiation dose. Regular performance evaluations, equipment maintenance, and safety inspections are necessary to prevent image degradation and reduce unnecessary patient exposure. In addition, comprehensive QC programs require collaboration among regulatory authorities, equipment manufacturers, and clinical personnel to ensure the reliability and long-term stability of imaging systems [6].

Quality assurance in medical imaging extends beyond equipment performance maintenance and constitutes a fundamental component of diagnostic accuracy and patient safety. In South Korea, concerns regarding deteriorating image quality associated with aging equipment, the increased risk of diagnostic errors, and unnecessary radiation exposure prompted the implementation of the Regulations on the Installation and Operation of Special Medical Equipment in January 2003. Subsequently, the Korean Institute for Accreditation of Medical Image (KIAMI) was established on July 31, 2004, to promote the quality of medical imaging through equipment inspections, education, and research activities [7]. Under this regulatory framework, medical imaging systems, including mammography, computed tomography (CT), and MRI, are subject to mandatory quality assurance evaluations involving relevant performance parameters, such as tube voltage accuracy, half-value layer, spatial resolution, and radiation dose measurements, depending on the imaging modality [8].

Despite these regulatory efforts, certain differences remain between mammographic quality control standards in South Korea and those implemented in other countries. One notable difference concerns the assessment of image loss near the chest wall in relation to the focal spot position. In quality control protocols adopted in Europe and Japan, evaluation of image coverage adjacent to the chest wall is included as an important component of mammography system performance assessment [9]. This evaluation is clinically relevant because incomplete visualization of breast tissue near the chest wall may result in missed lesions and potentially delay breast cancer detection. However, this assessment is not explicitly included in the current routine mammographic quality control criteria in South Korea [10,11]. Consequently, the possibility of incomplete visualization of clinically relevant breast tissue due to limitations in equipment performance cannot be entirely excluded [12].

In addition to evaluating the need for this quality control parameter, the present study investigates the applicability of a custom-designed phantom fabricated using three-dimensional (3D) printing technology. The potential of this phantom as a standardized testing tool for assessing image loss near the chest wall is also examined.

Therefore, this study aims to empirically evaluate the necessity of incorporating an assessment of image loss near the chest wall according to focal spot position into the mammographic quality control framework in South Korea. Furthermore, the study seeks to provide foundational evidence for potential improvements in national quality control standards and to assess the feasibility of using a 3D-printed phantom for this purpose. The findings are expected to contribute to the improvement of mammographic image quality, the reliability of breast tissue visualization, and the effectiveness of quality assurance practices, thereby potentially supporting earlier breast cancer detection and improved patient outcomes.

Ⅱ. MATERIAL AND METHODS

2.1. Fabrication of a Mammography Quality Control Phantom

2.1.1. Three-Dimensional Modeling of the Quality Control Phantom

A custom-designed mammography quality control (QC) phantom was modeled using Fusion 360 software (Autodesk, USA). The phantom was specifically designed to assess image loss near the chest wall during mammographic imaging. The three-dimensional (3D) model was developed for fabrication using stereolithography (SLA), a vat photopolymerization-based additive manufacturing technique.

2.1.2. Three-Dimensional Printing and Fabrication of the Quality Control Phantom

The QC phantom was fabricated using a Form 2 SLA 3D printer (Formlabs, USA), along with a resin washing unit and a post-curing unit. Additional materials included Solix instant adhesive and an iodinated X-ray contrast agent (Visipaque, GE Healthcare).

The overall dimensions of the phantom were designed to be 240 × 30 × 60 mm to accommodate the dimensions of the mammography compression paddle and image receptor platform. Owing to limitations associated with printing the entire phantom as a single structure, the phantom was divided into three individual sections, each measuring 80 × 30 × 60 mm. These sections were printed separately and subsequently bonded together using instant adhesive to form the complete phantom.

Four holes were incorporated into the phantom, with two positioned near each lateral edge at predetermined intervals. Each hole was designed with a length of 10 mm and markings at 2-mm intervals, providing five measurement increments. The holes were filled with an iodinated contrast agent (Visipaque, GE Healthcare) using a disposable syringe.

Following 3D printing, the resin-based components were washed with isopropyl alcohol to remove residual uncured resin and subsequently subjected to post-curing. The printing process required approximately 9 h and 30 min, followed by a 30-min washing procedure and a 30-min post-curing process at 60°C. The fabrication process and completed phantom are presented.

2.2. Quality Control Evaluation Using the Fabricated Phantom

The fabricated phantom was used to evaluate the quality control performance of mammography systems, with particular emphasis on identifying image loss near the chest wall.

2.2.1. Experimental Equipment and Materials

The experiment was conducted using two mammography systems: a research-purpose mammography system located in Gyeonggi Province, South Korea, and a clinical mammography system installed at H Hospital in Namyangju, South Korea. The experimental materials included a custom-designed 3D-printed QC phantom and two digital mammography systems: the AMULET Innovality (Fujifilm, Japan) and Selenia Dimensions (Hologic, USA).

2.2.2. Experimental Procedures and Image Analysis

The fabricated phantom was positioned on the image receptor platform of each mammography system and secured using the compression paddle to ensure consistent positioning during image acquisition. The focal spot position was maintained at a fixed setting throughout the experiment.

Mammographic images were acquired under four exposure conditions: three semi-automatic exposure settings with tube voltages of 30, 32, and 34 kVp, and one automatic exposure control (AEC) setting. A single image was obtained under each condition, resulting in four images per mammography system.

For each acquired image, the number of visible grooves marked at 2-mm intervals and the visible length of the contrast-filled holes were recorded to assess the extent of image loss near the chest wall.

Images acquired using the two mammography systems were subsequently analyzed using ImageJ software (version 1.53k, National Institutes of Health, USA). The analysis focused on evaluating the visibility of the phantom's measurement structures and identifying potential image loss in the region adjacent to the chest wall (Fig. 1).

Natural Resources for Human Health
eISSN: 2583-1194

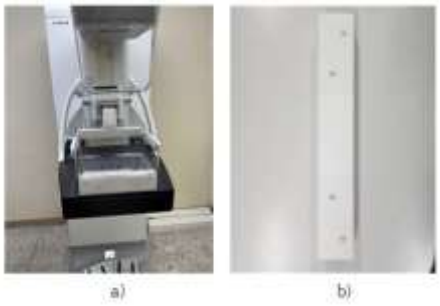


Fig. 1 Performance evaluation using the phantom

a) mammography b) Completed 3D printed phantom

2.3. Evaluation Criteria

The evaluation was performed in accordance with the Japanese mammography quality control guidelines [13]. According to these guidelines, all four contrast-filled holes, each with a depth of 10 mm and positioned at distances of 42.5 mm and 2.5 mm from the edges of the phantom, should be visible on the acquired mammographic images. Furthermore, at least three of the four markers should remain clearly visible up to a minimum distance of 6 mm from the beginning of each marked region. Image loss near the chest wall may occur when the focal spot is displaced toward the nipple side relative to the vertical reference line.

Ⅲ. RESULT

3. Results

3.1. Results of Quality Control Phantom Fabrication

The quality control phantom was successfully fabricated using stereolithography (SLA)-based 3D printing technology. Three individual phantom sections, each measuring 80 × 30 × 60 mm, were printed separately and subsequently assembled using adhesive to produce a final phantom with overall dimensions of 240 × 30 × 60 mm.

The fabricated phantom contained four holes, each with a diameter of 10 mm, with two holes positioned on each side. Each hole incorporated five grooves at 2-mm intervals to facilitate the assessment of image visibility. An iodinated contrast agent was injected into the holes to enhance their radiographic visibility. Subsequently, radiographic imaging was performed using a conventional X-ray system to verify the structural integrity and visibility of the fabricated holes.

The resulting radiographic images demonstrated that the contrast-filled holes were clearly identifiable, confirming the successful fabrication and radiographic visualization of the phantom's measurement structures.

3.2. Evaluation of Chest Wall-Side Image Loss According to Focal Spot Position

The extent of image loss near the chest wall was evaluated using mammography systems installed at S University in Gyeonggi Province and H Hospital in Namyangju, South Korea. The evaluation focused on the visibility of the contrast-filled holes and measurement grooves incorporated into the fabricated quality control phantom.

The mammography system at S University demonstrated a mean visible length of 6.0 mm, with three grooves identified on the acquired images (Table 1 and Fig. 2). In comparison, the mammography system at H Hospital exhibited a mean visible length of 5.6 mm (Table 2 and Fig. 3).

Although the mammography system at S University generally satisfied the evaluation criteria, some holes failed to meet the minimum visibility requirement of 6 mm at a tube voltage of 34 kVp.

According to the Japanese mammography quality control guidelines, the ability to visualize at least 6 mm of the designated measurement structures near the chest wall is used as an acceptance criterion for evaluating image coverage in this region.

When this criterion was applied to the two mammography systems, the system at S University generally met the acceptance

requirements, despite the observed deviations at 34 kVp. In contrast, the mammography system at H Hospital failed to meet the minimum visibility criterion for most of the evaluated holes.

These findings indicate differences in chest wall-side image coverage between the two mammography systems under the investigated exposure conditions.

Table 1. Research mammography equipment in Gyeonggi-do (unit: mm)

	1	2	3	4	average
AEC	6.110	6.070	6.170	6.480	6.208
30kVp	7.210	6.590	6.440	6.780	6.750
32kVp	7.070	6.680	6.350	6.680	6.695
34kVp	5,620	5.730	6.590	6.680	6.155
P/NP	**PASS**				

Table 2. Clinical mammography equipment in Namyangju (unit: mm)

	1	2	3	4	average
AEC	6.030	5.970	6.030	5.840	5.968
30kVp	6.030	5.970	5.970	5.820	5.948
32kVp	5.400	5.470	5.930	5.930	5.683
34kVp	4.210	4.400	5.510	5.770	4.973
P/NP	**NON-PASS**				



Fig 2. AEC mode of Research mammography equipment in Gyeonggi-do



Fig 3. AEC mode of Clinical mammography equipment in Namyangju

IV. DISCUSSION

In this study, a custom-designed mammography quality control (QC) phantom was fabricated using three-dimensional (3D) printing technology to evaluate image loss near the chest wall in relation to focal spot position. The phantom was developed as a potential alternative to commercially available QC phantoms used for evaluating chest wall-side image coverage in mammography systems. The fabricated phantom enabled the visualization and measurement of designated structures, demonstrating its feasibility for assessing image loss near the chest wall. Compared with conventional commercially available phantoms, the use of 3D printing technology may offer advantages in terms of manufacturing flexibility, potential cost reduction, and the ability to customize phantom configurations according to specific evaluation requirements. These characteristics suggest that custom-designed 3D-printed phantoms may serve as practical tools for mammography quality control, although further validation is required to establish their performance equivalence to commercially available devices.

Nevertheless, several limitations should be considered when interpreting the findings of this study. First, the evaluation was conducted using a limited number of mammography systems, restricting the generalizability of the results to other equipment models and clinical environments. Mammography systems differ among manufacturers in terms of focal spot geometry, detector configuration, compression paddle design, and image processing algorithms. Such variations may influence image reproducibility and the extent of image loss near the chest wall, even when identical QC phantoms are employed. Because the present study included only two mammography systems, the reproducibility and reliability of the proposed evaluation method across different equipment models could not be comprehensively established. Therefore, further investigations involving a wider range of mammography systems are necessary to determine the applicability of the proposed phantom-based assessment.

During the preliminary fabrication process, fused deposition modeling (FDM) 3D printing was initially employed. However, the resulting phantom exhibited limitations in reproducing the intended hole geometry, making it difficult to clearly identify the measurement structures on mammographic images. To address these limitations, stereolithography (SLA) printing was subsequently adopted. The SLA-based fabrication process provided improved structural precision and printing quality, allowing the intended phantom features to be reproduced more accurately [14]. Nevertheless, potential dimensional inaccuracies associated with the 3D printing process, as well as variations in printer performance and fabrication conditions, should be considered when evaluating the reliability of the fabricated phantom.

Although the holes were designed with a depth of 10 mm, slight differences were observed in the visible lengths of the four contrast-filled holes on the acquired radiographic images. These variations may have resulted from minor positioning errors, particularly imperfect alignment of the phantom parallel to the image receptor surface. In addition, measurement uncertainties associated with ImageJ analysis may have contributed to the observed differences. Variations in exposure parameters also affected the sharpness and visibility of the contrast-filled structures, potentially reducing the precision of length measurements. These findings highlight the importance of standardized phantom positioning, consistent image acquisition conditions, and appropriate image measurement procedures to improve the reproducibility of the proposed QC method.

The primary objective of this study was to investigate the applicability of a 3D-printed phantom for evaluating image loss near the chest wall in mammography systems, thereby contributing to the improvement of diagnostic image quality and patient safety.

Previous research has investigated the use of 3D-printed femoral phantoms for quality control in bone mineral density examinations, demonstrating the potential applicability of additive manufacturing technology in medical imaging quality assurance [15]. Both studies share the objective of improving diagnostic reliability through the development of phantom-based evaluation tools, with the broader aim of reducing unnecessary repeat examinations and radiation exposure. However, unlike previous studies primarily focused on evaluating the feasibility of 3D-printed phantoms, the present study additionally examined a mammographic QC parameter that is not explicitly included in the current routine quality control criteria in South Korea. This distinction highlights the potential contribution of the proposed phantom to identifying areas for improvement in existing mammography QC protocols.

The findings of this study provide preliminary evidence supporting the feasibility of using a custom-designed 3D-printed phantom to evaluate chest wall-side image coverage in mammography. Furthermore, the observed differences in image visibility between the evaluated mammography systems suggest that incorporating an assessment of image loss near the chest wall into routine QC procedures may warrant further consideration. By introducing a phantom-based evaluation method for a parameter not currently included in the national QC framework, this study provides a basis for further investigation into the potential refinement of mammography quality control standards in South Korea.

Although the assessment of image loss near the chest wall in relation to focal spot position is not currently included as a specific component of routine mammography QC criteria in South Korea, the present findings suggest that such an evaluation may be technically feasible using a 3D-printed phantom. The proposed method may therefore provide preliminary evidence for future discussions regarding the expansion and refinement of national mammography QC guidelines. However, additional validation is necessary before its routine clinical implementation can be recommended. Future studies should include multicenter evaluations involving mammography systems from different manufacturers, complementary investigations using clinical imaging data, and the development of advanced phantoms incorporating tissue-equivalent materials and more complex anatomical structures. Such investigations may further establish the measurement reliability, reproducibility, and clinical applicability of the proposed phantom and contribute to the development of more comprehensive mammography quality assurance protocols.

V. CONCLUSION

This study evaluated the feasibility of using a custom-designed 3D-printed phantom for mammography quality control and investigated the presence of image loss near the chest wall using the fabricated phantom. The experimental results demonstrated that the four mammographic images acquired using the research-purpose mammography system in Gyeonggi Province exhibited a mean visible hole length of 6.0 mm. In contrast, the four images obtained using the clinical mammography system in Namyangju showed a mean visible length of less than 6.0 mm. These findings indicate that certain mammography systems may fail to satisfy the acceptance criteria for evaluating chest wall-side image coverage, suggesting the potential occurrence of incomplete visualization in this region.

The observed differences between the two mammography systems may be associated with variations in equipment manufacturers, system configurations, equipment age, and imaging environments. Furthermore, additional factors, including patient anatomy, positioning reproducibility, and exposure parameters, may influence image coverage during clinical mammography. Therefore, consistent visualization of breast tissue adjacent to the chest wall cannot be assumed across all mammography systems, and the possibility of image loss in this region should be considered in routine clinical practice.

Overall, the findings suggest that the current mammography quality control framework in South Korea may not fully address the assessment of image coverage near the chest wall. Given that chest wall-side image coverage is evaluated as part of mammography quality control protocols in several other countries, consideration should be given to incorporating this assessment into the national quality control standards. The proposed 3D-printed phantom demonstrated preliminary feasibility as a practical evaluation tool for this purpose. Further validation across different mammography systems and clinical settings is warranted to establish its reliability and applicability. Incorporating an appropriately validated assessment of chest wall-side image loss into routine quality control procedures may contribute to the early identification of equipment-related imaging limitations and support improvements in mammographic image quality and diagnostic reliability.

REFERENCES

[1] Ministry of Health and Welfare. Cancer incidence and mortality status. E-Nara Indicators [Internet]. Sejong: Ministry of Health and Welfare; [cited 2026 Oct 17]. Available from: https://www.index.go.kr/unify/idx-info.do?idxCd=2770.

[2] Jung H, Jung JE, Hyun H, Won D. The evaluation of space dose distribution for digital mammography equipment. J Korean Soc Radiol. 2015;9(1):61-65. doi:10.7742/jksr.2015.9.1.61. Available from: https://doi.org/10.7742/jksr.2015.9.1.61.

[3] Shin JY, Lee SB, Jin GH, Lee SY, Lee JH. A survey on quality control of mammography equipment in some regions. Journal of the Korean Society of Radiological Science. 2008;2(4):11-25. DOI: Not verified. [Bibliographic details require verification.]

[4] Lee DY, Lee JS. Evaluation of scattered radiation dose according to the position of radiation workers during mammography. J Radiol Sci Technol. 2016;39(3):297-303. doi:10.17946/JRST.2016.39.3.01. Available from: https://doi.org/10.17946/JRST.2016.39.3.01.

[5] Kim JS. Dose evaluation according to breast implant insertion during mammography using Monte Carlo method [master's thesis]. Busan: Catholic University of Busan; 2021. DOI: Not verified. [Institutional record requires verification.]

[6] Heo Y, Kim K, Noh SC, Nam SH, Park JK. A base study on the constancy quality control test and clause of diagnosis radiation equipment. J Korean Soc Radiol. 2014;8(3):105-110. doi:10.7742/jksr.2014.8.3.105. Available from: https://doi.org/10.7742/jksr.2014.8.3.105.

[7] Ko KH. Quality control of mammography. Journal of the Korean Society of Breast Cancer Screening. 2006;3(1):75-79. DOI: Not verified. [Original journal record requires verification.]

[8] Ministry of Health and Welfare. Regulations on the installation and operation of special medical equipment [Internet]. Republic of Korea: Ministry of Health and Welfare; amendment details to be verified. Available from: https://www.law.go.kr/ .

[9] Reis C, Pascoal A, Sakellaris T, Koutalonis M. Quality assurance and quality control in mammography: a review of available guidance worldwide. Insights Imaging. 2013;4(5):539-553. doi:10.1007/s13244-013-0269-1. PMCID: PMC3781250. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC3781250/.

[10] Kim SJ, Ji TJ. Actual condition on accuracy control of mammography equipment in Kyeongsangbuk-do. J Radiol Sci Technol. 2006;29(1):29-37. DOI: Not verified. [Bibliographic details require verification.]

[11] Zheng HY, Cho PK, Kim TW, Kim JS, Jang HC, Lee MH. Quality management for mammography equipment and mammography. J Korean Soc Radiol. 2018;12(5):683-692. doi:10.7742/jksr.2018.12.5.683. Available from: https://doi.org/10.7742/jksr.2018.12.5.683.

[12] Park HJ, Jang JS. Establish selection process of performance management medical devices and test items based on risk management. J Biomed Eng Res. 2019;40(1):20-31. doi:10.9718/JBER.2019.40.1.20. Available from: https://doi.org/10.9718/JBER.2019.40.1.20.

[13] Japanese Society of Radiological Technology. Mammography quality control manual. Tokyo: Japanese Society of Radiological Technology; publication year and edition to be verified. DOI: Not verified.

[14] Heo JU, Bae SJ, Im DJ. A study on hydrophobic surface treatment for microfluidic system fabrication based on SLA 3D printing method. Korean Chem Eng Res. 2024;62(1):105-111. doi:10.9713/kcer.2024.62.1.105. Available from: https://doi.org/10.9713/kcer.2024.62.1.105.

[15] Hong DY, Lee J, Lee JH, Moon JW, Oh HS, Jung YW, et al. Evaluation of usefulness and fabrication of femur phantom on quality control of bone mineral density using 3D printing technology. J Radiol Sci Technol. 2023;46(1):1-8. DOI: Not identified in the KCI record. Available from: https://www.kci.go.kr/kciportal/landing/article.kci?arti_id=ART002931457.