Journal of Medical Imaging

MedicalImaging.SPIEDigitalLibrary.org

Comparison of screening full-field digital mammography and digital breast tomosynthesis technical recalls

Lonie R. Salkowski
Mai Elezaby
Amy M. Fowler
Elizabeth Burnside
Ryan W. Woods
Roberta M. Strigel

Comparison of screening full-field digital mammography and digital breast tomosynthesis technical recalls

Lonie R. Salkowski,^{a,b,*} Mai Elezaby,^a Amy M. Fowler,^{a,b,c} Elizabeth Burnside,^{a,c,d} Ryan W. Woods,^a and Roberta M. Strigel^{a,b,c}

^aUniversity of Wisconsin Madison, Department of Radiology, Madison, Wisconsin, United States

^bUniversity of Wisconsin Madison, Department of Medical Physics, Madison, Wisconsin, United States

^cUniversity of Wisconsin, Carbone Cancer Center, Madison, Wisconsin, United States

^dUniversity of Wisconsin School of Medicine and Public Health Institute of Clinical Translational Science, Madison, Wisconsin, United States

Abstract. Enhancing quality using the inspection program (EQUIP) augments the FDA/MQSA program ensuring image quality review and implementation of corrective processes. We compared technical recalls between digital breast tomosynthesis (DBT) and full-field digital mammography (FFDM). Prospectively recorded technical recalls of consecutive screening mammograms (10/2013 – 12/2017) were compared for imaging modality [FFDM, DBT + FFDM, DBT + synthesized mammography (SynM)], images requested, and indication(s) (motion, positioning, technical/artifact). Chi-squared tests evaluated statistical significance between proportions. Of 48,324 screening mammograms, 277 (0.57%) patients were recalled for 360 indications with 371 repeated views. DBT exams had significantly less recalls compared to FFDM ($X^2 = 25.239$; $p = 0 < 0.001$). 98 (27.2%) recalls were for motion, 192 (53.3%) positioning, and 70 (19.4%) technique/artifacts. These indications for technical recall were compared for FFDM, DBT + FFDM, and DBT + SynM. There were significant differences in the indications for technical recall prior to and after implementing DBT + SynM ($X^2 = 18.719$; $p < 0.001$). Technical recalls declined significantly with the inclusion of DBT (SynM/FFDM) compared to FFDM alone. Recalls for motion demonstrated the greatest decrease. Positioning remains a dominant factor for technical recall regardless of modality, supporting the opportunity for continued technologist education in positioning to decrease technical recalls. © 2018 Society of Photo-Optical Instrumentation Engineers (SPIE) [DOI: [10.1117/1.JMI.6.3.031403](https://doi.org/10.1117/1.JMI.6.3.031403)]

Keywords: technical recall; EQUIP; breast imaging; digital mammography; FFDM; tomosynthesis.

Paper 18175SSR received Aug. 12, 2018; accepted for publication Nov. 30, 2018; published online Dec. 22, 2018.

1 Introduction

Screening mammography for breast cancer detection in asymptomatic women is the only modality that has been shown in large randomized control trial to decrease cancer mortality.¹ Women who have cancers detected by screening mammography have higher survival rates compared to unscreened women due to the smaller tumor size and stage at detection.^{2–5} Quality assurance of screening mammography is essential for accurate mammographic interpretation.⁶ Improper mammographic positioning can result in the exclusion of tissue and potentially missed cancers.^{7–9} Delays in cancer detection due to observer error and technical issues have been reported in 22% of screen-detected cancers and 35% of interval breast cancers,¹⁰ emphasizing the importance of mammographic quality.

In 1992, the Food and Drug Administration (FDA) Mammography Quality Standards Act (MQSA) was enacted to set comprehensive quality standards for all aspects of mammography,^{11,12} and compliance requirements for all facilities performing breast imaging. Analog imaging was standard in breast imaging at that time. As a supplement to the MQSA accreditation process, the American College of Radiology Mammography Accreditation Program (ACRMAP) assures the quality of images acquired at each facility by reviewing an example of the facility's clinical images from each unit on

a triannual renewal cycle. Clinical images are assessed based on eight image features: positioning, compression, exposure, contrast, sharpness, noise, artifacts, and labeling.¹³ Despite the success of the MQSA and ACRMAP in improving and standardizing the quality of mammographic imaging, the most common technical failure of the ACR clinical image quality review is poor positioning.^{6,8,14–16} Even with the expansion of digital imaging, several studies demonstrated that poor positioning led to undetected cancers in both 2-D full-field digital mammography (FFDM),¹⁴ and digital breast tomosynthesis (DBT).^{17,18} One weakness of the ACR clinical image review is that it takes place only at the time of initial certification and renewal (every 3 years). In addition, there is no corrective-action process that involves all interpreting physicians and technologists. In January 2017, the Enhancing Quality Using the Inspection Program (EQUIP) was established to augment the FDA's MQSA program to ensure continuous image quality review and implement processes for corrective action.¹⁹ This program enforces that image quality is the combined responsibility of technologists and radiologists, and defines a method to provide feedback that generates necessary improvements.^{6,19}

A standard mammogram includes craniocaudal (CC) and mediolateral oblique (MLO) views of each breast to maximize the amount of breast tissue imaged (Fig. 1). Mammographic quality “positioning standards” are evaluated for each mammographic view. The CC view should have the nipple centered and

*Address all correspondence to Lonie R. Salkowski, E-mail: lsalkowski@uwhealth.org

Fig. 1 Illustration of positioning criteria of the breast. (a) Left MLO view demonstrating the pectoralis muscle, nipple in profile, and the IMF. (b) Left CC view demonstrating the nipple in profile and centered. The white line indicates the PNL comparison between the CC and MLO views.

in profile and include the medial and lateral borders of the breast.^{20–22} The MLO view is acquired with an angle range from 30 to 70 deg depending on the patient's body habitus. The MLO should include the pectoral muscle with a wide superior border and convex anterior border. The inframammary fold (IMF) should be open visualizing the top of the abdomen and without folds. The anterior breast should be compressed and not drooping.^{20–22} The CC and MLO are together evaluated to ensure that the maximal amount of breast tissue is imaged through the evaluation of the posterior nipple line (PNL). The PNL measurement is the distance from the nipple to the edge of the image (or edge of visualized pectoralis muscle) on the CC view, and the distance from the nipple to the pectoralis muscle on the MLO view (Fig. 1). These two measurements should be within 1 cm of length.^{20–22} Additionally, the pectoralis muscle should extend inferior to at least the level of the PNL on the MLO view to ensure adequate inclusion of posterior tissue.

Simultaneous with the implementation of the EQUIP program, substantive changes in screening mammography technology have been adopted. With the implementation of digital breast tomosynthesis (DBT), there have been several imaging techniques available beyond digital 2-D techniques (FFDM). During early implementation, DBT imaging was combined with FFDM. Following FDA approval, a synthesized mammogram (SynM) is reconstructed from the acquired digital tomosynthesis data. SynMs have replaced FFDM in the DBT exam and also

reduced patient radiation exposure. Now, there is an important opportunity to gain a greater understanding of the impact that current imaging technology has upon technical recalls/failures. There is little data on how these modalities and imaging techniques affect the radiologist's and technologist's assessment of image quality. The purpose of this study is to compare the impact of three categories of technical recalls (motion, positioning, and artifacts) between FFDM screening mammography and DBT, including both DBT with FFDM and DBT with SynM.

2 Methods

This HIPAA-compliant study was exempt from IRB review. Technical recalls from consecutive digital screening mammograms performed at our three imaging sites between October 2013 and December 2017, were reviewed for imaging modality (FFDM, DBT + FFDM, DBT + SynM), repeat imaging views requested, and indication(s) for technical recall as prospectively dictated in the mammography report and recorded in an on-line quality assurance (QA) program. Technical recalls were submitted from eight breast-imaging radiologists with a range of 3 to 30 years of experience in interpreting mammographic studies.

Mammographic imaging was performed on Hologic Selenia Dimensions later converted to Hologic 3Dimensions™. DBT images were initially interpreted on a dedicated Hologic Workstation. On July 24, 2015, our McKesson PACS workstations were upgraded to McKesson Radiology Mammography

Plus™ that allowed DBT imaging to be interpreted on PACS workstations in conjunction with the patient's other imaging files. This made image interpretation more efficient, however, the projection images acquired at the time of DBT images were no longer available for review.

For each technical recall, case identifiers that were collected to provide review of the images and dictated report included: date, imaging modality (FFDM, DBT + FFDM, DBT + SynM), the imaging site, technologist, and interpreting physician. Each technical recall included a request for the image(s) to be repeated and the indication(s). The image requested included right craniocaudal (RCC), right mediolateral oblique (RMLO), left craniocaudal (LCC), and left mediolateral oblique (LMLO). The indications for technical recall were grouped into three large categories: motion, positioning, and technique/artifacts. Positioning reasons for a technical recall included deficient tissue (posterior, lateral, medial, superior/axillary tail, and inferior), need for more pectoralis muscle, nipple not seen in profile, inability to see surgical clips or the lumpectomy site, and poor visualization of the IMF. The breakdown of reasons for technique/artifacts was artifacts, collimator issues, suboptimal tissue penetration, inadequate implant technique, deodorant artifact, and skin folds.

In October 2013, the three breast imaging facilities in our organization were updated with the capability of performing both FFDM and DBT imaging. After the implementation of DBT, patients were given the opportunity of having screening mammograms performed with FFDM or DBT. In the early adoption of DBT, screening mammograms with DBT were performed as a combination of FFDM and DBT. Later, a SynM rendered from the DBT data became available. To become accustomed to the SynM, there was an interval during which FFDM, DBT, and SynM were available for all cases. Beginning April 4, 2016, all DBT exams included only SynM.

The percentage of technical recalls was calculated as the number of technical recalls divided by the number of exams (by modality and overall). Within each modality (FFDM,

DBT + FFDM, DBT + SynM), the sum of each indication was determined and the percentage of that indication (number of recalls divided by the total number of recalls in that modality) was used for comparison within and between imaging modalities. The percentage (proportion) differences between technical recall indications and modality were evaluated using the " $N - 1$ " Chi-squared test,^{23,24} and Pearson Chi-square test using SSPS. Linear regression was used to evaluate correlation. Significance was assessed at $p < 0.05$.

3 Results

3.1 Distribution of Technical Recalls Between FFDM and DBT

Of the 48,324 screening mammograms, 37,896 mammograms were FFDM (78.42%) and 10,428 were DBT (21.58%). There were 274 patients recalled for the 277 technical recalls. Three patients had been recalled twice for technical reasons during our study interval. The overall technical recall rate for all mammograms performed was 0.57% ($n = 277$), with the technical recall rate for FFDM of 0.63% ($n = 238$) and 0.38% for DBT ($n = 39$). The DBT images presented here include both those combined with FFDM and/or SynM. There were significantly less technical recalls for exams that included DBT compared to FFDM ($X^2 = 25.239$; $p = 0 < 0.001$). For the 277 technical recalls, there were 371 views (RCC, RMLO, LCC, and LMLO) requested and 360 indications that were broadly classified as motion, positioning issues, and technique/artifacts.

3.2 Distribution of Technical Recalls for Technologists and Radiologists

Both radiologists and technologists are responsible for technical recalls. During this study, there were 9 radiologists and 12 technologists. The charts below (Figs. 2 and 3) demonstrate the overall distribution of cases for the radiologists and technologists. These charts indicate that there is no correlation between the

Fig. 2 Distribution of the technical recalls per number of exams performed over the study by technologists. Each technologist is represented by a data point.

Fig. 3 Distribution of the technical recalls per number of exams interpreted over the study by radiologists. Each radiologist is represented by a data point.

number of studies performed (technologists, $R^2 = 0.0013$) or interpreted (radiologists, $R^2 = 0.0899$) and the number of technical recalls.

3.3 Indications for Technical Recall

Of the 360 technical recall indications, there were 293 for FFDM and 69 for DBT. Motion was the cause in 31% ($n = 91$) of FFDM recalls compared to 10% ($n = 7$) of DBT recalls (Table 1). Proportionally, positioning is a significant indication for technical recall for DBT compared to FFDM [80.6% ($n = 54$) versus 47.1% ($n = 138$); $X^2 = 24.520$, $p < 0.0001$; Fig. 4]. The ability to obtain adequate posterior tissue is a major challenge for both FFDM and DBT. This proportion was significantly increased for DBT (35.8%) compared to FFDM (15.7%) ($X^2 = 14.028$; $p = 0.0002$). Artifacts such as deodorant ($X^2 = 4.501$; $p = 0.0339$) and skin folds ($X^2 = 0.366$; $p = 0.5450$) are more commonly recalled for FFDM compared to DBT.

3.4 Indications Within DBT Imaging Platforms

Early DBT imaging included FFDM images, and later the FFDM was replaced with SynM. During the early period of DBT implementation, there were 23,256 FFDM and 4912 DBT + FFDM exams performed, with 144 (0.62%) and 27 (0.55%) respective technical recalls ($X^2 = 0.323$, $p = 0.567$). Following SynM implementation, there were 14,640 FFDM and 5516 DBT + SynM exams, with 94 and 12 technical recalls resulting in respective technical recall rates of 0.64% and 0.22% ($X^2 = 13.802$, $p = 0.0002$).

The technical recall rate for FFDM remained constant prior to and after the implementation of the SynM with DBT imaging (0.62% versus 0.64%; $p = 0.773$). However, a significant decrease in technical recall rates was observed for DBT exams with the SynM only. The technical recall rate for DBT

Table 1 Indications for technical recall based on modality.

Indication for technical recall	Number of cases overall	% FFDM indications	% DBT ^a indications
Motion	98	31.1	10.4
Positioning issues	192	47.1	80.6
Posterior tissue	70	15.7	35.8
Pectoralis muscle	34	8.9	11.9
IMF	24	6.8	6.0
Nipple not in profile	15	4.8	1.5
Surgical clips/lumpectomy site	13	1.7	11.9
Lateral tissue	14	3.1	7.5
Medial tissue	13	3.1	6.0
Superior/axillary tail tissue	7	2.4	0.0
Inferior tissue	2	0.7	0.0
Technical/artifacts	70	21.8	9.0
Artifact	5	1.7	0.0
Collimator issue	1	0.3	0.0
Suboptimal penetration	4	1.0	1.5
Implant technique	4	1.4	0.0
Deodorant	28	9.2	1.5
Skin folds	28	8.2	6.0

^aDBT cases included both DBT + FFDM and DBT + SynM.

Fig. 4 Distribution of indications for technical recalls for FFDM and DBT.

dropped from 0.55% (DBT + FFDM $\pm$ SynM) to 0.22% (DBT + SynM) ($X^2 = 7.695$, $p = 0.006$).

3.4.1 Shift in technical recall indications

The indications for technical recall for FFDM exams remained constant prior to and after the implementation of DBT + SynM. However, there was a shift in indications for technical recall for DBT cases. After implementation, motion was no longer an indication for DBT technical recall (decrease from 15.6% to 0%; $X^2 = 3.776$, $p = 0.0520$). Indications for positioning increased from 77.8% to 86.4% ($p = 0.406$), and similarly an increase for technique/artifacts from 6.7% to 13.6% ($p = 0.357$; Fig. 5). This increase in technique/artifact recall was due to recalls for suboptimal penetration of the breast tissue (4.5%) and skin folds (9.1%).

3.4.2 Positioning technical recalls

The percentage of positioning technical recall indications increased for DBT exams with the implementation of the SynM. This was demonstrated with nonsignificant trends toward an increase in percentage of cases recalled for missing pectoralis muscle (8.9% to 18.2%) and also an increase in the percentage of cases lacking complete visualization of the surgical clips/lumpectomy site (8.9% to 18.2%). The indication for posterior tissue remained the highest positioning indication for technical recall before or after implementation of the SynM (37.8% and 31.8%, respectively). There was a nonsignificant increase in technical recalls for improper visualization of the IMF from 4.4% to 9.1%. Mild declines in technical recalls were seen in the positioning of medial (6.7% to 4.5%) and lateral breast tissue (8.9% to 4.5%).

Fig. 5 Changes in the indications for technical recall prior to and after the implementation of SynM with DBT imaging.

4 Discussion

MQSA's primary goal is to ensure high quality clinical mammographic images. At the 25-year anniversary of MQSA, the Division of Mammographic Quality Standards (DMQS) launched the EQUIP, which became part of the inspection process in 2017. The three components that EQUIP addresses in mammographic quality are: importance of a daily image quality review, regular facility wide quality reviews, and the personnel responsibilities for image quality.¹⁹ It also emphasizes that high quality images are a combined effort of the technologists and radiologists.^{6,19}

Our on-line QA program tracks technical recalls and also records the indications for the review. The technologist is informed of the technical recall and the indications. This process aids in determining the factor(s) affecting image quality and provides for appropriate education and training. The results of the overall QA process are reviewed with the technologists.

MQSA determines that if a technologist's repeat/reject analysis is greater than 2% increase, corrective action should be taken.²⁵ However, MQSA does not provide an acceptable range for technical recalls. This study demonstrated an overall technical recall rate of 0.57%, with a range of 0.11 to 1.39% (average of 0.45%) of mammograms for technologists (Fig. 2) and 0.07% to 0.79% (average of 0.39%) for radiologists (Fig. 3).

There was a higher overall recall rate for FFDM compared to DBT. The technical recall rate further decreased for DBT after implementation of the SynM. Within the categories of technical recall, FFDM had higher technical recall rates for motion and artifacts, whereas DBT exceeded FFDM in positioning technical recalls.

DBT can visualize the skin surface, thus definitively identifying deodorant artifact or skin folds, thereby reducing the need for technical recalls (Fig. 6). Although the skin folds are clearly seen on the DBT images, they can create a significant artifact on the SynM compared to that seen on the FFDM and make comparison to the prior mammogram exams suboptimal in

some cases. We also found a decrease in technical recalls due to motion using DBT, particularly in combination with SynM without FFDM. Perhaps, DBT and the SynM are not optimally suited to detect motion. Both the SynM and the DBT image stacks for review are created from the acquired projection images. At our institution, our mammograms are viewed on a PACS workstation. For DBT exams, both the SynM and DBT images stacks are available for review, however, the acquired projection images are not. The acquired projection images best demonstrate motion, and their absence may have had an impact on motion detection. Currently, the FDA does not mandate review of the projection images for clinical interpretation.

As DBT increases in clinical practice and replaces the FFDM for screening mammography, it will be important to identify potential causes of technical recalls. Overall, there was a decrease in recalls for DBT + SynM compared with DBT + FFDM and FFDM alone. However, although not significant, there were an increase percentage of cases recalled for missing pectoralis muscle (8.9% to 18.2%; $p = 0.274$) and cases lacking complete visualization of the surgical clips/lumpectomy site (8.9% to 18.2%; $p = 0.274$). Although the increase in proportion of recalls for these indications are likely due to a corresponding decrease in indications for motion and technique/artifacts, this is an aspect of positioning to be monitored and for potential additional training of the technologists. It is also important to note that the major positioning technical recall indication that persisted with DBT was missing posterior tissue, and technologist training in excellent positioning remains critical even as DBT is implemented fully into mammography practices.

Positioning has a great impact on the detection of small and subtle lesions at screening mammography.²² Positioning that excludes tissues has an impact on missing cancers.²² Furthermore, high-risk women, including BRCA mutation carriers, have a higher proportion of cancers in the posterior location of the breast.²⁶ Taplin et al.¹⁴ identified that the sensitivity of the screening exam changed with positioning success.

Fig. 6 (a) FFDM of the left MLO axillary region. The white arrow is pointing to tiny white "calcifications" in the axillary region, which may represent either calcifications or deodorant artifact. Breast tissue extends into the axilla; thus, this may be clinically important. (b) Left MLO DBT image of the same patient. These tiny white "calcifications" are only seen on the image for slice 1 (long white arrow pointing to slice number indicator), thus signifying that they are located on the skin surface and can be disregarded as artifact.

If the mammogram passed on positioning, it had 84.4% sensitivity, and if it failed positioning, sensitivity decreased to 66.3%. Thus, the exclusion of tissue, and especially posterior breast tissue, has a larger impact on patient care. Our study demonstrated that the largest percentage of excluded tissue was posterior regardless of imaging modality. Positioning errors, as a percentage of recalls, significantly increased for DBT ($p < 0.0001$). Furthermore, the exclusion of posterior tissue (as a percentage of recalls) with DBT compared to FFDM was significantly increased. These findings support that ongoing education in image quality remains necessary and important.^{27,28} Pal et al.²⁹ identified five factors that contribute to poor positioning: reluctance to repeat images (technologist and patient), patient difficulty, image quality evaluation inconsistency, insufficient time for patient care, and technologist engagement.

Regardless of whether mammogram images are obtained with FFDM, DBT + FFDM or DBT + SynM, positioning remains the Achilles heel of breast imaging. An objective review of the technical recalls of a program provides an opportunity to increase education in positioning and decrease technical recalls that can cause anxiety among patients and workflow inefficiencies.

There are limitations to this study. In the early implementation of the study, FFDM and DBT imaging was included with each screening mammogram. At the time of the prospective technical recall, it was not required for the radiologist to identify if the technical recall was based on the FFDM or DBT portion of the exam. Thus, during this time, it may inflate or deflate the corresponding data during this interval. This study was performed at a single academic institution thus these results may not be generalized to other institutions.

5 Conclusions and Future Work

Mammographic positioning remains a major factor of technical recalls, which is important because breast tissue not included on the image is a potential source of missed cancers. This problem has been demonstrated in studies with screen film mammography, FFDM, and more recently with DBT. The current digital mammography imaging equipment has minimized some of the technical reasons for mammographic technical deficiencies. Investments in a screening program to improve and maintain optimal positioning have some financial burdens (personnel, instructors, etc.). However, the overall gain is improved quality of breast imaging and better patient care. The goal of EQUIP is to reinforce image quality and to encourage breast imaging practices to identify ways to improve image quality and positioning.

Disclosures

Drs. Roberta Strigel and Amy Fowler receive research support from GE Healthcare.

Acknowledgments

We would like to thank our technologists who are continually striving to provide the best care for our patients. Also, we would like to thank Jenelle Smith, RT our lead technologist, for assistance in providing imaging numbers and quality reports used in this study. This work has been published in the Proc. of SPIE, 14th International Workshop on Breast Imaging (IWBI 2018), Volume 19, No. 58, and presented as a poster at IWBI.

References

1. R. A. Smith et al., "The randomized trials of breast cancer screening: what have we learned," *Radiol. Clin. North Am.* **42**, 793–806 (2004).
2. National Cancer Institute, "Breast cancer screening (PDQ®)– health professional version," 2018, https://www.cancer.gov/types/breast/hp/breast-screening-pdq#link/_93_toc (18 February 2018).
3. N. Howlader et al., Eds., *SEER Cancer Statistics Review, 1975-2014*, National Cancer Institute, Bethesda, MD, https://seer.cancer.gov/csr/1975_2014/, based on November 2016 SEER data submission, posted to the SEER web site, April 2017.
4. E. B. Elkin et al., "The effect of changes in tumor size on breast carcinoma survival in the U.S.: 1975–1999," *Cancer* **104**(6), 1149–1157 (2005).
5. M. Broeders et al., "The impact of mammographic screening on breast cancer mortality in Europe: a review of observational studies," *J. Med. Screening* **19**(1 Suppl), 14–25 (2012).
6. US Food & Drug Administration (FDA), "Poor positioning responsible for most clinical image deficiencies, failures," 2017, <https://www.fda.gov/Radiation-EmittingProducts/MammographyQualityStandardsActandProgram/FacilityScorecard/ucm495378.htm> (17 February 2018).
7. R. E. Bird, T. W. Wallace, and B. C. Yankaskas, "Analysis of cancers missed at screening mammography," *Radiology* **184**(3), 613–617 (1992).
8. R. L. Birdwell et al., "Mammographic characteristics of 115 missed cancers later detected with screening mammography and the potential utility of computer-aided detection," *Radiology* **219**(1), 192–202 (2001).
9. R. M. Kamal et al., "Missed breast carcinoma; why and how to avoid?" *J. Egypt. Natl. Cancer Inst.* **19**(3), 178–194 (2007).
10. C. J. Baines, D. V. McFarlane, and A. B. Miller, "The role of the reference radiologist. Estimates of inter-observer agreement and potential delay in cancer detection in the national breast screening study," *Invest. Radiol.* **25**(9), 971–976 (1990).
11. R. E. Hendrick, "Quality assurance in mammography. Accreditation, legislation, and compliance with quality assurance standards," *Radiol. Clin. North Am.* **30**(1), 243–255 (1992).
12. F. Houn, M. L. Elliott, and J. L. McCrohan, "The mammography quality standards act of 1992. History and philosophy," *Radiol. Clin. North Am.* **33**(6), 1059–1065 (1995).
13. L. W. Bassett, A. C. Hoyt, and T. Oshiro, "Digital mammography: clinical image evaluation," *Radiol. Clin. North Am.* **48**(5), 903–915 (2010).
14. S. H. Taplin et al., "Screening mammography: clinical image quality and the risk of interval breast cancer," *Am. J. Roentgenol.* **178**(4), 797–803 (2002).
15. B. I. Reiner, "Hidden costs of poor image quality: a radiologist's perspective," *J. Am. Coll. Radiol.* **11**(10), 974–978 (2014).
16. L. W. Bassett et al., "Reasons for failure of a mammography unit at clinical image review in the american college of radiology mammography accreditation program," *Radiology* **215**(3), 698–702 (2000).
17. I. Andersson et al., "Breast tomosynthesis and digital mammography: a comparison of breast cancer visibility and BIRADS classification in a population of cancers with subtle mammographic findings," *Eur. Radiol.* **18**(12), 2817–2825 (2008).
18. P. Skaane et al., "Follow-up and final results of the Oslo I Study comparing screen-film mammography and full-field digital mammography with soft-copy reading," *Acta Radiol.* **46**(7), 679–689 (2005).
19. US Food & Drug Administration (FDA), "EQUIP: enhancing quality using the inspection program," 2017, <https://www.fda.gov/Radiation-EmittingProducts/MammographyQualityStandardsActandProgram/FacilityScorecard/ucm526238.htm> (17 February 2018).
20. O. Peart, "Positioning challenges in mammography," *Radiol. Technol.* **85**(4), 417–439 (2014).
21. L. W. Bassett, "Mammographic positioning: evaluation from the view box," *Radiology* **188**(3), 803–806 (1993).
22. A. I. Huppe et al., "Mammography positioning standards in the digital era: is the status quo acceptable?" *Am. J. Roentgenol.* **209**(6), 1419–1425 (2017).
23. I. Campbell, "Chi-squared and Fisher-Irwin tests of two-by-two tables with small sample recommendations," *Stat. Med.* **26**, 3661–3675 (2007).
24. J. T. E. Richardson, "The analysis of 2 × 2 contingency tables –yet again," *Stat. Med.* **30**, 890–890 (2011).

25. US Food & Drug Administration (FDA), "Mammography quality standards act regulations," 2017, <https://www.fda.gov/radiation-emitting-products/mammographyqualitystandardsactandprogram/regulations/ucm110906.htm#s90012> (25 February 2018).
26. S. Schrading and C. K. Kuhl, "Mammographic, US, and MR imaging phenotypes of familial breast cancer," *Radiology* **246**(1), 58–70 (2008).
27. M. H. Guertin, "Technologists' characteristics and quality of positioning in daily practice in a Canadian breast cancer screening program," *Acad. Radiol.* **23**(11), 1359–1366 (2016).
28. M. H. Guertin et al., "Clinical image quality in daily practice of breast cancer mammography screening," *Can. Assoc. Radiol. J.* **65**, 199–206 (2014).
29. S. Pal et al., "Improving performance of mammographic breast positioning in an academic radiology practice," *Am. J. Roentgenol.* **210**, 807–815 (2018).

Lonie R. Salkowski is a radiologist who specializes in breast imaging. She also has a doctorate in education. Her research interests include mammographic image quality improvements, cognitive reasoning and perceptual skills of medical image interpretation, and simulation.

Mai Elezaby is a breast imaging radiologist with interests in resident and breast imaging fellowship education. She is an associate section chief for the academic division.

Amy M. Fowler is a breast imaging radiologist with research interests in the investigation of molecular imaging biomarkers to assess early therapeutic response for breast cancer in preclinical and translational clinical studies.

Elizabeth Burnside is a breast imaging radiologist whose research investigates the use of computational methods to improve decision-making in the domain of breast imaging in the pursuit of improving the population-based screening and diagnosis of breast cancer.

Ryan W. Woods is a breast imaging radiologist and is an associate section chief for the community division.

Roberta M. Strigel is a radiologist who specializes in breast imaging and is the chief of the breast imaging section. Her research interests are in improving breast MR imaging.