Evaluation of the quality of mammographic breast positioning in Quebec

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ABSTRACT

Background: While mammography is a reliable and cost-effective method for breast cancer screening, there are concerns that inadequate breast positioning in mammographic exams may lead to missed cancers. Studies examining the quality of positioning within the Canadian context are limited. Thus, the Ordre des technologues en imagerie médicale, en radio-oncologie et en électrophysiologie médicale du Québec launched a professional inspection among its members to assess the quality of breast positioning in mammographic exams.

Methods: This cross-sectional study is based on an inspection conducted between May 2017 and July 2017 among a 15% stratified random sample of all active technologists certified in mammography in Quebec. Each technologist provided 15 consecutive mammographic exams performed in the previous six months. The quality of positioning was then evaluated by senior technologists using a quality assessment tool specifically developed for this inspection. A technologist was deemed to have failed the professional inspection when at least 6 of the 15 mammograms were scored as critical failures.

Results: Among 522 technologists certified in mammography in Quebec, 76 technologists were randomly selected for the professional inspection and contributed 1127 mammographic exams. A total of 38 technologists (50.0%, 95% confidence interval 38.3%-61.7%) failed the professional inspection and 491 exams (43.6%) were found to have critical failures.

Interpretation: Our findings show that half of the technologists failed the inspection and a significant proportion of mammographic exams had critical failures in breast positioning. These results call for additional training for technologists and an assessment of its impact on breast cancer detection.

INTRODUCTION

In Canada, breast cancer is the most commonly diagnosed cancer in women and is expected to affect one in eight Canadian women throughout the course of their lifetime.(1) Early detection is paramount to maximizing treatment success and improving patient outcomes. Mammography is currently the most reliable and accepted method for detecting breast cancer but fails to detect between 16% and 30% of breast cancers.(2) Factors such as younger age and higher breast density have been shown to decrease the screening accuracy of mammograms.(2, 3) Improper breast positioning can also decrease the diagnostic sensitivity of the mammogram, potentially leading to unnecessary repeat examinations, higher radiation exposure, unnecessary invasive procedures such as biopsies and surgery, or missed breast cancer cases.(4-7)

There have been increasing concerns regarding the quality of breast positioning.(4, 8-10) In Canada, one small study evaluated the quality of 197 mammograms performed between 2004-2005 as part of the Quebec Breast Cancer Screening Program.(8) Findings showed that 49.7% of mammograms did not satisfy the quality criteria of breast positioning established by the Canadian Association of Radiologists. The paucity of more recent evidence however highlights the need for an updated evaluation of the quality of breast positioning and for the development of a comprehensive and reliable tool that can be effectively used to assess those mammograms.

Thus, the Ordre des technologues en imagerie médicale, en radio-oncologie et en électrophysiologie médicale du Québec launched a professional inspection among its members to assess the quality of breast positioning in mammographic exams. The objective of this study was thus to assess the quality of mammographic positioning in a representative sample of active technologists certified in mammography in the province of Quebec.

METHODS

Study Population

Between May 2017 and July 2017, at the request of the Ordre des technologues en imagerie médicale, en radio-oncologie et en électrophysiologie médicale du Québec (OTIMROEPMQ), we selected a representative sample of all active, certified medical radiation technologists with accredited training in breast imaging in Quebec in 2017. To select participants for the inspection, we used a stratified sampling strategy which was based on four criteria: 1) geographic location of the centre (urban versus rural); 2) annual volume of mammograms performed in the centre where the technologist practices (low versus high volume, using the median of 2266 as the cut-off); 3) annual number of mammograms performed by the technologist (low versus high, using the median of 709 as the cut-off; and 4) the number of years of experience (<3 years, 3-14 years, ≥15 years) with or without continuing education.

The stratification procedure prevented over-sampling of the most common individuals, for example technologists working in urban centres. Thus, the stratified sampling generated 48 possible combinations of strata from which one or more technologists were selected at random, to obtain a representative sample size of approximately 15% of all active technologists certified in mammography in Quebec. Tomosynthesis mammograms, single or double mastectomy patient images, and male patients with suspected breast cancer were excluded.

Development of the Quality Assessment Tool

To our knowledge, no reliable tool exists to accurately evaluate the quality of mammographic positioning. Consequently, we created a quality assessment tool with the main objective of limiting subjectivity while also maximizing the inter-rater agreement. We first

conducted a review of the scientific literature to establish a list of criteria for quality assessment in mammographic positioning. We also searched standardized guidelines such as the American College of Radiology, the Canadian Association of Radiologists, and the European Commission Initiative on Breast Cancer. We then created an expert panel composed of three technologists currently providing training in mammography imaging and recommended by their professional order for their superior expertise in breast imaging. The expert panel independently provided a set of criteria for the evaluation of the quality of mammographic positioning based on their professional experience and training. Separate sets of criteria were developed for craniocaudal (CC) views and mediolateral oblique (MLO) views. We then conducted multiple rounds of pilot evaluation in which we reviewed each criterion. For the overall quality score, we used a binary response (adequate vs critical failure) based on the PGMI (Perfect, Good, Moderate, Inadequate) evaluation system used for quality assurance in mammography in the United Kingdom.(11) To reduce subjectivity, we predefined the criteria necessary for an image to be evaluated as critical failure. Details of the pilot evaluation and predefined criteria are provided in **Supplementary Methods 1**.

The tool was tested for inter-rater agreement by the expert panel using a first sample of 20 mammograms and a second sample of 32 mammograms, which resulted in a high concordance rate of 97% (**Supplementary Methods 2** and **Supplementary Tables 1-2)**. The final tool contained eight criteria to evaluate positioning on CC view (**Supplementary Table 3**) and nine criteria on MLO view (**Supplementary Table 4**).

Data Collection and Analysis

The selected technologists were invited by their professional order to submit 15 consecutive mammograms conducted over a period of six months in 2017. For each mammogram submitted, we used medical records from the mammography clinics to collect the characteristics of the patient (age, weight, height, breast size and density, type of mammography). Characteristics of the technologists (type of training received, annual number of mammograms performed, number of years of experience) were self-reported, and characteristics of the clinics (location, number of patients, center designation, annual number of mammography performed) were obtained from the professional order. For technologists, a passing score was defined as a grade of 60% or more, which consisted of having at least 9 mammograms out of 15 evaluated as adequate. Conversely, failure consisted of having more than 6 mammograms out of 15 evaluated as critical failures.

Ethical approval

The current study did not require approval by an Ethics Committee as this was a professional inspection requested by the professional order of imaging technologists.

RESULTS

Of the 522 active technologists certified in mammography in Quebec, 76 were randomly selected for the professional inspection through stratified sampling. Sampling was conducted from 27 of those strata, as 21 of the 48 strata did not have active certified technologists. This sample represented 14.6% of all technologists certified in mammography in Quebec and was representative of the population of technologists working in that province.

Table 1 presents the characteristics of the technologists. The majority of technologists worked in an urban centre (n=68, 89.5%) and a high-volume centre (n=51, 67.1%). About one-fifth of technologists (n=16, 21.1%) completed additional qualifications in mammography imaging. Approximately half of technologists had between 3-14 years of experience in mammography imaging (n=42, 55.3%). Overall, technologists performed a median of 709 mammograms per year (interquartile range 284-1382, maximum 3497).

Each of the 76 selected technologists submitted 15 consecutive mammograms performed in the last six months, which resulted in the submission of 1140 exams. Of those, 13 had missing views or did not meet inclusion criteria, resulting in 1127 evaluable mammograms and their 4508 associated images (a mammogram consists of a sequence of four planar x-rays; one on CC view and one on MLO view for each breast). The characteristics of those 1127 patients and associated mammograms are presented in **Table 2**. A total of 879 mammograms (77.9%) were screening mammograms and 246 (21.8%) were diagnostic mammograms. The mean age of patients was 58.7 years (standard deviation 9.2) and the mean body mass index was 25.3 kg/m^2 (standard deviation 6.8).

Quality of Positioning on CC View

Most technologists (n=63, 83%) obtained a score above the minimum passing grade of 60%, which consisted of having at least 9 CC images out of 15 evaluated as adequate (**Supplementary Figure 1A**). **Table 3** presents the results of the evaluation of positioning on CC view for the 1127 mammograms, which consisted of 1127 right CC images and 1127 left CC images. We also evaluated the proportion of adequate CC images overall because images scored as adequate on the right are not necessarily scored as adequate on the left. The proportion of CC images scored as adequate were 77.8% for the right CC images (n=877) and 81.1% for the left CC images (n=915). A total of 72.5% of mammograms (n=817) had both CC images scored as adequate, which indicates that 27.5% of mammograms were scored as critical failures due to improper positioning on CC view. The most common reasons for a critical failure on CC view were poor visualization of deep tissues (33.6%), portion of breast not included (28.9%), and body-nipple distance larger than 1 cm of the same pectoral-nipple distance measurement on MLO view (23.2%).

Quality of Positioning on MLO View

A total of 80% of technologists (n=61) obtained a score above the passing score of 60% (**Supplementary Figure 1B)**. **Table 3** presents the results of the evaluation of positioning on MLO view for the 1127 mammograms, which consisted of 1127 right MLO images and 1127 left MLO images. We also evaluated the proportion of adequate MLO images overall. Similar to the CC results, the proportion of images scored as adequate were 80.0% for the right MLO images (n=902) and 82.4% for the left MLO images (n=929). A total of 74.0% of mammograms (n=834) had both MLO images scored as adequate, which indicates that 26.0% of mammograms were

scored as critical failures due to improper positioning on MLO view. The most common reasons for a critical failure on MLO view were poor visualization (21.3%), portion of breast not included (19.2%), and infra-mammary fold not well-demonstrated (18.9%).

Overall Quality of Breast Positioning

We combined bilateral CC and MLO images to evaluate the overall quality of the mammogram. For a mammogram to be considered adequate, both CC and MLO images had to be scored as adequate. A total of 50% of technologists (n=38, 95% confidence interval 38.3%-61.7%) did not have the minimum number of adequate mammograms, consisting of 9 out of 15 mammograms (**Supplementary Figure 2**). **Table 4** presents the results of the overall quality of positioning by combining both CC views and MLO views. A total of 56.4% (n=636) of the 1127 mammography exams were evaluated as adequate. However, these results suggest that the remaining 43.6% of the 1127 mammograms had at least one critical failure in positioning, consisting of 491 patients. Of those 491 patients, 201 (40.9%) had a critical failure in one of the four images, 209 (42.6%) had critical failures in two of the four images, and 81 (16.5%) had critical failures in either three or all four mammographic images. Additionally, 101 of the 491 patients (20.6%) had critical failures on the CC and MLO images on the same breast, meaning that those patients had no acceptable images for one of the two breasts.

Finally, in an exploratory descriptive analysis, we examined the variables associated with passing the evaluation. Overall, a higher proportion of technologists working in high-volume centres passed the evaluation, compared with technologists working in low-volume centres (58.8% vs 32.0%, respectively). Technologists who received additional qualifications also had a higher success rate than those who did not (69.0% vs 45.0%, respectively). There were

no marked differences according to geographic location of the centre (urban vs rural) and volume of mammograms performed by technologists.

INTERPRETATION

Our results indicate that 50% of technologists failed the professional inspection, where less than 9 out of 15 mammograms were scored as adequate. Overall, more than one-quarter of mammograms had critical failures on both CC images (27.5%). A similar proportion of mammograms also had critical failures on both MLO images (26.0%). Of the 1127 patients evaluated, 491 (43.6%) had a mammogram with at least one critical failure. Of those 491 patients, one-fifth (20.6%) had an entire breast with no adequate image.

Explanation of the Findings

Three studies examining the quality of mammograms conducted as part of the Quebec Breast Cancer Screening Program have shown that improper breast positioning was the most common factor affecting the quality of mammography exams, which consisted of 22.6%, 37.2% and 55.0% of the 730, 197, and 1209 mammograms evaluated, respectively.(5, 8, 13) In our study, 43.6% of mammograms had critical failures due to improper positioning. Improper positioning can potentially lead to an inconclusive examination and a repeat mammographic exam for the patient, and thus it is important that it be adequately conducted.

There is some evidence suggesting that positioning training, rather than years of experience, might improve the quality of mammographic examination. A Dutch study evaluating the quality of breast positioning in newly-trained technologists compared with experienced technologists found that more newly-trained technologists had adequate breast positioning overall than experienced technologists on CC views (97% vs 86%) and MLO views (92% vs 84%).(14) In a Quebec study, technologists who underwent hands-on positioning training were more likely to have adequate quality of mammographic positioning than those who did not

(adjusted ratio 1.3, 95% CI: 1.1-1.5).(9) Another study found that more technologists met the American College of Radiology criteria for quality breast positioning after undergoing mammographic positioning training (80% vs 67%), which consisted of lectures, hands-on training, and positioning coaching.(15)

Future Direction in the Area of Study

Our study highlights that a significant number of technologists failed the inspection despite having a certification in breast imaging. Therefore, it would be important for jurisdictions or professional orders to re-assess whether the number of hours of mammography training for technologists is sufficient, as well as the quality of such training. Our study also highlights that patients with a critical failure on their mammographic exam might need to undergo a repeat mammogram in order to be properly be evaluated. As mammographic exams with critical failures may also lead to missed breast cancer cases, future studies with large sample sizes should assess the impact of improper breast positioning on breast cancer incidence.

This study stems from an inspection ordered by the Ordre des technologues en imagerie médicale, en radio-oncologie et en électrophysiologie médicale du Québec (OTIMROEPMQ). Findings were shared with the professional order, which were subsequently presented to the Quebec Ministry of Health and Social Services. Upon the findings, the professional order temporarily stopped emitting new licenses to technologists until the development, in collaboration with the Ministry, of a new education program for technologists with a specific focus on positioning quality of mammograms.

Strengths and limitations

Our study has strengths and limitations. Our stratified sampling strategy resulted in a representative sample of certified technologists currently practicing in Quebec. Furthermore, the quality assessment tool had a high concordance between the expert evaluators. However, as with all quality assessment tools, some subjectivity is inherently present. Finally, while our sample size enabled us to conduct a representative evaluation of the quality of mammographic positioning, it was not large enough to assess the impact of improper breast positioning on missed breast cancer cases.

Conclusions

Our results suggest that half of the technologists failed the professional inspection, and a significant proportion of mammographic exams had critical failures in breast positioning. Our findings call for other jurisdictions to evaluate the quality of mammographic positioning to ensure that examinations are adequately performed, and to assess the need for additional training. The quality assessment tool helped better estimate this need. Finally, future studies should assess the impact of improper breast positioning on breast cancer detection.

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DISCLOSURES

JR received consulting fees from Biogen for work unrelated to this study. LA received consulting fees from Janssen and Pfizer for work unrelated to this study.

REFERENCES

1. Canadian Cancer Statistics Advisory C. Canadian Cancer Statistics 2019. Toronto, ON: Canadian Cancer Society; 2019.
2. Fuller MS, Lee CI, Elmore JG. Breast cancer screening: an evidence-based update. Med Clin North Am. 2015;99(3):451-68.
3. Carney PA, Miglioretti DL, Yankaskas BC, Kerlikowske K, Rosenberg R, Rutter CM, et al. Individual and combined effects of age, breast density, and hormone replacement therapy use on the accuracy of screening mammography. Ann Intern Med. 2003;138(3):168-75.
4. Richli Meystre N, Henner A, Sa Dos Reis C, Strom B, Pires Jorge JA, Kukkes T, et al. Characterization of radiographers' mammography practice in five European countries: a pilot study. Insights Imaging. 2019;10(1):31.
5. Guertin MH, Theberge I, Zomahoun HTV, Dufresne MP, Pelletier E, Brisson J. Mammography Clinical Image Quality and the False Positive Rate in a Canadian Breast Cancer Screening Program. Can Assoc Radiol J. 2018;69(2):169-75.
6. Sweeney RI, Lewis SJ, Hogg P, McEntee MF. A review of mammographic positioning image quality criteria for the craniocaudal projection. Br J Radiol. 2018;91(1082):20170611.
7. Mercieca N, Portelli JL, Jadva-Patel H. Mammographic image reject rate analysis and cause - A National Maltese Study. Radiography (Lond). 2017;23(1):25-31.
8. Guertin MH, Theberge I, Dufresne MP, Zomahoun HT, Major D, Tremblay R, et al. Clinical image quality in daily practice of breast cancer mammography screening. Can Assoc Radiol J. 2014;65(3):199-206.

9. Guertin MH, Theberge I, Zomahoun HT, Dufresne MP, Pelletier E, Brisson J. Technologists' Characteristics and Quality of Positioning in Daily Practice in a Canadian Breast Cancer Screening Program. Acad Radiol. 2016;23(11):1359-66.

10. Popli MB, Teotia R, Narang M, Krishna H. Breast Positioning during Mammography: Mistakes to be Avoided. Breast Cancer (Auckl). 2014;8:119-24.

11. 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):539-53.

12. Cancer CPA. Quality Determinants of Breast Cancer Screening with Mammography in Canada. Toronto; 2013.

13. Theberge I, Guertin MH, Vandal N, Daigle JM, Dufresne MP, Wadden N, et al. Clinical Image Quality and Sensitivity in an Organized Mammography Screening Program. Can Assoc Radiol J. 2018;69(1):16-23.

14. Landsveld-Verhoeven C, den Heeten GJ, Timmers JM, Broeders MJ. [The correct mammographic positioning in breast cancer screening]. Ned Tijdschr Geneeskd. 2015;159:A9488.

15. Pal S, Ikeda DM, Jesinger RA, Mickelsen LJ, Chen CA, Larson DB. Improving Performance of Mammographic Breast Positioning in an Academic Radiology Practice. AJR Am J Roentgenol. 2018;210(4):807-15.

Table 1. Characteristics of technologists

Characteristics	
Total, n (%)	76 (100.0)
Urban centre, n (%)	68 (89.5)
High-volume centre, n (%) [a]	51 (67.1)
High annual volume of exams performed, n (%) [b]	38 (50.0)
Years of experience, n (%)	
< 3 years	4 (5.3)
3 - 14 years	42 (55.3)
≥ 15 years	30 (39.5)
Continuing education, n (%)	16 (21.1)

[a] A high-volume centre was defined as a centre performing ≥2266 annual mammography exams
[b] A high annual volume was defined as a technologist performing ≥709 mammographic exams per year

Table 2. Baseline characteristics of patients

Baseline characteristics	
Total, n (%)	1127 (100)
Age, years, mean (SD)[a]	58.7 (9.2)
Body mass index, kg/m^2, n (%)[b]	25.3 (6.8)
Modality, n (%)	
Computed radiography	446 (39.6)
Digital radiography	679 (60.2)
Missing	2 (0.2)
Type of exam, n (%)	
Bilateral mammogram, screening	878 (77.9)
Bilateral mammogram, diagnostic	246 (21.8)
Missing	3 (0.3)
Breast size, n (%)	
Small (<8 cm)	463 (41.1)
Medium (8-14.9 cm)	593 (52.6)
Large (>15 cm)	64 (5.9)
Missing	7 (0.6)
Breast type, n (%)	
Regular	1024 (90.8)
Implant	49 (4.5)
Scar	22 (2.0)
Other	4 (0.4)
Missing	28 (2.5)
Specific conditions	
None	1069 (94.9)
Limited mobility (e.g., wheelchair)	6 (0.5)
Shoulder pain	6 (0.5)
Sensitive/Very sensitive patient	7 (0.6)
Other	2 (0.2)
Missing	37 (3.3)
Cutaneous markers	157 (14.0)
Images compared with previous exam	929 (82.5)

Abbreviations: SD, standard deviation

[a] A total of 8 patients had missing data for age

[b] A total of 231 patients had missing data for body mass index

Table 3. Evaluation of breast positioning on CC view and MLO view

	Right-side images, n (%)	Left-side images, n (%)	Overall view, n (%)
CC view			
Adequate	877 (77.8)	915 (81.1)	817 (72.5)
Critical failure	250 (22.2)	213 (18.9)	310 (27.5)
Total	1127 (100.0)	1127 (100.0)	1127 (100.0)
MLO view			
Adequate	902 (80.0)	929 (82.4)	834 (74.0)
Critical failure	225 (20.0)	198 (17.6)	293 (26.0)
Total	1127 (100.0)	1127 (100.0)	1127 (100.0)

Abbreviations: CC, craniocaudal; MLO, mediolateral oblique

Table 4. Global evaluation of breast positioning

	Overall CC view, n (%)	Overall MLO view, n (%)	Overall mammography, n (%)
Adequate	817 (72.5)	831 (74.0)	636 (56.4)
Critical failure	310 (27.5)	293 (26.0)	491 (43.6)
Total	1127 (100.0)	1127 (100.0)	1127 (100.0)

Abbreviations: CC, craniocaudal; MLO, mediolateral oblique

SUPPLEMENTARY MATERIAL

Evaluation of the quality of mammographic breast positioning in Quebec

Supplementary Methods 1	Pilot evaluation of the tool
Supplementary Methods 2	Reliability testing of the tool and results of concordance testing
Supplementary Table 1	Number of mammograms with critical failures in a sample of 20 mammograms
Supplementary Table 2	Results of concordance testing by position and view
Supplementary Table 3	Evaluation grid for positioning on CC view
Supplementary Table 4	Evaluation grid for positioning on MLO view
Supplementary Figure 1	Distribution of scores from evaluation of the quality of breast positioning on CC view **(A)** and on MLO view **(B)**
Supplementary Figure 2	Distribution of scores for global evaluation of breast positioning

Supplementary Methods 1

A total of nine rounds of pilot evaluation were conducted to obtain the final version of the quality assessment tool.

In the first round, the objective was to create an exhaustive list of criteria for quality assessment in mammographic positioning. We conducted a review of the scientific literature to establish a list of criteria and searched standardized guidelines such as the American College of Radiology, the Canadian Association of Radiologists, and the European Commission Initiative on Breast Cancer. Criteria were compiled into a master list which included 16 criteria for CC views, 19 criteria for MLO views, and 15 criteria categorized in "Other".

In the second round, the expert panel independently provided a set of criteria for the evaluation of the quality of mammographic positioning based on their professional experience and training. Criteria that were unanimously judged as non-essential for the evaluation of the quality of mammography were excluded from the master list.

In the third round, the objectives of the tool were to 1) construct a tool that would be used to evaluate mammograms that are adequate versus inadequate and 2) of the mammograms that are evaluated as adequate, create a more detailed evaluation grid based on the PGMI (Perfect, Good, Moderate, Inadequate) evaluation system.(1)

In the fourth round, each criterion and its response were revised by the expert panel for its relevance and clinical application, and criterion for which there were full agreement were included.

In the fifth and sixth rounds, responses to each criterion were condensed to avoid redundancy then re-organised hierarchically from best to worst response. This version of the tool included 8 criteria for CC view and 9 criteria for MLO view. A decision rule was also established to maximized inter-rater reliability. Each criterion was examined to establish the respective

response that would lead to a critical failure. The criteria for a critical failure were predefined to reduce subjectivity. For CC views, a mammogram was scored as a critical failure when answer 4 was selected for criteria 2, 3, 4, 7 and 8, or when answer 2 was selected for criterion 5. For MLO views, a mammogram was scored as a critical failure when answer 4 was selected for criteria 2, 3, 5, 7, 8 and 9, or when answer 3 was selected for criterion 4.

In the seventh and eighth rounds, the evaluation grid was independently tested by the expert panel on a sample of classic and complex mammograms (**Supplementary Methods 2).** The expert panel then met and discussed each mammogram and provided comments on the evaluation grid. Changes to the grid were made, which led to the final version (**Supplementary Table 3** for CC view and **Supplementary Table 4 for** MLO view**)**.

References

1. 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):539-53.

Supplementary Methods 2

To test the reliability of the tool, the three expert evaluators were asked to independently evaluate each mammogram independently and provide a score for the 4 images corresponding to each mammogram (right CC, left CC, right MLO, and left MLO). According to the predefined criteria, each of the 20 mammograms were then classified as acceptable or critical failure. The evaluator's responses were compiled into contingency tables to determine the percentage of agreement between evaluators. This was done for each of the 4 images, for both views, and for the overall mammogram. Failure of a single image in the right CC/MLO or left CC/MLO resulted in an overall failure in CC or in MLO, respectively. Ultimately, a mammogram was considered as critical failure if one of the two views (i.e. in CC or MLO) was scored as inadequate.

Supplementary Table 1 presents the number and proportion of mammograms scored as critical failure by each evaluator. Evaluators 2 and 3 had a similar number of mammograms scored as critical failure, while Evaluator 1 had a higher number of mammograms scored as critical failure (15%, 20% and 35%, respectively).

Supplementary Table 2 shows the degree of concordance between the evaluators for each view, each side and overall. This revealed a high level of agreement between the three evaluators, with concordance rates ranging from 75% to 100%, for an average concordance of 76.7%. The Cohen's kappa statistic for these images resulted in a $k = 0.45$, which corresponds to a moderate inter-rater agreement. To establish the final average reliability, the three evaluators received an additional set of 32 images, including 272 items. The final concordance was 97%, corresponding to a near-perfect agreement between the evaluators.

Supplementary Table 1. Number of mammograms with critical failures in a sample of 20 mammograms

Evaluator	Mammograms with critical failures, n	% (95% confidence interval)
1	7	35 (18-57)
2	3	15 (5-36)
3	4	20 (8-42)

Supplementary Table 2. Results of concordance testing by position and view

Evaluator	Right CC	Left CC	Right MLO	Left MLO	Overall mammogram
1 vs 2	90%	75%	85%	95%	65%
1 vs 3	90%	90%	85%	100%	85%
2 vs 3	100%	85%	90%	90%	80%

Abbreviations: CC, craniocaudal; MLO, mediolateral oblique

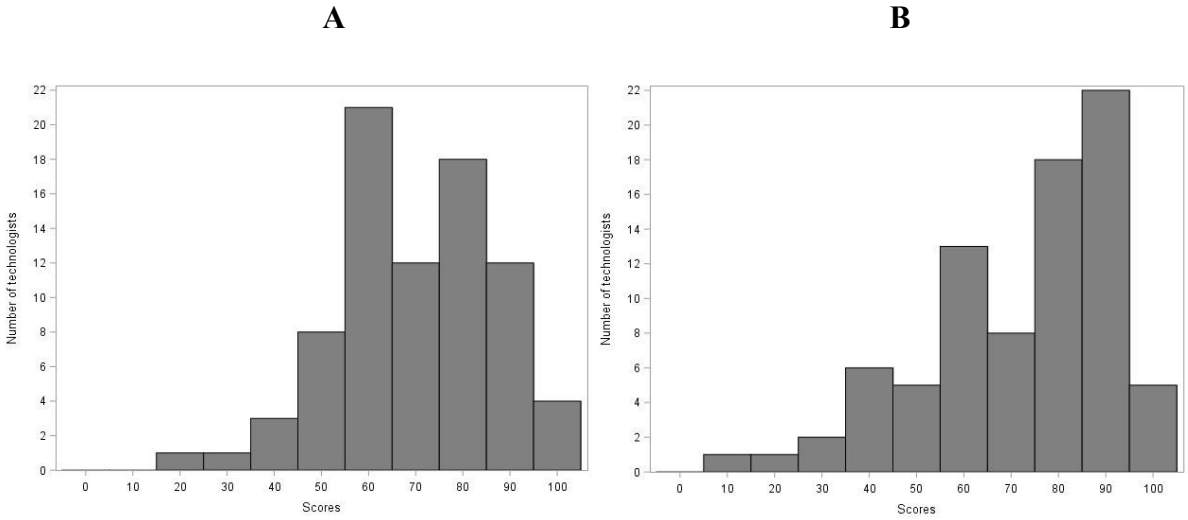
Supplementary Table 3. Evaluation grid for positioning on CC view

Positionnement CC	Réponse
1. Image évaluable	□1 Oui 2 Non, qualité de l'image inadéquate (i.e. qualité technique, implants mammaires, etc.)
2. Partie du sein coupée	□1 Non □2 Oui, mais seulement la peau coupée □3 Oui, tissu mammaire coupée, mais corrigé avec une image complémentaire □4 Oui, tissu mammaire coupée et pas corrigé avec une image complémentaire
3. Ligne du mamelon au corps est perpendiculaire au bord de l'image (partie interne et externe incluse)	□1 Oui □2 Non, mamelon désorienté (cause morphologique particulière ou autre cause) mais partie interne et externe incluse □3 Non, mamelon désorienté, partie interne et/ou externe non incluse, mais corrigé avec une image complémentaire □4 Non, mamelon désorienté, partie interne et/ou externe non incluses, et pas corrigé avec une image complémentaire
4. Bonne visualisation des tissus profonds	□1 Oui, avec graisse rétro-glandulaire □2 Oui, sein dense sans graisse rétro-glandulaire □3 Non, mais corrigé avec une image complémentaire □4 Non, et pas corrigé avec une image complémentaire
5. Ligne du mamelon au corps sur le CC est ≤1cm de la ligne du mamelon au pectoral sur le MLO	□1 Oui □2 Non □3 Mesure non-applicable (ligne non valide sur le MLO)
6. Mamelon vu de profil	□1 Oui 2 Non, mais aucune superposition avec le tissu glandulaire (rétro-aréolaire) ou indiqué avec un marqueur de plomb 3 Non, superposition avec le tissu glandulaire (rétro-aréolaire), mais corrigé avec une image complémentaire □4 Non, superposition avec le tissu glandulaire (rétro-aréolaire), et pas corrigé avec une image complémentaire ou non indiqué avec un marqueur de plomb ou pas
7. Artéfacts et superposition (cheveux, bijoux, épaules, menton, image floue, etc.)	□1 Non □2 Oui, mais n'obstrue pas l'image □3 Oui, obstrue l'image, mais corrigé avec une image complémentaire □4Oui, obstrue l'image, et pas corrigé avec une image complémentaire
8. Plis de peau dans le sein (incluant plis causés par une cicatrice)	□1 Non □2 Oui, mais n'obstrue pas l'image □3 Oui, obstrue l'image mais corrigé avec une image complémentaire □4Oui, obstrue l'image et pas corrigé avec une image complémentaire

Supplementary Table 4. Evaluation grid for positioning on MLO view

Positionnement MLO	Réponse
1. Image évaluable	□¹ Oui □² Non, qualité d'image inadéquate (i.e. qualité technique, implants mammaires, etc.)
2. Partie du sein coupée	□¹ Non □² Oui, mais seulement la peau coupée □³ Oui, tissu mammaire coupé, mais corrigé avec une image complémentaire □⁴ Oui, tissu mammaire coupé et pas corrigé avec une image complémentaire
3. Bonne visualisation des tissus profonds	□¹ Oui, avec graisse rétro-glandulaire □² Oui, sein dense sans graisse rétro-glandulaire □³ Non, mais corrigé avec une image complémentaire ou acceptable selon la morphologie de la patiente ou autres causes □⁴ Non, et pas corrigé avec une image complémentaire
4. Quantité adéquate de muscle pectoral sur l'image (le bord inférieur du muscle pectoral se situe près de la ligne mamelon-pectoral ou plus bas)	□¹ Oui □² Non, mais acceptable selon la morphologie de la patiente (ex: réduction mammaire ou autres causes) □³ Non, inacceptable
5. Vue de la largeur maximale du muscle pectoral (muscle à angle)	□¹ Oui □²Non, mais acceptable selon la morphologie de la patiente ou autres causes □³Non, mais corrigé avec une image complémentaire □⁴Non, et pas corrigé avec une image complémentaire
6. Mamelon vu de profil	□¹Oui □² Non, mais aucune superposition avec le tissu glandulaire (rétro-aréolaire) ou indiqué avec un marqueur de plomb ou non □³ Non, superposition avec le tissu glandulaire (rétro-aréolaire), mais corrigé avec une image complémentaire □⁴ Non, superposition avec le tissu glandulaire (rétro-aréolaire), et pas corrigé avec une image complémentaire ou marqueur de Pb
7. Angle infra-mammaire bien ouvert et démontré (ex. sein bien soulevé et non-affaissé)	□¹ Oui □² Non, mais le tissu mammaire est démontré □³ Non, le tissu mammaire n'est pas démontré, mais corrigé avec une image complémentaire □⁴Non, le tissu mammaire n'est pas démontré et pas corrigé avec une image complémentaire
8. Artéfacts et superposition (muscle dorsale, cheveux, bijoux, épaules, menton, image floue, etc.)	□¹ Non □²Oui, mais n'obstrue pas l'image □³ Oui, obstrue l'image, mais corrigé avec une image complémentaire □⁴ Oui, obstrue l'image et pas corrigé avec une image complémentaire
9. Plis de peau dans le sein (incluant plis causés par une cicatrice)	□¹ Non □² Oui, mais n'obstrue pas l'image □³ Oui, obstrue l'image mais corrigé avec une image complémentaire □⁴Oui, obstrue l'image et pas corrigé avec une image complémentaire

Supplementary Figure 1. Distribution of scores from evaluation of the quality of breast positioning on CC view **(A)** and on MLO view **(B)**



Supplementary Figure 2. Distribution of scores for global evaluation of breast positioning