# Contrast-enhanced mammography in high-dense breasts: a narrative review

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**Background and Objective:** Contrast-enhanced mammography (CEM) combines iodine-based contrast agents with dual-energy imaging to enhance the detection of breast cancer, especially in women with dense breast tissue. Dense breasts, which obscure conventional mammography results, present unique diagnostic challenges and an elevated risk of cancer. This review explores the role of CEM in improving diagnostic accuracy in high-density breasts, its comparative performance with other imaging modalities, and its potential implications for clinical practice.

**Methods:** We conducted a narrative analysis on the use of CEM in dense breast tissue by searching PubMed, Web of Science (WoS), and Google Scholar between September and November 2024. Keywords, rather than MeSH terms, were utilized to refine the search, focusing on terms appearing in article titles. Sixty-six articles were identified, and duplicates or non-eligible studies were excluded, resulting in a final selection of 21 articles published between 2013 and 2024. Additional references were identified through snowballing to contextualize findings.

**Key Content and Findings:** CEM demonstrates high sensitivity (89–97.7%) and specificity (50–89%) in detecting malignancies within dense breasts, offering comparable diagnostic accuracy to magnetic resonance imaging (MRI) but with better accessibility and lower cost. Unlike traditional mammography, CEM enhances visibility through functional imaging of contrast uptake, improving detection of small or occult lesions. It also aids in pre-surgical planning by assessing tumor size and multiplicity with greater precision. However, CEM is not without limitations, including radiation exposure and variability in equipment standards. Comparative analyses suggest CEM bridges the gap between conventional mammography and advanced techniques like MRI, particularly in resource-constrained settings.

**Conclusions:** CEM represents a significant advancement in breast cancer detection, addressing limitations posed by dense breast tissue. Its diagnostic accuracy, cost-effectiveness, and patient accessibility position it as a valuable tool in personalized screening strategies. Further standardization and integration into clinical workflows could expand its role in routine breast cancer management.

**Keywords:** Contrast-enhanced mammography (CEM); breast cancer; dense breasts; diagnostic imaging; screening

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## Introduction

### *Background*

Contrast-enhanced mammography (CEM) is an advanced imaging modality that combines an iodine-based contrast agent with dual-energy mammography to improve diagnostic precision. In standard practice, an intravenous (i.v.) contrast agent (1.5 mL/kg body weight) is administered two minutes prior to imaging (1). Then, a 2D digital mammography (DM) with a dual-energy approach is performed, capturing one low-energy (26–33 kVp) image, resembling a conventional mammogram, and one high-energy (44–50 kVp) image to display iodine uptake, though this high-energy image alone is not typically used for diagnostic evaluation (2). Through digital subtraction, these images are synthesized to produce a diagnostic-quality recombined image of the breast, emphasizing regions with contrast uptake.

Although no standard acquisition protocol has been universally adopted, an initial series of four mammograms, capturing both cranio-caudal (CC) and medio-lateral-oblique (MLO) views for each breast, is commonly obtained, beginning with the breast showing the most suspicious findings. If needed, additional images may be acquired within an eight-minute window post-contrast infusion to assess uptake and washout patterns (1,3). After that interval of time, there is no clear evidence of the usefulness of further acquisitions since contrast could be totally washed out from the breast (4,5).

CEM facilitates the detection of breast cancer by exploiting increased contrast uptake due to tumor-associated neovascularization, which is significantly more pronounced than in normal tissue (3,4). The dual-energy technique enables differentiation between regions of high and low contrast medium absorption, emphasizing areas with notable iodine uptake while minimizing the visibility of regions with lower uptake. While studies indicate that CEM achieves high sensitivity and specificity in detecting malignancies, it remains somewhat inferior to breast magnetic resonance imaging (MRI) in diagnostic accuracy (6). Additionally, high breast density (BD), correlated with an elevated risk of breast cancer (7), not only can limit the utility of conventional mammography, but it can also increase the probability of a higher background parenchymal enhancement (BPE) in CEM (8). However, CEM could address this limitation by suppressing glandular parenchyma through its dual-energy approach, allowing for improved sensitivity in early detection for patients with dense breast tissue (9). Similarly to MRI, also with CEM, BPE could be influenced by the phases of the menstrual cycle, increasing false-positive and false-negative results, but this aspect is currently controversial (8,10). Finally, also variations in mammography equipment and post-processing techniques across different manufacturers may further impact BPE, as equipment differences in machine design, anode/filter combinations, film-focus distance, and grid configuration are conceivable sources of variation, with potential implications for diagnostic clarity and consistency (11).

### *Rationale and knowledge gap*

The term “breast density” (BD) refers specifically to the quantity of epithelial and stromal components within the breast and should not be mistaken for tactile consistency observed during a physical examination (12). The radiographic appearance of breasts varies according to differences in tissue composition, resulting in distinct attenuation properties among fat, stroma, and epithelial tissue. Radiographically, fat appears lucent and dark on mammographic images, whereas epithelium and stroma are radiographically dense and appear lighter (13). Then, increased BD poses challenges for lesion detection due to the masking effect (14).

Digital breast tomosynthesis (DBT) has been adopted into modern clinical practice as a sophisticated modality aimed at addressing the limitations of conventional full-field DM (FFDM) in the detection of breast cancer within dense breast tissue. Unlike FFDM, DBT acquires a series of mammographic images to construct a three-dimensional representation of the breast using a single compression. This technique enables radiologists to review the breast in a sequential, slice-by-slice manner, effectively reducing the masking effect associated with dense breast tissue and enhancing the detection of small breast cancers, including subtle opacities and architectural distortions (15).

BD is extremely relevant in breast cancer screening, as breast cancers that are not screen-detected in women with high-density breasts may present as interval cancers between routine screenings and, consequently, may be diagnosed at a later stage. BD can be visually assessed by radiologists or evaluated by artificial intelligence (AI) on FFDM, DBT and CEM. Standardizing its evaluation can help radiologists modify the recall rate and personalizing screening procedures (14).

Given all these aspects, as previously mentioned, CEM could address the limitations related to high BD, by

**Table 1** The search strategy summary

| Items | Specification |
|---|---|
| Date of search | 10 October 2024 |
| Databases and other sources searched | Web of Science, PubMed, Google Scholar |
| Search terms used | Dense breast, dense breasts, CESM, contrast-enhanced mammography, CEM, CEDM, contrast-enhanced digital mammography, contrast-enhanced spectral mammography |
| Timeframe | 2013–2024 |
| Inclusion and exclusion criteria | Inclusion criteria: research articles, reviews, English language |
| | Exclusion criteria: abstract only, posters, other languages different from English |
| Selection process | Selection was conducted independently. Articles were selected by consensus from all the authors |

suppressing glandular parenchyma through its dual-energy approach, allowing for improved sensitivity. Furthermore, the use of i.v. contrast could provide useful information for the characterization of a suspicious lesion.

### *Objective*

Our paper aims to assess the impact of CEM on breast cancer detection in women with high BD. Through a review of the literature, we will examine the strengths and limitations of this technique and offer insights and recommendations for future research. We present this article in accordance with the Narrative Review reporting checklist (available at https://tbcr.amegroups.com/article/view/10.21037/tbcr-24-64/rc).

## Methods

In this literature review, we conducted a narrative analysis on the use of CEM in highly dense breasts. The search was performed between September and November 2024 in the databases PubMed, Web of Science (WoS), and Google Scholar, using various keywords to better identify the scope of the study. We deliberately chose keywords instead of MeSH terms, as the MeSH terms were too generic to capture the specific focus of the research. Consequently, the search query was as follows:

"Dense breast" OR "dense breasts" AND CESM OR "contrast-enhanced mammography" OR CEM OR CEDM OR "contrast-enhanced digital mammography" OR "contrast-enhanced spectral mammography".

We included only papers where these terms appeared in the title to avoid retrieving non-specific works. This strategy yielded 66 papers: 17 from PubMed, 19 from WoS, and 30 from Google Scholar. Several duplicates were identified and removed during the subsequent step of the search process. Inclusion criteria were English-language articles, empirical research, and review articles relevant to contextualizing our findings (*Table 1*).

After removing duplicates, three researchers independently screened the abstracts of the remaining articles. Ultimately, we analyzed a subset of 21 articles published between 2013 and 2024 (*Table 2*). Each selected article was read by at least two researchers, and their notes were compared and thematically organized.

In addition to these 21 selected articles, we included 32 additional articles to contextualize and interpret our findings. These additional articles were identified through snowballing, by examining references within the selected articles, and were included when they contributed to the contextual understanding of our findings. The flow chart of the study is presented in *Figure 1*.

## Review

### *Screening recommendations*

Screening programs have been among the most successful strategies for reducing breast cancer mortality in average-risk women, particularly through the use of DM. These programs are widely recommended by the World Health Organization (WHO) (37). The American College of Radiology (ACR) advises annual screening mammography beginning at age 40 years for women of average risk (38). However, the lifetime risk of breast cancer varies due to factors such as genetic mutations (e.g., BRCA1: 69%; BRCA2: 72%), family history, prior chest radiation at a young age, personal history of breast cancer or high-risk

**Table 2** Articles included in the narrative review

| Ref. | First author | Type of article | Patients | Results |
|---|---|---|---|---|
| (16) | Sorin V, *et al.* | Retrospective study | 611 | CEM significantly improved cancer detection sensitivity compared to mammography and ultrasound |
| (17) | Lin ST, *et al.* | Systematic review & meta-analysis | 827 | CEM exhibited high diagnostic performance for dense breasts with a sensitivity of 95% and specificity of 81% |
| (18) | Grażyńska A, *et al.* | Retrospective study | 792 | CEM showed high sensitivity (96.2%) and NPV in extremely dense breasts, performing well as an alternative to MRI |
| (19) | Nissan N, *et al.* | Retrospective study | 609 | CEM showed higher sensitivity but lower specificity in female patients with extremely dense breasts, although specificity improved at follow-up, compared with low-energy imaging |
| (20) | Chalabi N, *et al.* | Prospective study | 68 | CEM identified breast cancer with 88.9% sensitivity and 100% specificity in dense breasts |
| (21) | Mori M, *et al.* | Prospective study | 72 | CEM had higher diagnostic accuracy (90.9%) than digital mammography (72.7%) for dense breasts |
| (22) | Mohamed SAS, *et al.* | Prospective study | 25 | CEM was superior in lesion detection and characterization, altering surgical plans in 57% of cases |
| (23) | Sudhir R, *et al.* | Prospective study | 130 | CEM showed superior sensitivity compared to 2D mammography, DBT, and DBT with ultrasound in dense breast cancer detection |
| (24) | Mokhtar O, *et al.* | Original research | 60 | CEM offered better diagnostic accuracy (97.7% sensitivity) compared to digital mammography and ultrasound |
| (25) | Azzam H, *et al.* | Comparative study | 37 | CEM showed 89% diagnostic accuracy, outperforming mammography and tomosynthesis for dense breasts |
| (26) | Lu Z, *et al.* | Comparative study | 115 | Comparable diagnostic performances of CEM and ultrasound in symptomatic dense breast patients |
| (27) | Moffa G, *et al.* | Prospective study | 51 | CEM showed higher diagnostic performance than digital mammography combined with ultrasound in dense breasts |
| (28) | Barakat MMK, *et al.* | Prospective study | 35 | CEM helped downgrade benign and upgrade malignant lesions effectively, reducing unnecessary biopsies |
| (29) | Moustafa AFI, *et al.* | Original research | 160 | CEM improved accuracy in identifying lesion multiplicity in dense breasts, increasing accuracy to 100% |
| (30) | Goh Y, *et al.* | Retrospective study | 200 | CEM altered surgical plans in 18% of cases, revealing larger tumor sizes and additional lesions |
| (31) | Bozzini A, *et al.* | Clinical trial | 160 | CEM showed comparable sensitivity to MRI and ultrasound, enhancing pre-surgical evaluation in dense breasts |
| (32) | Ainakulova AS, *et al.* | Original research | 151 | CEM with delayed imaging increased specificity for differentiating malignant from benign lesions in dense breasts |
| (33) | Rudnicki W, *et al.* | Original research | 121 | CEM showed similar results to MRI in dense breasts, with slight advantages in specific conditions |
| (34) | Qin Y, *et al.* | Original research | 167 | CEM demonstrated high diagnostic accuracy, moderate correlation with MRI, and was recommended as an alternative in dense breast diagnosis |
| (35) | Anwar R, *et al.* | Comparative study | 32 | CEM and DW MRI showed good diagnostic accuracy |
| (36) | Miller MM, *et al.* | Prospective study | 163 | High acceptance for CEM in screening, with 91.4% willing to repeat and 95.1% recommending it to others |

CEM, contrast-enhanced mammography; DBT, digital breast tomosynthesis; DW, diffusion weighted; MRI, magnetic resonance imaging; NPV, negative predictive value.

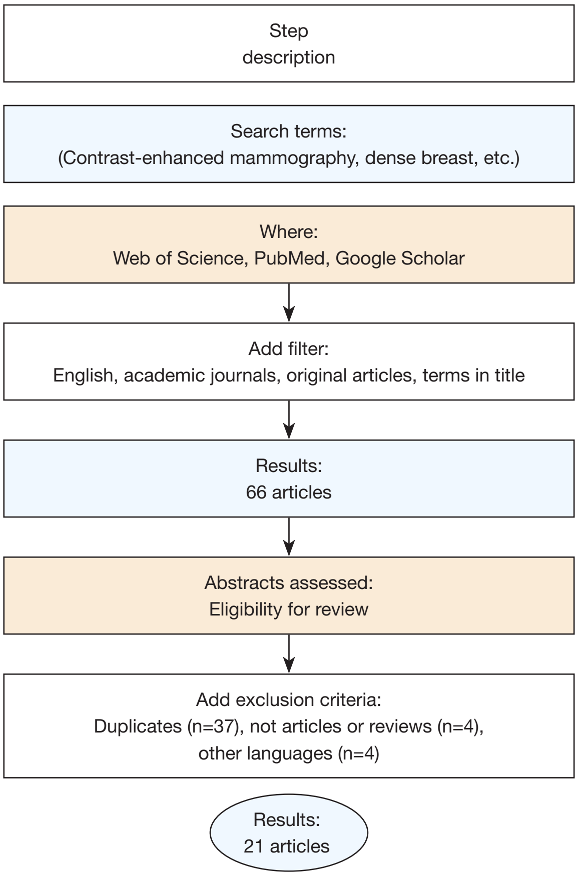


**Figure 1** Flow chart of the study.

lesions, BD, and race/ethnicity (>20% risk) (38,39).

Women at high risk (≥20% lifetime risk) include those with genetic mutations (e.g., BRCA1: 69%, BRCA2: 72%, ATM: 20–40%, TP53: >60%, PTEN: 40–60%, NF1: 20–40%, PALB2: 41–60%), as well as those who underwent chest or abdominal radiation therapy at a young age (40). For these women, the sensitivity of mammography is limited (25–59%) (16), necessitating supplemental screening. Furthermore, these patients exhibit increased vulnerability to X-rays, particularly those under 30 years of age, for whom the risk of radiation-induced breast cancer is higher compared to the general population and increases with higher radiation doses. For these women MRI is the most sensitive screening tool, and it is recommended even with some limitations due to its cost and availability (41).

Intermediate-risk women (15–20% lifetime risk) include those with a family or personal history of breast cancer, biopsy-proven high-risk lesions (e.g., lobular carcinoma *in situ*, atypical ductal hyperplasia, and atypical lobular hyperplasia), or dense breasts. BD independently increases breast cancer risk and reduces mammographic sensitivity. It is estimated that 43–46% of U.S. women over age 40 years have dense breasts, with those having extremely dense breasts at approximately double the average risk (7).

In women aged 50–70 years with extremely dense breasts, the European Society of Breast Imaging (EUSOBI) recommends screening with breast MRI every 2–4 years. However, due to the limited availability of MRI, alternative methods, such as ultrasound (US) in combination with mammography, are proposed. Patients should be informed about the differing performance levels of these non-mammographic screening methods (42).

CEM is emerging as a potential supplemental screening tool for women with dense breasts, elevated risk factors, or contraindications to MRI. It offers higher sensitivity and specificity than mammography or US alone and demonstrates diagnostic performance closer to that of MRI, though it remains more accessible and cost-effective (38).

### *Diagnostic performance of CEM in dense breasts*

The diagnostic accuracy of CEM has been extensively studied, particularly in populations with dense breasts where traditional mammographic methods often fall short. CEM enhances detection rates by combining the anatomical details of mammography with functional information from iodine-based contrast agents, which highlight areas of increased vascularity and angiogenesis—a hallmark of malignancy.

Several key studies have established the efficacy of CEM in this context. A meta-analysis conducted by Lin *et al.* (17) reported pooled sensitivity and specificity values of 95% [95% confidence interval (CI): 92–97%] and 81% (95% CI: 70–89%), respectively, for detecting suspicious lesions in dense breasts. Grażyńska *et al.* (18) demonstrated a sensitivity of 97.3% and a specificity of 59.2% for patients with extremely dense breasts. Similarly, Nissan *et al.* (19) confirmed that the sensitivity of CEM was higher than the low energy (LE) images (88.9% *vs.* 27.8%) even with a decrease in CEM specificity compared with LE imaging (88.9% *vs.* 96.2%). Nevertheless, compared with specificity at baseline, CEM specificity at follow-up improved to 90.7%.

Notably, CEM has proven to be particularly valuable in scenarios where conventional mammography fails to identify lesions. Chalabi and Osman (20) highlighted CEM's sensitivity (88.9%) and specificity (100%) for occult lesions that escaped detection by DM. This superior performance is mirrored in studies such as those by Mori *et al.* (21) and Mohamed *et al.* (22), which collectively affirm CEM's higher sensitivity compared to DM alone. Nevertheless, in the latter work, the specificity value was lower than the previous work (63.6% *vs.* 94.1% *vs.* 85.9%). The reason for this discrepancy may be the different number of patients enrolled in each study which was very small for Mohamed than the other ones (25 *vs.* 68 *vs.* 72).

CEM demonstrated greater sensitivity and diagnostic accuracy than DM and US in multiple studies (16,23-28). In all these works, CEM sensitivity ranged between 89–97.7% while specificity ranged between 50–89%. These values are significantly different from those of mammography alone (52.4–93.2% sensitivity; 43–90.5% specificity), DBT alone (82.8–93% sensitivity; 43–81% specificity), DBT or mammography with US (88.5–97% sensitivity; 32.4–85 specificity).

In particular, the study by Barakat *et al.* (28) evaluates the role of CEM in characterizing indeterminate and equivocal breast lesions [Breast Imaging Reporting and Data System (BI-RADS) 3 and 4] in women with dense breasts, as identified by US. The findings reveal that CEM outperforms US in specificity (86.4% *vs.* 63.6%) and accuracy (88.6% *vs.* 74.29%), while maintaining comparable sensitivity (92.3%). Contrast-enhanced digital mammography (CEDM) facilitated the downgrading of 40% of lesions to benign and upgrading of 14.2% to malignant, reducing unnecessary biopsies and improving diagnostic precision.

These findings underscore the ability of CEM to detect malignancies with high sensitivity, even in challenging imaging conditions.

### *Tumor size and multiplicity assessment*

CEM has demonstrated significant advantages in accurately assessing tumor size and identifying multifocal or multicentric lesions, both of which are critical for determining the appropriate surgical and therapeutic approach (43). DM and US have been shown to correlate poorly with eventual histological size and have been reported to underestimate breast cancer size in up to 35% of patients (44,45). This is the reason why several studies have proposed additional contrast-enhanced imaging, such as MRI or CEM, in pre-operative breast cancer assessment.

Moustafa *et al.* (29) evaluated the utility of CEM in preoperative assessments, finding that its addition to sonomammography increased the accuracy of detecting multiple malignant lesions from 81.8% to 100%. This ability to identify multiplicity is particularly relevant for dense-breast populations, where the sensitivity of conventional methods is often diminished.

Other studies corroborate these findings, emphasizing the importance of CEM in pre-surgical planning. For example, Goh *et al.* (30) found that CEM altered surgical plans in 18% of cases, with changes driven by the detection of larger tumor extents or additional lesions not identified through other modalities. Similarly, Bozzini *et al.* (31) demonstrated that CEM yielded detection rates for malignant lesions comparable to MRI (93.8% *vs.* 97.7%) while maintaining better concordance with histopathological measurements (64.6% *vs.* 69.9% for MRI). These results highlight the critical role of CEM in improving surgical outcomes and tailoring treatment strategies.

In terms of lesion morphology, Ainakulova *et al.* (32) analyzed the impact of delayed imaging protocols on CEM performance. They found that delayed-phase imaging enhanced specificity by 12.4% through better characterization of lesion shape, margins, and enhancement patterns. Furthermore, the persistent enhancement was typically associated with benign lesions; conversely, plateau and washout were associated with malignant ones. Such improvements underscore the versatility of CEM in both detection and detailed lesion analysis, similarly to MRI.

### *Comparison with MRI*

MRI is widely regarded as the gold standard for breast cancer imaging due to its unmatched sensitivity. However, its limitations—such as low specificity with high rates of false positive result, high cost, long examination times, and contraindications for certain patients (e.g., those with pacemakers or claustrophobia)—have spurred interest in alternative modalities like CEM (46-48). To overcome MRI limitations, several authors proposed different approaches (49-51). First-pass MRI and abbreviated breast MRI (AB-MRI) were designed to streamline breast cancer imaging by significantly reducing scan times to 4–5 minutes and around 10 minutes, respectively. First-pass MRI focuses on capturing the initial phase of contrast enhancement, while AB-MRI utilizes a limited sequence set to detect cancer with high sensitivity. These methods hold significant potential for improving breast cancer screening, particularly in dense breasts, by offering shorter imaging times and reduced costs. However, they face limitations that can impact diagnostic accuracy. Both approaches primarily target early contrast uptake, potentially missing lesions with late or minimal enhancement, such as certain low-grade ductal carcinoma in situ (DCIS) or tumors influenced by hormonal changes. The lack of kinetic data and reliance on fewer sequences may increase the risk of false negatives, especially in complex cases. Additionally, artifacts, including motion or parenchymal enhancement, can obscure findings. Unlike CEM, which can detect microcalcifications often associated with early-stage DCIS, first-pass MRI and AB-MRI are limited in evaluating non-enhancing lesions, making CEM a complementary tool for comprehensive cancer detection. These limitations underscore the need for careful protocol optimization and consideration of patient-specific factors to mitigate risks and enhance diagnostic accuracy.

Studies comparing CEM to MRI consistently show that while MRI offers slightly higher sensitivity in some cases, CEM provides comparable diagnostic accuracy with added benefits of accessibility and shorter examination times. Rudnicki *et al.* (33) reported equivalent sensitivity (100%) for both modalities in dense-breast populations, although MRI showed higher specificity (25% *vs.* 15% for CEM). Similarly, Qin *et al.* (34) demonstrated strong concordance between CEM and dynamic contrast-enhanced MRI (DCE-MRI) in lesion size estimation and BI-RADS scoring. With a kappa value of 0.607, their findings affirm CEM as a viable alternative to MRI, especially in resource-limited settings or for patients unable to undergo MRI.

Moreover, they reported sensitivity, specificity, and an area under the curve (AUC) of 82.4%, 96.4%, and 0.894, respectively, in benign-malignant discrimination. Such capabilities not only improve early detection but also reduce unnecessary biopsies and interventions, making CEM a critical tool for breast cancer management (34).

Despite its advantages, CEM does not entirely replace MRI in all scenarios. Anwar *et al.* (35) noted that diffusion-weighted MRI (DW-MRI) had higher sensitivity (96.77%) and specificity (66.67%) compared to CEM (90.32% and 33.33%, respectively) in diagnostic accuracy and also a higher sensitivity (100% *vs.* 88.8%) in detecting multiple malignant lesions. Nonetheless, CEM's faster imaging process and broader patient compatibility make it a practical choice for many clinical situations.

### *Advantages and limitations of CEM*

CEM offers numerous advantages that make it an attractive option for breast cancer imaging. Its shorter examination time, ease of use, and compatibility with metallic implants or claustrophobic patients set it apart from MRI. Additionally, CEM requires no gantry, making it more accessible for patients with large breasts or obesity. These factors contribute to higher patient satisfaction, as highlighted by Miller *et al.* (36), who found that most patients experienced minimal discomfort and expressed a strong preference for CEM over traditional mammography for future screenings.

However, CEM is not without limitations. It involves exposure to iodine-based contrast agents, which carry a small risk of allergic reactions (0.82%) (3). In breast MRI, the contrast agent (gadolinium) is administered at 0.1 mmol/kg, equivalent to 5–7 mL for patients weighing 50–70 kg. In contrast, CEM uses an iodinated agent at 1.5 mL/kg, requiring 75–100 mL for patients in the same weight range, delivered at a rate of 3 mL/s. This shows that CEM requires a much larger volume of contrast compared to CE-MRI for the same patient weight (6).

The radiation dose associated with CEM is approximately 30% higher than that of DM but remains within acceptable safety guidelines (52). Indeed, Calabrò *et al.* (53) demonstrated high inter-reader concordance in interpreting CEM examinations with and without the delayed phase, achieving a Cohen's $\kappa$>0.75. Their analysis also assessed the impact of the radiation dose associated with the delayed phase, revealing that it accounts for approximately 36% of the total average glandular dose (AGD) of a CEM examination. Conversely to Ainakulova *et al.* (32), since the delayed phase did not provide significant benefits for clinical decision-making or disease management, its inclusion was deemed to contribute to unnecessary radiation exposure.

Field-of-view limitations, lack of direct biopsy capabilities, and the absence of Food and Drug Administration (FDA) approval for screening further constrain its use. Moreover, CEM may not be suitable for certain high-risk populations, such as BRCA mutation carriers or pregnant women, due to its radiation exposure.

Nevertheless, the practicality of CEM, combined with its diagnostic performance, positions it as a strong alternative to MRI in many clinical settings. Its ability to bridge the gap between traditional mammography and advanced imaging techniques ensures that more women, particularly those with dense breasts, receive accurate and timely breast cancer screening.

## Conclusions

CEM represents a transformative advancement in breast cancer imaging. With diagnostic accuracy approaching that of MRI and clear advantages in accessibility, cost, and patient comfort, CEM has proven to be a valuable tool for addressing the challenges posed by dense breast tissue. While MRI remains the gold standard in certain contexts, CEM offers a practical and effective alternative that can significantly improve early detection and management of breast cancer. Its combination of high sensitivity, lower costs, and ease of integration into existing clinical workflows makes it a promising option, particularly in resource-limited settings.

As research continues to refine its applications and address current limitations, it is poised to play a pivotal role in personalized breast cancer care and broader screening strategies.

The recent introduction of CEM-guided biopsy, not yet fully available across all commercially available equipment, represents a further significant technological advancement. This development has the potential to provide the decisive impetus for the broader adoption of CEM as an additional tool for the early detection of breast cancer, particularly in cases where lesions are visible only after contrast administration, especially in dense breast tissue.

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## Footnote

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*Ethical Statement:* The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.



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