SOLICITED REVIEW / *Breast imaging*

Angiomammography: A review of current evidences

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Abstract   Although mammography is currently the imaging technique of choice for screening and diagnosis, it has some limitations, especially in patients with high-density breasts. The evolution from film screen to full-field digital mammography has recently led to the development of new imaging techniques, which are less expensive and widely available. Contrast-enhanced spectral mammography (CESM) is one of them, coupling X-ray breast imaging to the intravenous administration of an iodinated contrast material. CESM provides both morphological information, similar to mammography, and functional information of tumor perfusion. In this review, the imaging technique, the specificity of interpretation of CESM compared to MRI and the currently available data are presented. The clinical performances of CESM versus those of mammography and MRI and its additional value in preoperative local assessment and screening is discussed. The potential advantages and disadvantages are mentioned and we also discuss how CESM contributes to the detection of lesions and how it can be used in daily clinical workflow.
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Although mammography is currently the imaging technique of choice for screening and diagnosis, it has some limitations, especially in patients with high-density breasts. The evolution from film screen to full-field digital mammography has recently led to the development of new imaging techniques, which are less expensive and widely available. Contrast-enhanced spectral mammography (CESM) is one of them, coupling x-ray breast imaging to the intravenous administration of an iodinated contrast material. CESM provides both morphological information, similar to mammography, and functional information of tumor perfusion.

In this review, the imaging technique, the specificity of interpretation of CESM compared to MRI and the currently available data are presented. The clinical performances of CESM versus those of mammography and MRI and its

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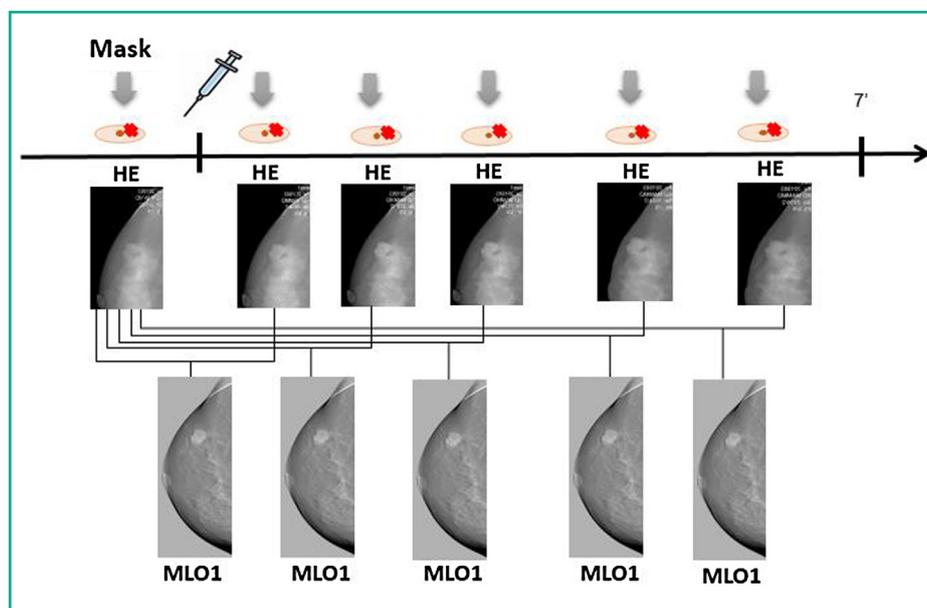
Figure 1. Figure shows angiomammography images based on temporal high-energy acquisition and corresponding non subtracted images.

additional value in preoperative local assessment and screening are discussed. The potential advantages and disadvantages are mentioned and we also discuss how CESM contributes to the detection of lesions and how it can be used in daily clinical workflow.

Technique

Since many years, contrast agents are used with both computed tomography (CT) and magnetic resonance imaging (MRI) technique for cancer detection. Angiogenesis is assessed by tracking the uptake and the washout of contrast agent in tissue. After the first description of human breast uptake of radioactive iodine in 1974 [1]. Chang et al. did the first preliminary report of contrast application on breast using a dedicated breast CT in 1976 [2]. The first contrast-enhanced subtraction angiography of the breast was performed in 1985 [3] followed by the first contrast-enhanced MRI of the breast one year later [4].

The first technique used for angiomammography was the temporal subtraction technique, similar to breast MRI in which pre-contrast image was subtracted from corresponding post-contrast image (Fig. 1). To maximize the sensitivity of the mammography to low concentrations of iodine, the x-ray spectrum was shaped to have energies that are just above the K-edge of iodine (33.2 keV) and only high-energy (45—49 kVp) images of a single view of one breast were acquired. Preliminaries studies using this technique highlighted specific limitations in particular the possibility to image only a single view of one breast, the poor patient compliance, due to the need to leave the patient under compression for the duration of the examination, the limited contrast uptake to the breast resulting from the breast compression and the poor image quality resulting from motion artifacts in the subtracted images [5,6].

To overcome these limitations, a dual-energy acquisition, (i.e., the so called ''CESM''), was then applied. Dual-energy technique uses the energy dependence of the x-ray attenuation through materials of different compositions in the breast. For each view, a pair of low and high-energy images is acquired after an initial contrast medium administration (Fig. 2). Then a specific recombination of low and high-energy images, which is not a simple subtraction but a weighted combination of the two images to maximize the visibility of weak concentrations of iodine in lesions, is performed. The major advantage of this technique is the possibility to decompress the breast between each images acquisition. A regular dual-energy angiomammography examination includes 8 images: 4 low energy images (1 by view and by breast) and 4 recombined (or subtracted) images corresponding perfectly to low energy image. This technique allows adding some additional views such as strict lateral view of the breast of concern or the possibility to image only one view of one breast for kinetic analysis.

Both techniques require a hardware upgrading of the conventional full-field digital mammograph with the adjunction of a new filter material (i.e., the copper) in addition to usual molybdenum and rhodium filters used in mammography and software upgrading for subtraction or low and high-energy recombination. The iodinated contrast agent injection is similar to that used for a CT examination (quantity 1.5 mL/kg of body weight, Iodine conc. 300—350 mg/mL, rate 3 mL/s using a power injector). For CESM, the contrast material is administered two minutes prior to the first image acquisition, using preferably an automated injector.

Dose issue

The extra-radiation dose depends on breast thickness. The increase in radiation dose of CESM compared to a regular mammography ranges from 106% to 180%. It also depends on the type of mammograph used for CESM image acquisition
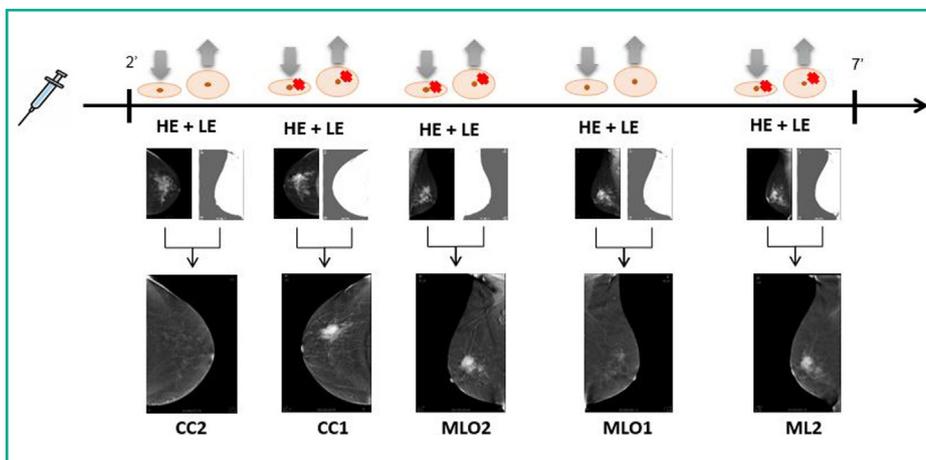
Figure 2. Figure shows angiomammography images based on dual-energy technique.

Table 1

Authors [ref.]	AGD (mGy/view)		Mean breast thickness ratio	Ratio CESM vs. MG	Dose CESM vs. MG (mGy/view)	Equipment/ number of patients
	MG	CESM				
Dromain et al. [8]	NA	0.7—3.6	NA	1.20	NA	Prototype (GE) n = 120 patients
Badr et al. [9]	1.72	2.65	56/57	1.54	+0.93	SenoBright® (GE) n = 104 patients
Fallenberg et al. [10]	1.78	1.89	55.4/53.6	1.06	+0.11	Prototype (GE) n = 107 patients
Jeukens et al. [7]	1.55	2.80	58.4/56.1	1.81	+1.25	Senobright® (GE) n = 715 patients
James et al. [11]	2.1	3.0	63/63	1.43	+0.9	Selenia Dimensions® (Hologic) n = 173 patients

MG: mammography; CESM: contrast-enhanced spectral mammography; AGD: average glandular dose; mGy: milligray; NA: not applicable; GE: General Electric Healthcare.

and type of mammographic system used for the comparison (Table 1). It is acceptable in diagnostic setting and inferior to the recommended mammographic dose. The lifetime attributable risk of angiomammography has been evaluated close to zero between 60 and 80 years and with an incidence of 2.0 and a mortality of 0.5 cases/100,000 persons at 40 years compared to 1.2 and 0.25 cases/100,000 persons respectively for full-field digital mammography [7]. However, this increase in radiation dose should be justify by proper indication of angiomammography.

Interpretation

Interpretation of CESM images requires a combination of mammographic and MRI descriptors. Indeed, mammographic descriptors are the most appropriate descriptors for the interpretation of the low energy image that is similar to a standard digital mammogram displaying morphological information. Indeed, the patient positioning and the tube voltage used in the LE exposure is the same as that used in a standard digital mammogram (MX). The prior administration of intravenous iodinated contrast is the only difference between the low energy image and standard digital mammogram but with very limited impact as the spectrum of the LE exposure is below the k-edge of iodine (33 keV). This has been confirmed in clinical studies showing that the low energy image of CESM examinations has a diagnostic accuracy similar to that of standard mammography [10,12,13]. These results suggest that when a CESM examination is planned, additional mammography can be avoided with the possibility of saving up to 61% of radiation dose [10]. MRI descriptors are the most frequently used descriptors for the interpretation of the subtracted image (recombination of low and high-energy images) that provide information similar to dynamic enhanced T1-weighted MR images. However, these descriptors do not take into account the specifics of this two-dimensional (2D) projection subtracted image. Indeed, even if CESM assessment is, similar to breast MRI, based on analysis of contrast uptake and washout of breast lesions, there are several technical differences between both examinations that may affect image interpretation.

Table 2

	CESM	Breast MRI
Imaging	2D projection Overlapping of contrast uptake in the gland and the lesion	3D thin slices
Contrast resolution	Iodine/X-ray Lower degrees of contrast enhancement	GBCA/MRI
Temporal resolution	Different views are imaged at different times Difficulty to assess symmetry of features	Both breasts imaged simultaneously
Quantity of contrast agent	Adapted to the body weight ($\sim 90\,cm^3$) Delayed peak of enhancement 2—3 min	$15\,cm^3$ of GBCA + $20\,cm^3$ saline Peak of enhancement at 1 min 30 s
Compression	During images acquisition	Without
Positioning	Identical to MG Perfect correlation with low energy image	Procubitus
Unenhanced images	Low energy image Visualization of calcifications	T1- and T2-weighted images (with and without fat suppression) DWI Useful for characterization
Kinetic analysis	None or 1 breast (temporal technique)	Yes

CESM: contrast-enhanced spectral mammography; 2D: two-dimensional; 3D: three-dimensional; MRI: magnetic resonance imaging; MG: mammography; GDBA: gadolinium-based contrast agent; DWI: diffusion-weighted images.

Theses major differences and their impact on interpretation are summarized in Table 2.

Regarding CESM subtracted images interpretation it is important to keep in mind that CESM images are projection images responsible for an overlap between parenchymal enhancement and tumor enhancement and also an overlap of the enhancement of all the tumor thickness. Hence, the intensity of enhancement depends on tumor size and is more pronounced in large lesions than in small ones (Fig. 3). By comparison with MRI, internal enhancement pattern on CESM has limited value and the rim enhancement sign has a different significance. A new ''eclipse sign'' has thus been described as being highly suggestive of a benign cystic lesion (Fig. 4).

Recognition and characterization of artifacts are also important for the correct interpretation of CESM examination. Indeed, artifacts may create pseudo-lesions and obscure actual lesions. Due to its specific acquisition and post treatment processing, most of these artifacts are unique to CESM examination. These artifacts include skin line artifacts, the breast-in-breast artifact due to difference of scattered radiation between different breast thicknesses (Fig. 5), ridge artifact visible between structures with very different densities (fat and dense gland) due to the reconstruction algorithm, ripple artifact due to patient motion between the low and high-energy acquisition [14]. Iodine contamination artifact corresponding to the presence of iodine on the breast skin due to a contamination by the technician has also been described [15]. Iodine contamination artifact could be very tricky to diagnose and should not be misinterpreted as tumor enhancement. Recognition of this artifact is based on visualization of finger prints and or the presence of enhancement on the breast skin in one incidence (Fig. 6).

Clinical performance

First studies on contrast mammography used a temporal technique and showed an increased sensitivity compared to digital standard mammography without decreasing the specificity [5,6,16]. The increased sensitivity was particularly more pronounced in women with dense breast tissue. The great value of these studies was to demonstrate that the dynamic information, provided by signal intensity time-curves, did not have any impact on the sensitivity of contrast-enhanced mammography. The peak of enhancement was observed to be delayed compared to breast MRI (2 min 30 vs. 1 min 30, respectively).

Sensitivity of CESM compared to mammography

Most studies have evaluated the diagnostic performance of CESM in addition to mammography in patients referred from breast screening [17] or as a problem-solving tool and in preoperative staging [8,18]. CESM helps increase sensitivity without decreasing specificity, due to higher contrast and better lesion delineation than mammography alone. Results of the major clinical studies comparing CESM and mammography for the detection of breast cancer are summarized in Table 3 [8,10,17,19—24].

Sensitivity of CESM compared with MRI

Most of studies have compared CESM and MRI for the extent of disease in patients with known breast cancers. The clinical performance of CESM in comparison with MRI is summarized in Table 4 [19,24—29].
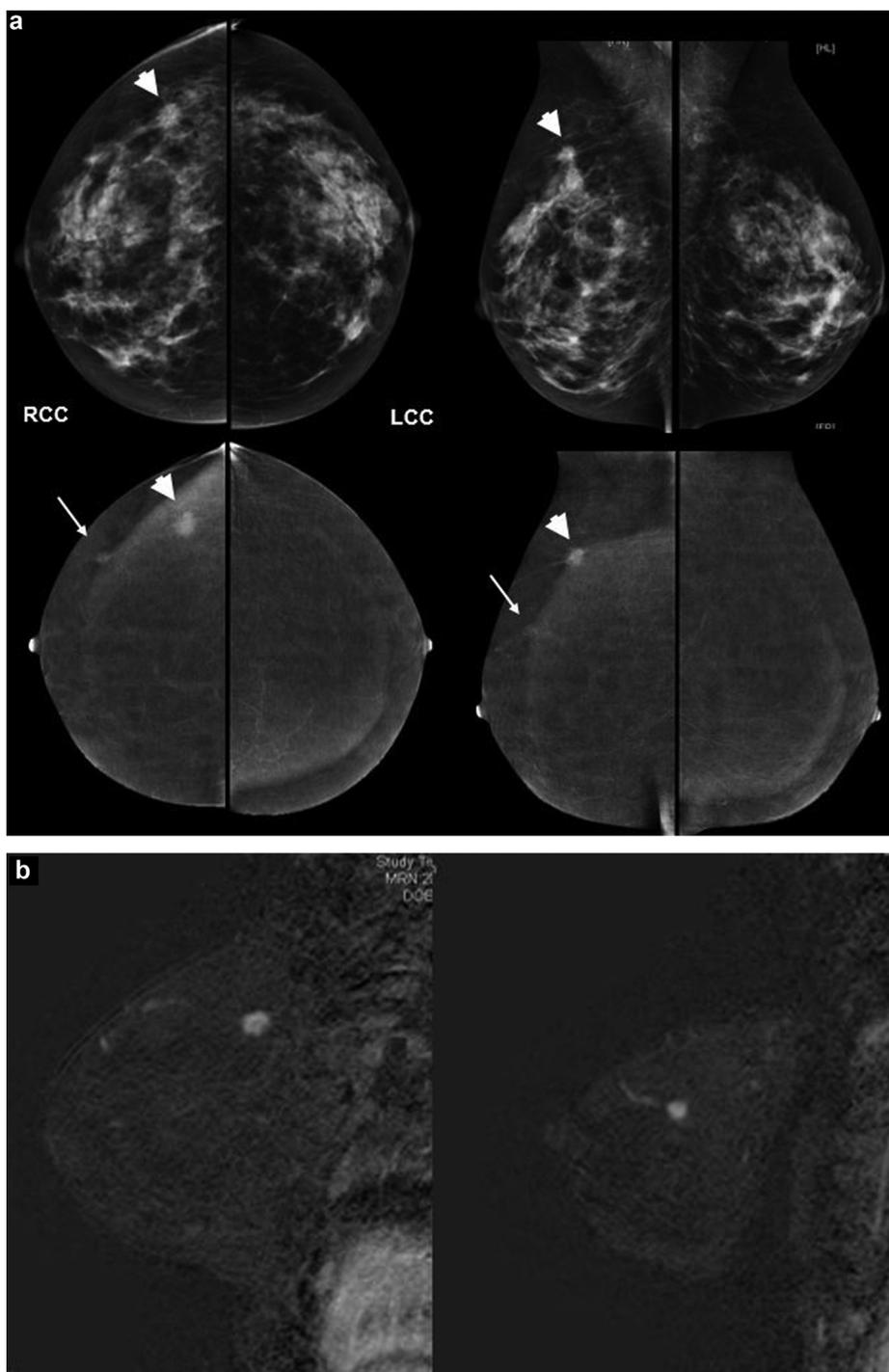
Figure 3.   A 56-year-old woman with a bifocal invasive lobular carcinoma: a: Angiomammography with low and recombined images (a) shows 2 enhancing breast masses with an intensity of enhancement more pronounced for the largest lesion (arrowhead) than for the smallest lesion (arrow); b: on breast MRI, both lesions have similar conspicuity.

Value of CESM for the detection of non-invasive cancers

CESM has some advantages over MRI for the detection and characterization of non-invasive carcinoma in particular in the presence of cluster of calcifications. Indeed, CESM allows direct correlation between low energy image and subtracted image acquired with the same positioning during a single examination. It is important to emphasize that when calcifications are visible on low energy images and considered as suspicious, CESM must be considered as suspicious (positive) even if no enhancement is present on recombined image. Only few studies have evaluated the value of CESM in patients with cluster of calcifications. Cheung et al.
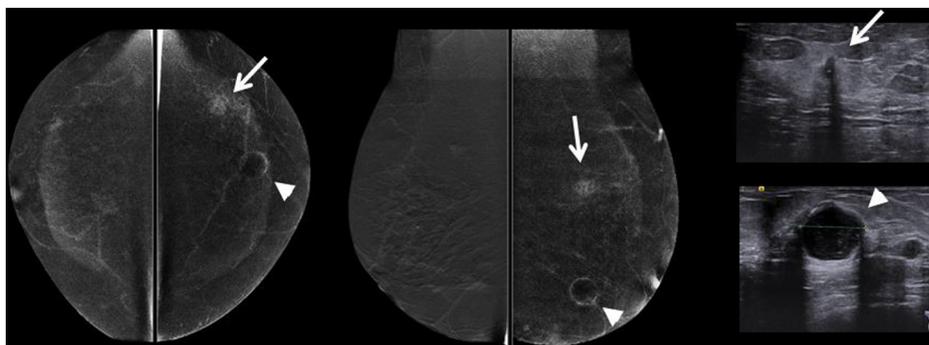
Figure 4. The eclipse sigh highly suggestive of a benign cyst. Subtracted CESM images show two lesions: a mass forming enhancing lesion with irregular margins on the upper outer quadrant (arrow) highly suggestive for malignant lesion and a dark round mass surrounded by a thin rim of enhancement on the lower outer quadrant highly suggestive for benign cyst (arrowhead). Ultrasound images were consistent with these findings.
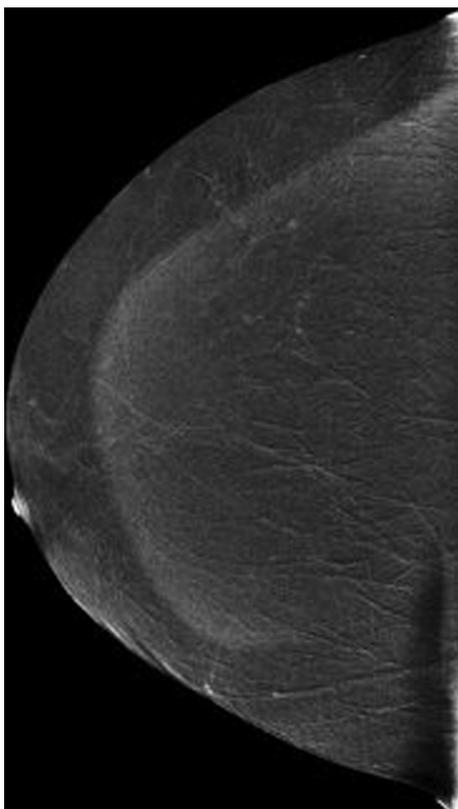
Figure 5. Breast artifact. This artifact, which is specific to CESM examination, is due to the difference of scattered radiation between areas of the breast having different breast thicknesses.

showed 91% sensitivity with 94% negative predictive value in 59 patients with BIRADS 4 cluster of calcifications for CESM [30]. Similar to MRI, some DCIS did not show enhancement.

CESM limitations

Most of false negative findings on CESM are due to masking effect due to background parenchymal enhancement and non-enhancing breast cancers, similar to breast MRI, but also to lesions being out of the field of view [31]. Indeed, the positioning during CESM examination being the same than regular mammography, deep lesions or lesions localized in the blind spots of image projection can be missed (Fig. 7). Major causes of missed cancers on CESM are summarized in Table 5 [8,19,30].

Similar to MRI, not all enhancing lesions depicted on recombined CESM images are malignant. Major causes of false-positive findings on CESM are summarized in Table 6 [8,19,30].

Patient experience

CESM offers many advantages in term of patient experience compare to breast MRI. Patients who underwent both examinations generally better tolerated CESM than MRI. In a study performed in 49 patients, Hobbs et al. have shown that CESM was significantly preferred to MRI due to the faster procedure time, greater comfort and lower noise level and lower rates of anxiety [33]. However, MRI was considered better than CESM in terms of breast compression and lower side effects during intravenous injection of contrast agent. Phillips et al. prospectively evaluated patient preferences as part of a study comparing CESM and MRI in 43 women at high-risk [34]. Experience with CESM was better than with MRI for 68%, and 79% of patients indicated that they would prefer CESM rather than MRI for screening pending similar diagnostic capabilities [34]. Finally, potential side effect due to contrast material administration was not considered as a limitation by the patient.

Clinical indications

CESM is currently an alternative to contrast-enhanced MRI for patients with contraindication to MRI or gadolinium-based contrast agent administration as well as to limited MRI availability [35].

Breast MRI contraindications

Richter et al. have performed CESM in 118 patients with contraindications to MRI [36]. In patients who had CESM for the assessment of disease extent, CESM yielded 98.8% sensitivity. The NPV was 85.7%, significantly higher than

Table 3

Authors	n	Indication	Analysis	MG (%)	CESM (%)
Dromain et al. [8]	120	Suspect findings	Per patient	78	92
Jochelson et al. [19]	52	Known cancer	Per patient	81	96
			Per lesion	59	83
Fallenberg et al. [25]	80	Known cancer	Per patient	81	100
Fallenberg et al. [10]	118	Known cancer	Per patient	78	95
Luczynca et al. [20]	152	Suspect findings	Per patient	91	100
Lobbes et al. [17]	113	Recall from screening	Per patient	97	100
Lalji et al. [21]	199	Recall from screening	Per patient (10 readers)	93	97
Tennant et al. [22]	100	Symptomatic patients	Per lesion	84	95
Luczynska et al. [23]	116	Symptomatic patients	Per lesion	90	100
Fallenberg et al. [24]	178	Known cancer	Per lesion (all)	55	72
			Index lesions	81	94
			Additional lesions	17	95

MG: mammography; CESM: contrast-enhanced spectral mammograpy; MRII: magnetic resonance imaging; n: number of patients.

Table 4

Authors	n	Indication	Analysis	MG (%)	CESM (%)	MRI (%)
Jochelson et al. [19]	52	Known cancer	Per patient	81	96	96
			Per lesion	59	83	93
Dromain et al. [29]	53	Known cancer	Per patient	NA	94	100
			Per lesion		93	98
Fallenberg et al. [25]	80	Known cancer	Per patient	81	100	97
Luczynca et al. [26]	102	Suspicious lesion	Per patient	NA	100	93
Chou et al., 2015 [28]	185	Suspicious lesion	Per patient	NA	93–98	86–93
Wang et al. [27]	77	Suspicious lesion	Per patient	NA	95.8	93.8
Fallenberg et al. [24]	178	Known cancer	Per lesion (all)	55	72	76
			Index lesions	81	94	39
			Additional lesions	17	95	49

MG: mammography; CESM: contrast-enhanced spectral mammography; MRI: magnetic resonance imaging; n: number of patients; NA: not applicable.

Table 5

|	FN of CESM	Histopathological findings
Dromain et al. [8]	6/80 (7.5%)	2 DCIS 2 tubular carcinoma 2 IDC
Jochelson et al. [19]	2/52 (3.8%)	1 ILC (2 cm) 1 IDC + DCIS (5 mm)
Dromain et al. [29]	6/82 (7.3%)	3 lesions outside the field of view 3 ILC (7, 10 and 7 mm)
Tardivel et al. [30]	10/221 (4.5%)	2 DCIS 2 ILC 6 IDC (1 was masked by background parenchymal enhancement, 2 low enhancing lesions interpreted as probably benign and 3 resulting from suboptimal patient positioning)

FN: false negatives; CESM: contrast-enhanced spectral mammography; DCIS: ductal carcinoma in situ; IDC: invasive ductal carcinoma; ILC: invasive lobular carcinoma.

Table 6

|	Number of FP on CESM	Number of FP on MRI	Histopathological findings
Dromain et al. [8]	13 (13/50; 26%)	NA	3 fibroadenoma, 2 radial scars, 2 adenosis, 1 intraductal papilloma, 1 grade 1 phylloïd tumor, 2 fat necrosis, 2 fibrocystic mastopathy
Jochelson et al. [19]	2 (2/52; 9%) PPV = 97%	13 (13/52; 25%) PPV = 85%	1 radial scar, 1 fibroadenoma
Dromain et al. [29]	1 (1/54; 2%) PPV = 99%	5 (5/54; 9%) PPV = 94%	1 cylindric metaplasia
Tardivel et al. [30]	18 (18/299; 6%) PPV = 91%	NA	5 high-risk lesions (3 LCIS, 1 atypical ductal hyperplasia, 1 papilloma), 3 fibroadenomas, 1 intramammary lymph node, 1 non atypical papillar hyperplasia, 1 fibrocystic disease, 2 abcesses, 1 adenosis

CESM: contrast-enhanced spectral mammography; MRI: magnetic resonance imaging; FP: false-positives; NA: not applicable; PPV: positive predictive value; LCIS: lobular carcinoma in situ.
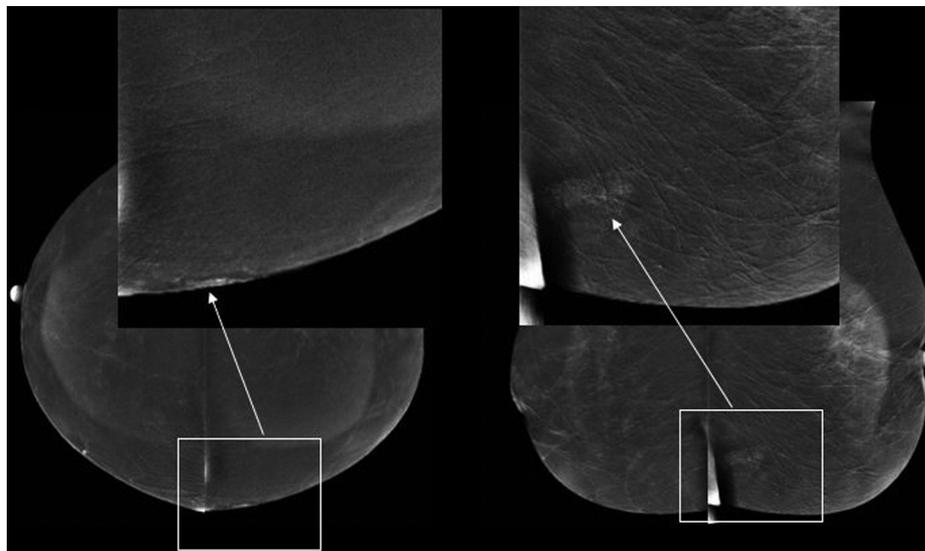
Figure 6. Iodine contamination artifact of breast skin mimicking a non-mass enhancement on angiomammography. Parameters that suggest that this finding may be artefactual are: if non-mass enhancement is only seen on one view and does not persist on additional or repeated imaging, and resolved after washing the breast.
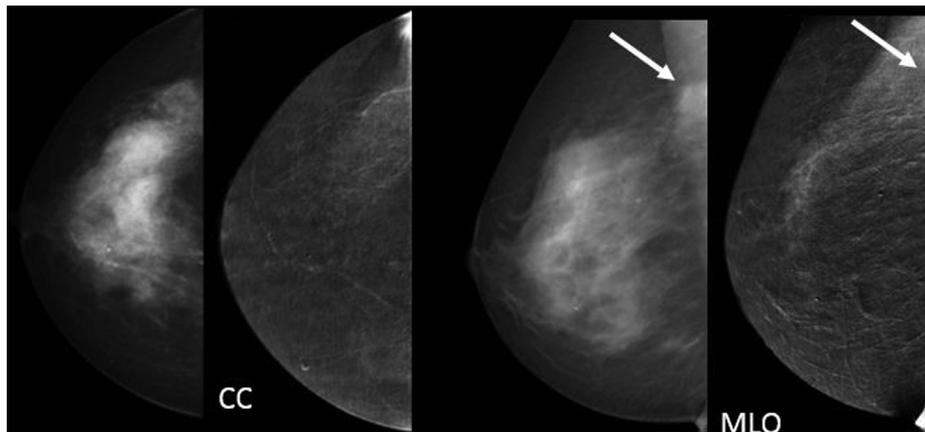
Figure 7. False negative finding at CESM due to a deep lesion (arrow) out of the field of view. Note that the positioning of the MLO image is suboptimal compared to the positioning of the regular mammogram.
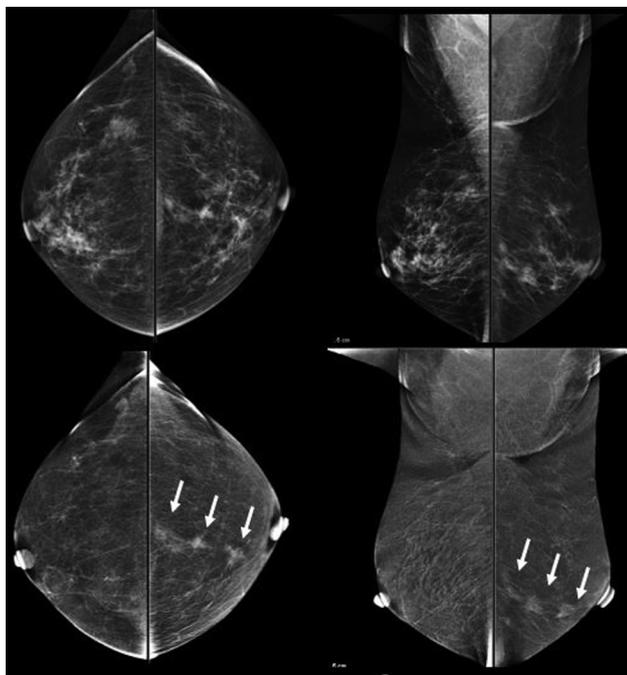
Figure 8. 64-year-old woman with a left breast nipple bleeding. CESM recombined images shows a 4 cm retro areolar non-mass enhancement (arrows) highly suggestive of malignant lesion. Histopathological analysis revealed grade 2 invasive ductal carcinoma and ductal carcinoma in situ.

that of mammography (30.7%) [36]. In patients imaged for problem-solving after biopsy that revealed benign findings, CESM allowed the detection of clips distant from the enhancing lesion in 2 patients. Repeat biopsy led to the diagnosis of malignant lesion in both patients [36]. In patients imaged for neoadjuvant chemotherapy monitoring, a discordance was found between CESM findings and histopathological findings in 1/5 patients, consisting in partial response on CESM not confirmed at pathological analysis [36].

Problem-solving

CESM is an excellent problem-solving tool to address inconclusive findings on screening mammograms [17]. Compared to mammography, CESM increases the sensitivity, specificity, positive predictive value and negative predictive value by 3%, 88%, 37% and 3%, respectively [17]. These results demonstrate that CESM is especially useful in downgrading lesions depicted on mammogram and thus decrease patient recall due to false-positive findings. Moreover, the high negative predictive value of CESM suggests that a negative CESM excludes breast cancer.

Symptomatic patients

CESM may favorably replace conventional mammography as a first step examination in symptomatic patients, as they generally have a higher prevalence of breast cancer than the average screening population (Fig. 8). Tennant et al. retrospectively analyzed CESM examinations in 100 consecutive symptomatic patients presenting with palpable breast

abnormalities [22]. They found 97% sensitivity and 91% negative predictive value for CESM in the detection of breast cancer. The diagnostic accuracy of CESM was significantly higher (AUC = 0.93) than that of mammography (AUC = 0.82), by contrast with mammography was not affected by breast density.

Assessment of the extent of disease

Regarding the assessment of disease extent, CESM has similar sensitivity for the detection of the primary cancer and a slightly lower sensitivity than MRI for the detection of secondary foci (Figs. 9 and 10). Moreover, CESM provides a good estimate of lesion size similar to MRI [24,37]. Finally, CESM tends to generate less false-positive findings than breast MRI. The largest prospective study to date has compared CESM and MRI in 178 women with known breast cancers [24]. Using a retrospective review by 3 readers, CESM showed similar breast cancer diagnostic performance than MRI (AUC = 0.84 for CESM, AUC = 0.85 for MRI) with slightly lower sensitivity for all lesion (index + additional) (70% for CESM vs. 76% for MRI) but higher specificity (94% for CESM vs. 88% for MRI) [24]. Inter-reader agreement was better for CESM (0.71, 0.73, 0.77) than for MRI (0.67, 0.72, 0.74) [24].

Dense breast

Dense breast is an independent risk factor for breast cancer [38,39] and the most important cause of false negative findings on mammography in women with breast cancer [40]. Studies have shown that, in contrary to mammography, CESM sensitivity is not affected by breast density, suggesting that CESM could be of value in the screening of dense breast population [25,30]. Fallenberg et al. have compared mammography to mammography + CESM in patients with dense breast [25]. They studied 107 patients including 56 patients with dense breasts (including BIRADS 3 and 4 breast density) [25]. Although a drop of sensitivity was observed between non-dense and dense breasts (85.8% vs. 71.6%, respectively), no differences in terms of sensitivity were observed for CESM between non-dense and dense breasts (96.5% vs. 93.8, respectively) (Fig. 11). Similar results were found by Cheung et al. [30]. In a study performed in 89 women with dense breast, CESM had a sensitivity of 92.7% with a significantly higher interobserver concordance than mammography alone [30].

Neoadjuvant chemotherapy monitoring

Another potential clinical indication of CESM in replacement of breast MRI is the assessment of tumor response to neoadjuvant therapy. A study that included 21 patients showed 91% specificity in predicting response to neoadjuvant chemotherapy and 100% sensitivity in predicting complete tumor response [41]. Some discordances between pathology and radiological response in CESM images were observed in chemo-resistant tumors. Although results are promising, larger studies are needed to better determine the potential for CESM to replace breast MRI in this indication.
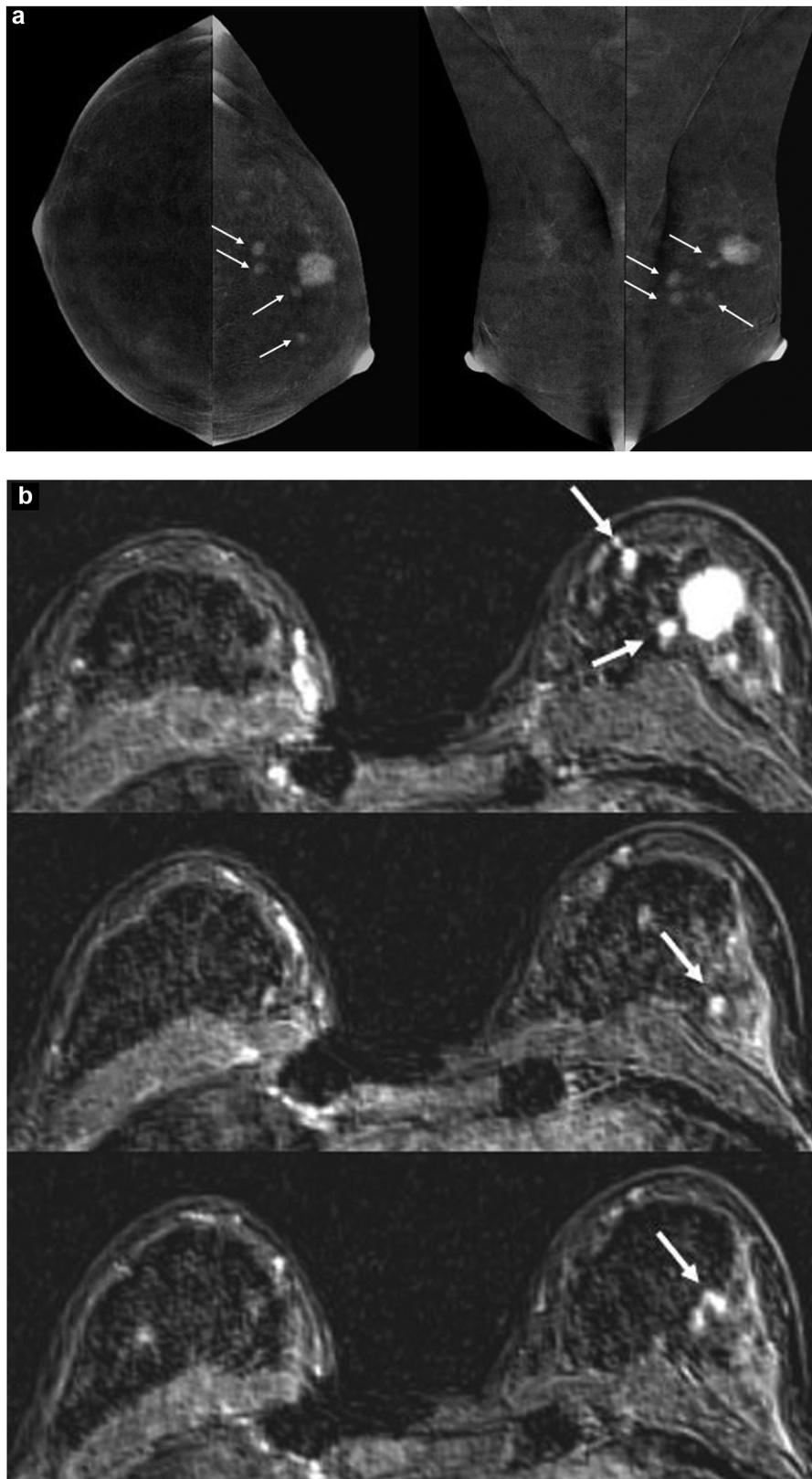
Figure 9. 43-year-old woman with a histologically proven lobular carcinoma of the left breast: a: CESM recombined image shows the index tumor but also 4 additional ipsilateral foci (arrows) highly suspicious for multifocal tumor; b: breast MRI shows similar findings (arrows). A multifocal lobular carcinoma was histopathologically confirmed after second look ultrasound and biopsy of the nodule that was the most distant from the index tumor.
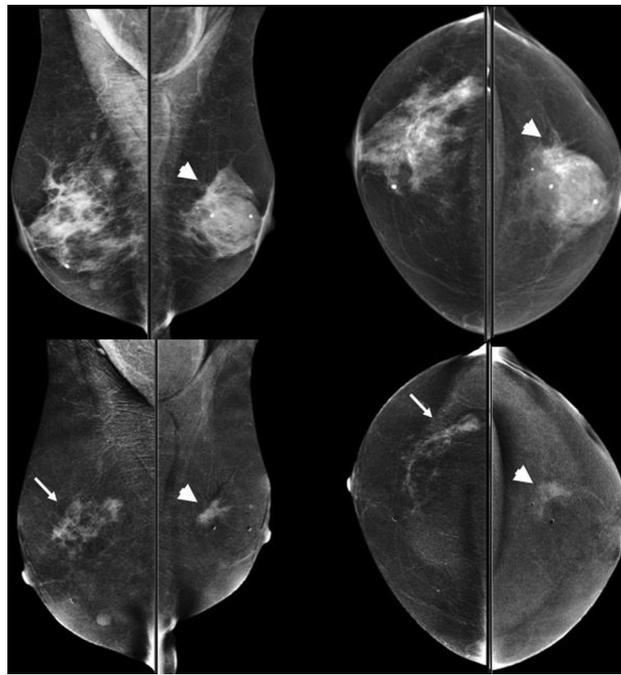
Figure 10. 62-year-old woman with a palpable mass in the left breast. Mammography shows a spiculated mass on the superior and outer quadrant of the left breast with intense enhancement on recombined CESM images highly suggestive for malignant lesion. CESM recombined images also depict a segmental non-mass enhancement on the right breast suggestive for ductal carcinoma in situ. Histopathological analysis confirmed grade 2 invasive ductal carcinoma on the left breast and a ductal carcinoma in situ on the right breast.
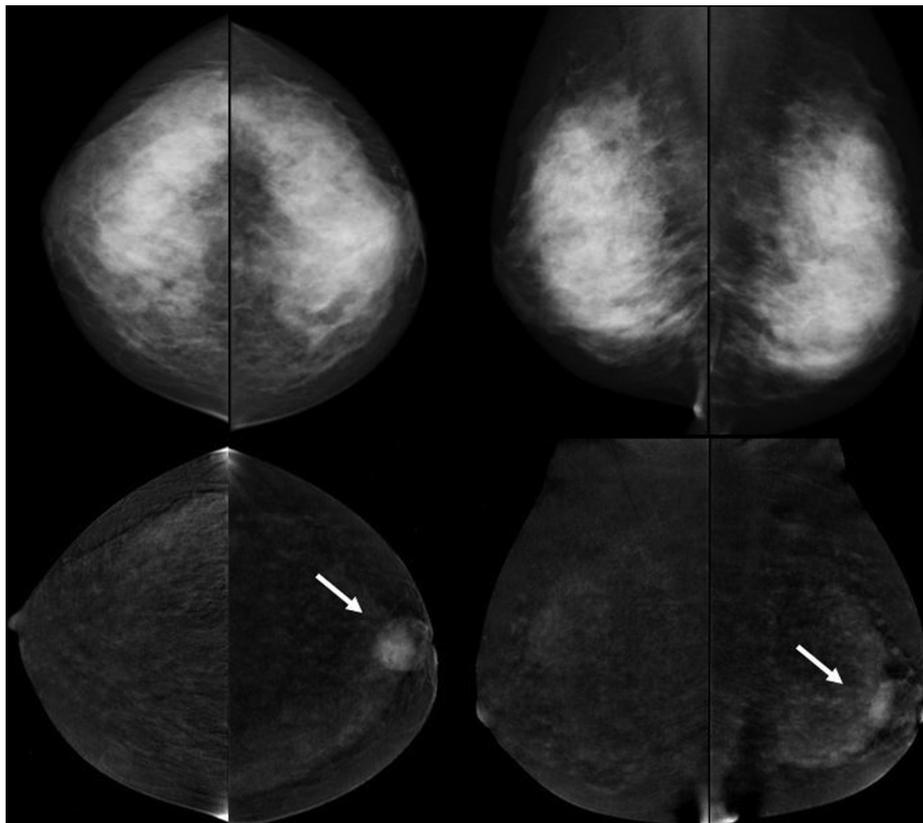
Figure 11. 58-year-old woman with a nipple retraction. Mammography images show a not very dense breast (BIRADS D) with no abnormal finding except the nipple area thickening. On recombined CESM images, a retroareolar mass enhancement is well depicted. Histopathological analysis confirmed invasive ductal carcinoma.

Screening

CESM has the potential to provide, in a single examination, both the yearly mammogram and the supplemental contrast examination that are recommended for the screening of high-risk patients. Limited evidence is available regarding the value of CESM for breast screening. To date, only one pilot study has evaluated the performance of CESM in high-risk women [42]. Three hundred and seven patients were screened with both CESM and MRI. The first-round screening found three cancers including two invasive ductal carcinomas and one ductal carcinoma in situ that were histologically proven 9 months later [42]. MRI showed all the 3 cancers whereas CESM detected only the 2 invasive ones. None of these 3 cancers was detectable on the low energy images. The number of screened CESM patients called back for additional imaging was 7.5%. False-positive rate was 5.3% for CESM and 5.9% for MRI. On 2-years follow-up, 5 additional cancers were found with no palpable breast cancers. Additional data is needed to validate the usefulness and clinical performance of CESM in targeted screening population taking into account the risk of breast cancer in the targeted population, the increased radiation dose, and the potential side effects of contrast material administration in a large-scale healthy population.

Conclusion

Angiomammography, using dual-energy technique, is an emerging technique for breast cancer detection with an ease of implementation, good patient experience, increased sensitivity compared to mammography with no loss of specificity, in particular in dense breast, and very close performance to breast MRI. Current clinical indications are those of breast MRI in case of contraindication to breast MRI or limited access to breast MRI. However, in the future, angiomammography could also be an alternative to mammography in symptomatic patients or high-risk stratified screening such as dense breasts. Other perspectives include the development of contrast-enhanced digital breast tomosynthesis (CE-DBT), combining the benefit of three-dimensional assessment of the breast and dynamic information from the dual-energy acquisition after contrast injection, and the possibility to perform CESM-guided biopsies.

Author contribution statements

Clarisse Dromain: wrote the manuscript with support from Naik Vitti violli and Jean-Yves Meuwly.

All 3 authors contributed to the final manuscript.

Uncited reference

[32].

Disclosure of interest

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