



REVIEW / *Breast imaging*

Breast tomosynthesis: What do we know and where do we stand?



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KEYWORDS

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Abstract Digital breast tomosynthesis (DBT) is a new imaging technology that addresses the limitation caused by overlapping structures in conventional two-dimensional digital mammography owing to the acquisition of a series of low-dose projection images. This unique technique provides a dual benefit to patients screened for breast cancer. First, DBT increases the cancer detection rate mostly by highlighting architectural distortions and allowing better assessment of masses shape and margins. Second, DBT helps reduce recall rate by discarding asymmetries related to overlapping tissue. However, DBT is not included in the majority of cancer screening programs worldwide. Several issues still need to be addressed such as over-diagnosis and over-treatment, lack of reduction of interval breast cancer, quality control and storage, and radiation dose. In the diagnostic setting, DBT increases the diagnostic accuracy and reduces the number of indeterminate lesions in symptomatic women. Its aforementioned performances regarding asymmetries, masses and architectural distortions allow reducing the number of additional views while working-up a screening-detected lesion. Tumor size is also better assessed at DBT as well as multicentricity, two significant benefits in the staging of breast cancer. Finally, DBT allows a better analysis of scars and helps reduce the rate of indeterminate findings after surgery. Although somewhat limited by high breast density, DBT globally outperforms digital mammography in both screening and diagnostic breast imaging. Additional research is however needed, particularly on relevant screening outcomes. This review describes the main performances of breast DBT in breast cancer screening and diagnosis and the resulting consequences in both settings.

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Conventional two-dimensional (2D) mammography is widely acknowledged as the most effective method for detecting breast cancer and improving the outcome of the disease. A meta-analysis of 11 randomized trials concluded that mammography screening leads to a reduction of 20% in breast cancer mortality [1]. The main limitation of this technique is a potential tissue overlap that decreases sensitivity and specificity especially in dense breasts. Indeed, detection of the digital signal depends on the total attenuation of the x-ray beam by the intervening tissue. Overlapping tissue can consequently obscure an area of interest and lead to false-negatives, explaining the 15–30% undetected cancers by standard screening. In addition, the overlap of normal structures in the breast can create a pseudolesion, often named summation artifact, which can generate false-positive findings. This leads to further investigations, unnecessary follow-up or biopsy, all responsible for anxiety and non-attendance for next routine breast screening tests [2,3].

Digital breast tomosynthesis (DBT) is a new imaging technology that addresses this limitation by acquiring a series of low-dose projection images. DBT images are acquired as the x-ray tube travels across a limited arc above the breast and multiple low-dose x-ray exposures are obtained. Reconstruction algorithms allow producing a set of parallel images planes through the whole breast, typically with 1-mm spacing. Digital mammography (DM) and DBT images can be acquired using the same breast compression [4].

The purpose of this review is to describe the state of the art in terms of performances of breast DBT in breast cancer screening and diagnosis (what do we know?) and the consequences that have been drawn from these performances (where do we stand?). Lastly, we shortly address the advanced applications of DBT including DBT-guided biopsy, computer-aided detection (CAD) applied to DBT, contrast-enhanced DBT, and multimodality imaging combining DBT with other imaging techniques.

Screening

What do we know?

The first studies demonstrating the good performances of DBT in breast cancer screening were retrospective with multiple readers [5,6]. They were significantly enriched with patients with breast cancer since the prevalence of malignancy varied between 15 and 50%, so from 30 to 100 times larger than in the usual screening setting. In most of those studies, a large part of the population underwent DBT on the basis of an abnormal mammogram, constituting a selection bias in favor of DM in terms of sensitivity. By contrast, specificity of DBT was also potentially artificially increased since the potential false-positives recruited by DBT were not included. Those enriched retrospective multireader studies showed at least non-inferiority of DBT compared to DM, and superiority of DBT when area under curve (AUC) was used for assessment and when two-view DBT + two-view DM were compared to two-view DM. Among those studies, the TOMMY trial was particularly relevant in a population of more than 8000 women with 7684/8869 recruited following a screening mammography recall: AUC

DBT + DM was significantly better than DM alone ($P < 0.001$) mostly related to an increased specificity ($P < 0.001$) in the DBT arms [7]. There was a marginal improvement in sensitivity ($P > 0.07$) in the DBT arms except for invasive tumors of size 11–20 mm for which it was significant ($P < 0.006$).

The actual potential improvement in screening may not have been demonstrated due to selection bias in the enriched studies. Studies in real screening conditions can give more realistic data. There were two different designs of studies according to their origin. Most of the studies performed in European centers [8–12] except from one [13] were prospective and paired studies in which patients were their own control (i.e., each woman was imaged at screening with both DM and DBT) whereas studies from the United States [14,15] and one from Italy [13] were retrospective and compared the results of different periods of screening with a different number of patients since some screening centers in both countries have been switching from screening with DM to screening with DBT. Although different in their designs, these studies led to consistent results. A summarize of all studies from Europe and of the two largest multicenter studies from the United States is presented in Tables 1 and 2.

Cancer detection

All studies shown in Table 1 reported on DBT (interpreted with DM or SM) compared with DM alone, except for one study which compared a single DBT stand-alone view with 2 DM views [12]. The effect of DBT on breast cancer detection rates (in absolute terms per 1000 screening examinations) mostly led to a significant increase in breast cancer detection rate ranging from 1.3‰ to 4‰. The only study showing a non-significant 0.5‰ increase was the only randomized and controlled trial ever published on the matter [11]. However, as part of the plausible explanations for this discrepancy, this study was performed using a first-generation DBT and synthetic digital mammography unit, possibly perfectible [16]. When comparing the radiological appearance of the detected cancers, there was a higher proportion of architectural distortions in DBT compared to DM screening [13,17].

Screening recall

The effect of DBT on recall rates, in absolute terms, ranged from a statistically significant increase in recall of 1.1% to a statistically significant decrease in recall of 1.8%. The only study showing an increase was also the only one comparing the standard 2 DM views with a single DBT stand-alone view [12] instead of DM + DBT. Even though there is no consensual result about the effect of DBT screening on recall, the large majority of the studies, including the only randomized controlled one, reported a decrease in recall rate. Focal asymmetry was the most affected mammographic finding by the addition of DBT, with a decrease in asymmetry recalls of 58% [18]. Indeed, DBT allows discarding focal asymmetries by showing that they are created by crossing Cooper ligaments and fibroglandular tissue.

Impact of DBT according to the experience of the readers

In several studies, implementation of DBT in screening programs showed varying impacts depending on the reader's

Table 1 Results of digital breast tomosynthesis in breast screening: cancer detection rate.

Origin	Design	Modalities	Equipment	Population	DM(‰)	DM + DBT ^a (‰)	Increase in CDR due to DBT (‰)	Multiplying factor	Reference (year)
Europe	Prospective	DM 2 views vs. DM + DBT 2 views	Hologic	12,631	7.1	9.4	2.3	1.31	Skaane et al. (2013) [8]
Europe	Single center Prospective	DM 2 views vs. DM + DBT 2 views	Hologic	7293	5.3	8.1	2.8	1.51	Ciatto et al. (2013) [9]
Europe	Single center Prospective	DM 2 views vs. DM + DBT 2 views	Hologic	9672	6.1	8.5	2.4	1.28	Bernardi et al. (2016) [10]
Europe	Single center Prospective	DM 2 views vs. DBT 1 MLO view ^a	Siemens	14,581	6.5	8.7	2.2	1.34	Zackrisson et al. (2019) [12] ^a
Europe	Single center Prospective multicenter	DM 2 views vs. SM + DBT 2 views	GE Healthcare	14,369 (DM)	6.1	6.6	0.5	1.08	Hofvind et al. (2019) [11]
Europe	Randomized			14,380 (SM + DBT) 29,360 (DM)	5.2	9.2	4	1.77	Caumo et al. (2018) [13]
USA	Retrospective	DM 2 views vs. DM + DBT 2 views	Hologic	34,071 (SM + DBT) 181,187 (DM)	2.9	4.2	1.3	1.41	Friedewald et al. (2014) [14]
USA	Retrospective	DM 2 views vs. DM + DBT 2 views	Hologic	173,663 (DM + DBT) 142,883 (DM)	4.4	5.9	1.5	1.45	Conant et al. (2016) [15]
	Multicenter			55,998 (DM + DBT)					

DM: digital mammography; DBT: digital breast tomosynthesis; CDR: cancer detection rate; SM: synthetic mammography; MLO: mediolateral oblique; vs.: versus.

^a Except for Zackrisson's study (DBT stand-alone).

Table 2 Results of digital breast tomosynthesis in breast screening: recall rate.

Origin	Design	Modalities	Equipment	Population (n)	RR DM (%)	RR DBT(%)	Decrease in RR due to DBT (%)	Multiplying factor	Reference (year)
Europe	Prospective	DM 2 views vs. DM + DBT 2 views	Hologic	12,631	10.3	8.5	1.8	0.83	Skaane et al. (2013) [8]
Europe	Single center Prospective	DM 2 views vs. DM + DBT 2 views	Hologic	7293	4.5	3.5	1	0.77	Ciatto et al. (2013) [9]
Europe	Single center Prospective	DM 2 views vs. DM + DBT 2 views	Hologic	9672	4.9	4.4	0.5	0.9	Bernardi et al. (2016) [10]
Europe	Single center Prospective Single center	DM 2 views vs. DBT 1 MLO view	Siemens	14,581	2.5	3.6	-1.1	1.44	Zackrisson et al. (2019) [12]
Europe	Prospective multicenter	DM 2 views vs. SM + DBT 2 views	GE Healthcare	14,369 (DM)	4	3.1	0.9	0.78	Hofvind et al. (2019) [11]
Europe	Randomized			14,380 (SM + DBT)					
Europe	Retrospective	DM 2 views vs. SM + DBT 2 views	Hologic	166,666 (DM)	4.2	4	0.2	0.95	Caumo et al. (2018) [13]
USA	Single center Retrospective			14,423 (SM + DBT)					
USA	Retrospective	DM 2 views vs. DM + DBT 2 views	Hologic	181,187 (DM)	10.7	9.1	1.6	0.85	Friedewald et al. (2014) [14]
USA	Multicenter Retrospective			173,663 (DM + DBT)					
USA	Retrospective	DM 2 views vs. DM + DBT 2 views	Hologic	142,883 (DM)	10.4	8.7	1.7	0.84	Conant et al. (2016) [15]
	Multicenter			55,998 (DM + DBT)					

RR: recall rate; DM: digital mammography; DBT: digital breast tomosynthesis; SM: synthetic mammography; MLO: mediolateral oblique; vs: versus.

experience. The increase in sensitivity was significantly greater for junior readers than for senior ones. However, the recall rate decreased with the improvement of specificity, regardless of the reader's experience [19]. Moreover, early performance improvements after digital DBT adoption were sustained regardless of DBT volume, radiologist subspecialty, or breast density [20]. These results prompt reconsidering our screening practice by including DBT and encourage trials that investigate new mammography strategies [21]. It would question the benefit of second reading recommended by European Guidelines for quality assurance in breast cancer screening, given that this practice is an economic burden for every screening program.

Value of DBT in women with dense breast

A known limitation of conventional 2D mammography is tissue overlap, favored by high breast density, which may contribute to obscuring actual breast lesions (i.e., masking effect) and also creating pseudolesions (i.e., summation artifact). Because DBT can reduce tissue superimposition, it could reveal lesions that would otherwise have been missed and reduce false-positive findings by discarding summation artifacts [22]. However, to be efficient in that matter, DBT needs interface between tumoral fibroglandular tissue and fat, which may miss in extremely dense breasts, making DBT poorly efficient in detecting additional cancer in BIRADS D patients [23]. The value of DBT in women with dense breast is therefore questionable. A meta-analysis including 11 screening studies has shown that DBT + DM increased cancer detection rate in women with dense breasts [24]. On the opposite, recall rates were significantly reduced in retrospective studies comparing two groups of participants but not in prospective paired studies [24]. Of interest, a recent multicenter study comparing DM and DBT in two different populations has shown that the benefit brought by DBT for detection of breast cancer was superior in non-dense breast than in dense breast (odds ratio: 1.55 vs. 1.39, respectively) [25].

To summarize, DBT increases cancer detection rate compared to DM alone, with a variable improvement of up to 4%, more evident in prospective studies than in retrospective ones. The effect of DBT + DM on recall is not as consistent as that for cancer detection. However a majority of studies reported a reduction in recall. Furthermore, although present, the benefit of DBT is lower in patients with dense breast. However, despite its advantages, DBT is not included in any European breast cancer screening recommendation. There are still several issues in that matter which will be discussed in the next section.

Where do we stand: the issues that need to be addressed regarding the implementation of DBT as a screening tool

Over-diagnosis and over-treatment

DBT can reveal smaller or more subtle cancers than DM. A large fraction of the invasive cancers detected only by DBT present as spiculated masses (Fig. 1) or architectural distortions; the latter in particular being known as a mammographic feature of good prognosis in cancers. Whether

detection of those additional cancers will be of benefit in terms of mortality is still debated. A meta-analysis including eleven eligible studies comparing DBT + DM to DM alone showed a significant improvement in detection of invasive cancers, stage T1 and nodal negative cancers, and all histologic grades but more preferentially grade 1 breast cancer [26]. However, adding DBT did not increase detection of ductal carcinoma in situ (DCIS), stage \geq T2 invasive cancers, or nodal-positive cancers [26]. The preferential ratio of invasive-to-in situ carcinoma may alleviate some concerns regarding over-diagnosis related to DBT. However, DBT screening leads to a higher proportion of good prognosis cases such as grade 1 cancers and specific favorable histological types like tubular invasive breast cancers [13]. It can therefore be suggested that in the absence of DBT screening, some of these cancers would have been detected at subsequent DM screening rounds without consequence on prognosis.

Lack of reduction of interval breast cancer

This is the main constraint in recommending systematic use of DBT in the screening setting. Published data are very limited but do not demonstrate any significant decrease in interval breast cancer. In a retrospective multicenter study from the United States, the interval breast cancer rate was 0.7‰ with DBT and 0.5‰ with DM, a non-significant difference [27]. However, in this study, medical records were possibly inadequate [27]. On the opposite, in a prospective Norwegian trial, clinical follow-up of the patients included was reliable [28]. The interval cancer rate post-DBT was 2.1‰, similar to the one after DM rounds [28]. Furthermore, post-DBT interval cancers had similar prognostic criteria compared to the ones in prior DM rounds in terms of size, grade and node status [28].

Benign lesions discovered by architectural distortion

Although the overall recall rate decreased or remained unchanged after DBT, the specific architectural distortion (AD) recall rate increased with DBT [18]. The great majority of ADs detected by DBT does not correspond to malignancy and DBT-detected suspicious ADs have a lower malignancy outcome compared with 2D mammography – detected ones, although still high enough to warrant biopsy. In a study assessing the outcome of architectural distortions with no associated mass, one third of the 181 ADs was detected only by DBT with a 10% risk of malignancy, significantly inferior to the 43% risk in 2D-detected AD [29]. Furthermore, the radial scar detection rate has dramatically increased from 0.04% to 10% with DBT imaging in a recent study comparing, before and after introduction of DBT, on the one hand the rate of radial scars diagnosed by core biopsy and on the other the rate of upgrading to malignancy or high-risk lesions [30]. However, malignancy and high risk lesion rates (respectively about 3% and superior to 10%) remained high, maintaining excisional biopsy still necessary [30]. Basically, AD is a feature corresponding generally to a benign lesion when discovered by DBT but that still needs at least imaging-guided biopsy and in some cases excisional biopsy. This explains why in some screening programs such as the Verona screening program [31], the recall rate with invasive

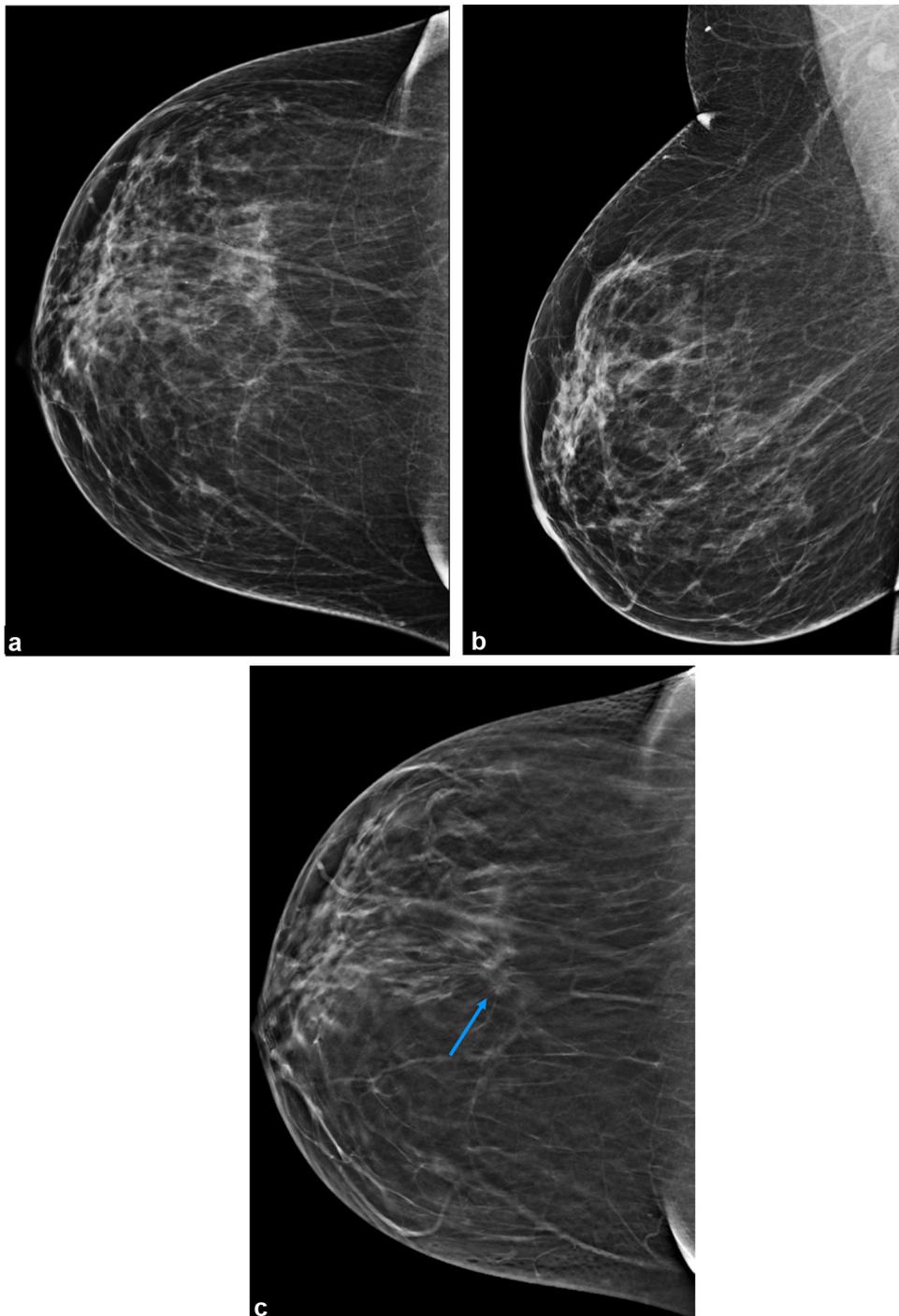


Figure 1. A 77-year-old woman with invasive breast carcinoma. Two-dimensional cranio-caudal (a) and mediolateral oblique (b) mammogram of the right breast shows no abnormality. Cranio-caudal digital breast tomosynthesis (c) of the same breast unveils an irregular mass with spiculated margins (arrow). Invasive carcinoma was confirmed after histopathological analysis of biopsy specimen.

assessment almost doubled with DBT although the overall recall rate was unchanged.

Supplemental screening by breast ultrasound remains necessary

Results from the prospective ASTOUND 2 multicenter trial have shown that among patients with dense breasts and a

negative 2D mammography, the rate of ultrasound-detected cancers (4.9%) was superior to the DBT-detected one (2.83%) [32]. However, DBT yielded significantly fewer false-positive recalls (0.3%) than ultrasound (1%). This important study highlights two points. First, DBT may reveal supplementary cancers in dense breast by comparison to DM, but despite the development of DBT, ultrasound will continue to play a role in dense breast patients screening.

Quality control and storage

DBT has raised specific issues regarding quality control and storage. One DBT view takes up the same amount of storage space than one computed tomography (CT) examination. However, the increase of data storage systems capacity and the development of protocols for quality control of the physical and technical aspects of DBT available since March 2018 (Euref tomo protocol version 1-03) have resolved the main problems. Nevertheless, some countries insist on drawing up their specificities for quality control of DBT units.

Additional reading time

Reading time is almost doubled with DBT compared to DM, increasing by 40 to 60 seconds depending on the series [33]. Theoretically, this would have negative effects on costs and patients flow. However, the impact varies according to the screening policy used. When screening includes clinical exam, eventual additional views and ultrasound in dense breasts, this additional time does not weigh significantly.

Radiation dose

The risk/benefit ratio of screening programs must take into account radiation dose. Adding DBT to DM more than doubles this dose. When considering the previous issues, this could appear as a major limitation for introducing DBT in breast screening. However, synthesized mammography (SM) generated from the DBT data set obviates the additional radiation dose of the conventional 2D exposure; the DBT data set is collapsed into a single slice, similar to the maximum intensity projection (MIP) image in magnetic resonance imaging. Comparative screening studies [10,34–36] have provided consistent evidence that cancer detection rate do not differ between integrated DM + DBT (range, 5.45–8.5%) and SM + DBT (range, 5.03–8.8%). Also, although the recall measures were relatively heterogeneous among the included studies, little difference was found between the two modalities [24]. In two European programs, cancer detection rate with SM + DBT even reached 9.3 and 9.4% [27,37]. It is therefore clear that transitioning to DBT screening should aim to use synthetic mammography.

In summary, there are still two key issues before recommending DBT in breast cancer screening. First, although including a lot of patients and reporting rather converging results, published trials have some limitations and only one of them, aforementioned, was randomized and controlled. Then, the current literature about DBT overall focuses on traditional performance metrics such as cancer detection rate but does not address clinical outcomes such as disease-free survival or recurrence. However, trials with mortality as endpoint are not relevant given the long time separating diagnosis to death in women with breast cancer. Hence, trials using meaningful improved outcomes such as cancer stage at time of diagnosis and interval breast cancer could inform breast screening practices for the near future. As discussed above, DBT permits diagnosing more cancers of good prognosis. The interpretation of this data is equivocal: detecting smaller cancers could permit a reduction of metastatic cancer and of mortality, but conversely it is unclear whether some of these low-grade and low-stage cancers might have become clinically significant before the

next screening round. Data are therefore expected from randomized controlled trials about the real impact of DBT on interval cancers, the most suitable outcome.

Diagnosis, staging and follow-up

Diagnosis

Assessment of symptomatic women

Little has been published about the role of DBT in symptomatic women (i.e., those with palpable lump, skin retraction or nipple discharge). One study that compared retrospectively DM and DM + DBT in symptomatic patients who had subtle imaging signs concluded that adding DBT to DM in that setting increased diagnostic accuracy and reduced the amount of indeterminate lesions, reclassifying them accurately as either suspicious of malignancy or benign [38]. Another study compared the diagnostic efficacy of DM + DBT and DM combined with MRI in symptomatic women [39]. Diagnostic performance of DBT and MRI combined with DM was superior to that of DM alone in symptomatic women; MRI + DM were slightly better than DBT + DM, but this difference was not statistically significant [39]. However, in a symptomatic woman, ultrasound should be the first line examination and the contribution of DBT is limited to patients with subtle and/or equivocal findings at DM and ultrasound [38].

Work-up of screening-detected suspicious finding

In this setting, the potential benefit of DBT is double: to enable a second-look in equivocal cases where no discrete lesion is identified for biopsy, and to analyze the characteristics of a confirmed abnormality shown by DM.

Numerous equivocal findings correspond to asymmetries. The strength of DBT is to decrease the recall rate and the BIRADS 3 grading, resulting in fewer follow-up diagnostic studies [40]. Indeed, this technique allows dismissing an asymmetry when tissue superimposition is shown (Fig. 2) or conversely confirming a true asymmetry and sometimes reclassify it as a mass.

Masses are characterized by their shape, margins, density and content. The shape of a lesion is often better defined at DBT (Fig. 3). This can result in reclassification of an irregular shape to a lobular shape, but the lobular feature refers to both benign and malignant lesions [41]. The main asset of DBT is to unveil spiculated margins that were previously obscured on DM. This better visualization leads to an increased degree of suspicion, and consequently an increased BIRADS classification [37,42,43]. On the other hand, DBT loses information about the density of a mass and equal or high density masses on DM may appear low dense on a DBT section [44]. Fortunately, this information is given by the synthetic reconstruction. The internal composition of a mass can also be analyzed by DBT. Fat-containing lesions, including lymph nodes, lipomas, hamartomas, and galactoceles are generally considered as benign. However, breast cancers can engulf surrounding adipose tissue as they grow and fat within a mass is not specific for benignity. Thus, masses seen at DBT should be evaluated according to their

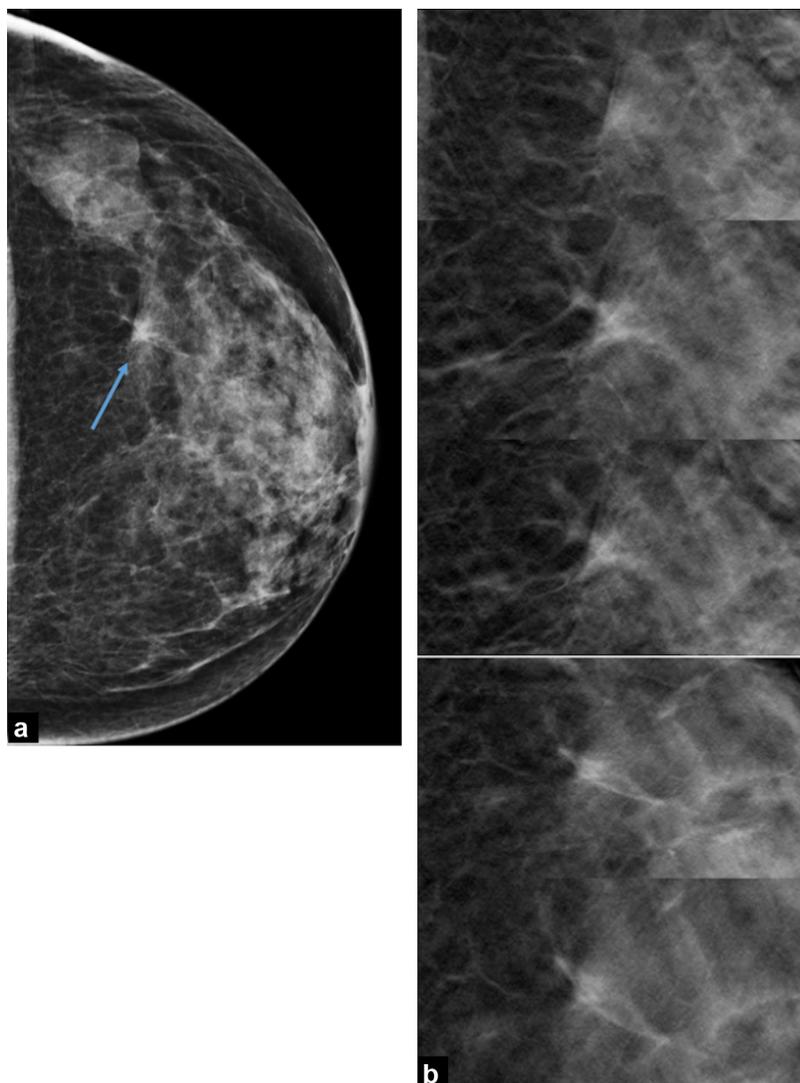


Figure 2. A 53-year-old woman who underwent breast screening. Two-dimensional cranio-caudal mammogram of the left breast (a) shows an asymmetry (arrow) cranio-caudal digital breast tomosynthesis of the same breast (b) discards it by showing no underlying mass but overlapping structures.

shape and margins rather than the presence of fat [45]. AD is a common manifestation of cancers noted at DBT and 50% of cancers that manifested as AD at DBT were occult at DM. DBT highlights the radiating lines that converge to a point in true architectural distortions or reveals an underlying mass that may have been obscured or occult at DM. In this latter case, the suspicion of malignancy is increased [45].

There has been no definitive consensus in the recent literature regarding characterization of microcalcifications with DBT. Published studies have produced varying results [33]. Different techniques used for image acquisition and reconstruction may partly account for this variability. The main limitation of DBT for characterizing microcalcifications is the lower ability to correctly analyze cluster distribution. This limitation may be solved in some systems by the addition of synthetic mammography. A recent study has shown that SM + DBT and DM had similar sensitivity and specificity for the detection of microcalcifications previously identified for recall at screening mammography [46]. But it must be

kept in mind that DBT with SM does not improve or alter the results of DM in the characterization of microcalcifications. So, in the particular setting of microcalcifications, spot magnification views remain mandatory for appropriate characterization.

An important clinical question is the replacement of additional views by DBT for assessment of screening-detected abnormalities. In clinical practice, this change is already achieved. In a recent multicenter, retrospective study of 194,437 DBT screenings compared with 131,292 DM screening, women screened with DBT were more likely to proceed directly to ultrasound without additional mammography views compared with women screened with DM [47]. However, the body of evidence on DBT by comparison to additional mammography views is limited [48]. As shown in Table 3, published data are sparse and conclude to the non-inferiority of DBT by comparison to additional views [49–52]. As noted by Li et al., the lack of robust published studies may be explained by the fact that introducing DBT

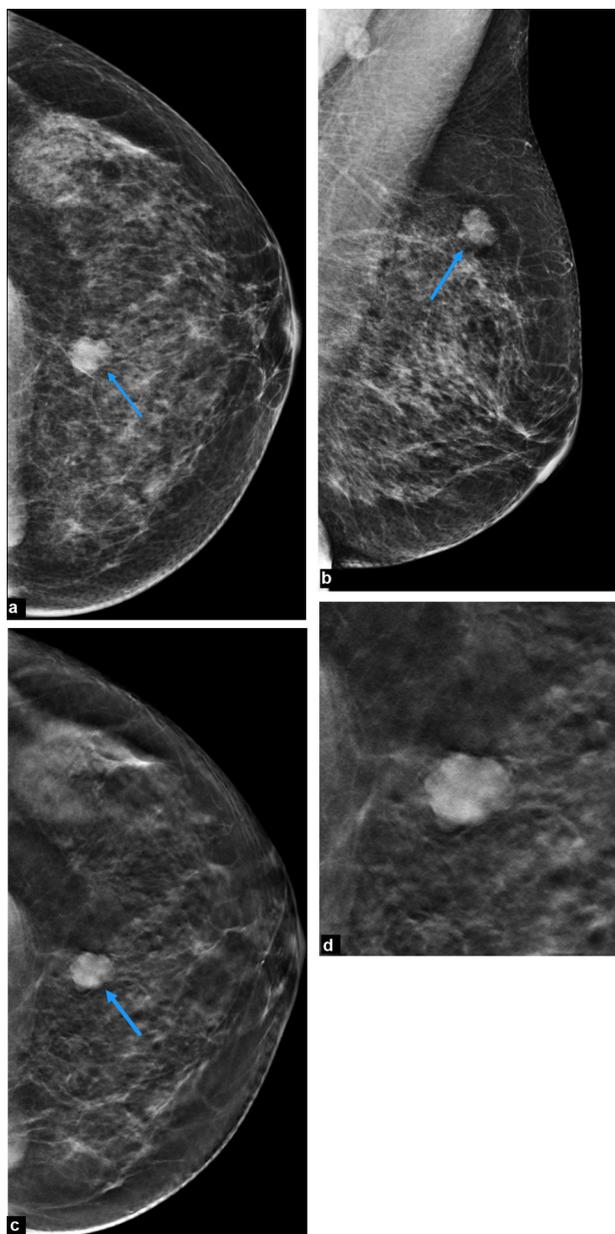


Figure 3. A 43-year-old woman with breast fibroadenoma. Two-dimensional cranio-caudal (a) and mediolateral oblique (b) mammogram of the left breast shows an oval mass with poorly defined margins (arrows). Cranio-caudal digital breast tomosynthesis of the same breast (c) and zoomed on the area of interest (d) allows better visualization of the microlobulated margins (arrow). Histopathological analysis revealed fibroadenoma.

as an imaging work-up tool for screening-recalled abnormalities (following DM screening) seems counter-intuitive when DBT is now being assessed as a primary screening modality [48].

Targeted evaluation after MRI

Second-look ultrasound and MG are fully used to help characterizing an enhancing lesion. Ultrasound allows identification of 50 to 70% of the enhancing lesions. Two studies

have focused on the DBT ability to characterize MRI lesions unidentified at targeted ultrasound in patients with newly diagnosed breast cancer [53,54]. They have shown that DBT could help identify 50 to 60% of the lesions unidentified at ultrasound [53,54].

Staging of breast cancer

Size of the index lesion

The accuracy of tumor size measured by DBT has been evaluated and compared to that of DM in several studies [55–57]. These studies assessed correlation between DBT or DM size and pathological size by choosing a criterion of ± 10 mm or ± 5 mm as threshold [55–57]. They all concluded that DBT had a better accuracy than DM in measuring tumor size [55–57].

Multifocality and multicentricity

Little is known about the role of DBT as an adjunct to DM in the staging of women with known breast cancer, and particularly about its ability to diagnose multifocal, multicentric or bilateral disease. In two published studies performed with a lesion-by-lesion analysis, the sensitivity of DM+DBT was about 90% [58,59]. However, these studies pooled index and additional lesions, and no specific data was reported regarding the value of DM+DBT and the contribution of DBT for the diagnosis of multifocal or bilateral cancer. Our group has conducted a prospective study to compare the diagnostic accuracy of DM and DBT combined with DM in the identification of additional ipsilateral and contralateral cancer in women newly diagnosed with breast cancer [60]. This study included 166 patients, of which 24 women (14%) exhibited multifocal lesions, 20 (12%) multicentric lesions, 39 (23%) additional ipsilateral and 18 (11%) bilateral lesions [60]. We have showed that in terms of sensitivity or of area under the curve (AUC), DM+DBT was superior to DM for the diagnosis of multicentric, additional ipsilateral or contralateral lesions with a gain in sensitivity of about 10% (Fig. 4) [60]. However, the performance remained relatively mild with sensitivities varying between 50 and 60% according to the assessed criteria [60]. Moreover, the added value of DBT was limited to women with non-dense breasts. In conclusion, DBT could not replace a breast examination obtained using a contrast agent such as MRI [61] in local breast cancer staging when needed.

Follow-up after breast conservative surgery

Similar to screening mammography, DBT also helps differentiate between post-treatment changes such as scars or asymmetries due to parenchymal edema and true recurrence. In the only published study on the role of DBT after breast surgery, the addition of DBT to DM reduced the rate of indeterminate findings in surveillance of patients after breast cancer treatment [62]. DBT could better identify the fat density within a scar often associated with benign calcifications and differentiate it from a mass indicating tumor recurrence [63].

Table 3 Diagnostic performances of digital breast tomosynthesis vs. additional conventional mammography views for assessment of screen-detected abnormalities.

Number of patients	Type of lesions	Prevalence BC	Se AV (%)	Se DBT (%)	P-value	Sp AV(%)	Sp DBT(%)	P-value	Reference (year)
288	Consecutive abnormalities in a BC population screening Microcalcifications excluded	55/288	90.9	96.4	NS	42.2	56.6	<0.001	Heywang et al. (2017) [49]
238	Consecutive abnormalities in a BC population screening Microcalcifications excluded	35/238	86	90	NS	64	59	<0.001	Whelehan et al. (2017) [50]
131	Abnormalities seen in DM	8/131	100	88–100	NS	94	89–94	N.S.	Brandt et al. (2013) [51]
52	Consecutive abnormalities in a BC population screening Microcalcifications excluded	9/52	100	100	NS	94	100	N.S.	Tagliafico et al. (2012) [52]

BC: breast cancer; DBT: digital breast tomosynthesis; DM: digital mammography; Se: sensitivity; AV: additional views; NS: non significant; Sp: specificity.

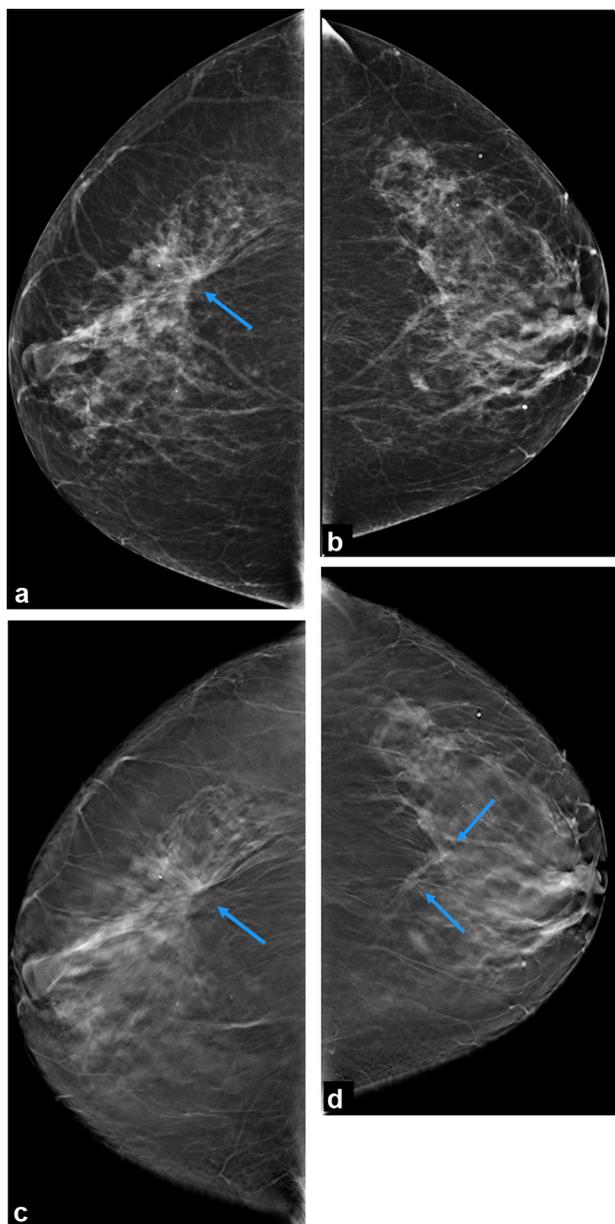


Figure 4. A 73-year-old woman who underwent breast screening. Two-dimensional cranio-caudal mammogram of the right (a) and left breast (b) shows architectural distortion in the right breast (arrow) and no significant finding in the left breast. Cranio-caudal digital breast tomosynthesis of the right breast (c) and of the left breast (d) confirms the architectural distortion (arrow in c) and highlights two spiculated masses in the contralateral breast (arrows in d). Biopsy revealed invasive ductal carcinoma of the right breast and invasive lobular carcinoma of the left breast.

Advanced applications

DBT-guided vacuum-assisted breast biopsy

The development of DBT-guided procedures is not a work in progress since they are performed in daily clinical practice in numerous breast units. Such procedures have two major advantages: making biopsy possible when stereotactic guidance is challenging or when the finding is only seen at DBT such as ADs, and making the procedure faster and easier

than traditional stereotactic biopsy thanks to faster acquisition of images and easier and more precise targeting of the abnormality by pseudo-three-dimensional (3D) scrolling and by avoiding 15 degree stereo pair images. A recent study has shown that DBT-guided biopsy had a higher rate of technical success than does stereotactic vacuum-assisted biopsy and can be performed in less than half the time and with one-fourth of the exposure [64]. Given its high technical success rate and its simplicity, DBT-guided VABB, when available, is recommended to be used for suspicious DBT lesions with no ultrasound correlate, even if they are seen at DM (Fig. 5).

CAD

CAD can be used in breast imaging [65]. Regarding DM, CAD is used in more than 80% of all screening DM to assist radiologists in detecting breast cancer in the United States [66]. On the opposite, it is hardly used in DBT screening. In particular, the use of CAD in the detection of microcalcifications on DBT and SM, a relative weakness of DBT, must be considered as an important development pathway. A radiologist reader study evaluated the use of concurrent CAD in an enriched sample of DBT examinations including calcified and non-calcified lesions [63]. Radiologists used concurrent DBT CAD to review CAD-enhanced synthetic images and to navigate to DBT planes to confirm or dismiss potential lesions seen on CAD-enhanced synthetic images. Concurrent use of CAD with DBT resulted in almost 30% faster reading time, while maintaining reader interpretation performance [67]. To date, artificial intelligence devices are developing in the field of DBT to reduce oversight errors, improve categorization of lesion seen on DBT and increase confidence in decisions.

Contrast-media-enhanced DBT

Contrast-media-enhanced DBT is technically feasible. There is certainly an interest in associating DBT and contrast-enhanced mammography, particularly in the setting of staging breast cancer for which contrast agent is useful. However, studies are needed to address clinical diagnostic benefit of contrast-media-enhanced DBT.

Fusion imaging

Since DBT provides pseudo-3D images of the breast, the development of multimodality systems combining DBT with other 3D modalities such as 3D-automated breast ultrasound, radionuclide imaging or even MRI is a promising research approach [68]. More advanced prototypes combine 3D-automated breast ultrasound and DBT in a single device; in a recent study, image acquisition and processing by the prototype has been shown to be fast and accurate, with some limitations in ultrasound coverage and image quality [69]. However these multimodality systems are still in progress and it may take several years before they can be used in clinical practice.

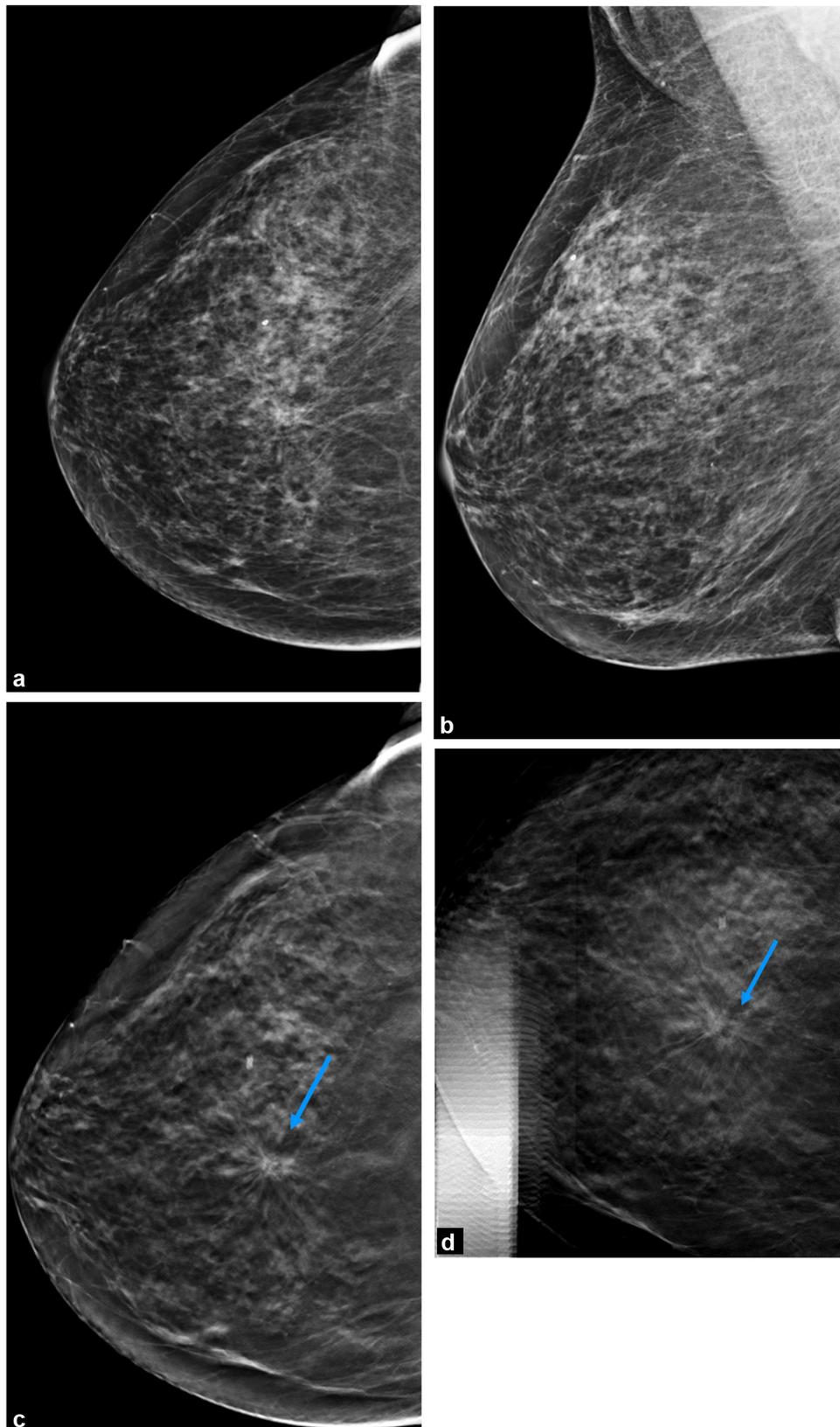


Figure 5. A 77-year-old woman who underwent breast screening. Two-dimensional cranio-caudal (a) and mediolateral oblique (b) mammogram of the right breast shows no abnormality. Cranio-caudal digital breast tomosynthesis (DBT) of the same breast (c) highlights a small mass with spiculated margins (arrow) whereas no lesion was visible at ultrasound. DBT-guided biopsy of the right breast using a cranio-caudal approach (d) revealed an invasive carcinoma (arrow).

Conclusion

In summary, DBT clearly outperforms DM in both screening and diagnostic breast imaging. Although these data are promising, additional research is needed to better assess the effect of DBT in screening outcomes and particularly on the rate of interval cancer. Indeed, a decrease of interval breast cancer in population screened by DBT is needed to recommend DBT in national policies of screening.

Informed consent and patient details

The authors declare that this report does not contain any personal information that could lead to the identification of the patient(s).

The authors declare that they obtained a written informed consent from the patients and/or volunteers included in the article. The authors also confirm that the personal details of the patients and/or volunteers have been removed.

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Contributions of authors

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