Accuracy of Mammography, Digital Breast Tomosynthesis, Ultrasound and MR Imaging in Preoperative Assessment of Breast Cancer

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Abstract. *Aim: To define the accuracy of digital breast tomosynthesis (DBT) and magnetic resonance imaging (MRI) added to digital mammography (DM) and ultrasound (US) in the preoperative assessment of breast cancer. Patients and Methods: We performed a prospective study of 200 consecutive women with histologically-proven breast cancer using the above imaging techniques. Accuracy measurements were estimated using a lesion-by-lesion analysis for unifocal, multifocal/multicentric, bilateral and all carcinomas. We also calculated sensitivity according to breast density. Results: DBT had higher sensitivity than DM (90.7% vs. 85.2%). Combined DM and DBT with US yielded a 97.7% sensitivity; despite high sensitivity of MRI (98.8%), the addition of MRI to combined DM with DBT and US did not significantly improve sensitivity. Overall accuracy did not significantly differ between MRI and DM with DBT and US (92.3% vs. 93.7%). Breast density affected sensitivity of DM and DBT (statistically significant difference for DM), not MRI. Conclusion: There is little gain in sensitivity and no gain in overall accuracy, by performing MRI for patients who have been evaluated with DM with DBT and US.*

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Breast cancer assessment and treatment has evolved considerably in the past decade, including the range of breast imaging modalities. Women suspected or known to have breast cancer on the basis of conventional imaging [mammography and ultrasound (US)] now have the option of undergoing additional imaging before progressing to histological evaluation and surgical management. In particular, magnetic resonance imaging (MRI) has been increasingly used in addition to conventional imaging for preoperative assessment in patients newly-diagnosed with breast cancer, although this remains a controversial practice (1, 2). The recent availability and application of digital breast tomosynthesis (DBT) (3) further challenges clinicians in terms of deciding whether (and which) imaging additional to conventional imaging improves the accuracy of preoperative assessment.

We aimed to examine the gain in accuracy when DBT is added to conventional imaging, and to compare this with MRI, in women suspected of having breast cancer on the basis of conventional imaging. The purpose of our study was to help define the accuracy and therefore the potential application of these additional imaging modalities in the preoperative setting for patients newly-diagnosed with breast cancer.

Patients and Methods

Study design. We performed a prospective study that included women who attended our Breast Center (January 2012-January 2013) for mammography, and who had also undergone US and MRI, and were found to have breast cancer. Mammography consisted of digital mammography (DM), and DBT. An Institutional

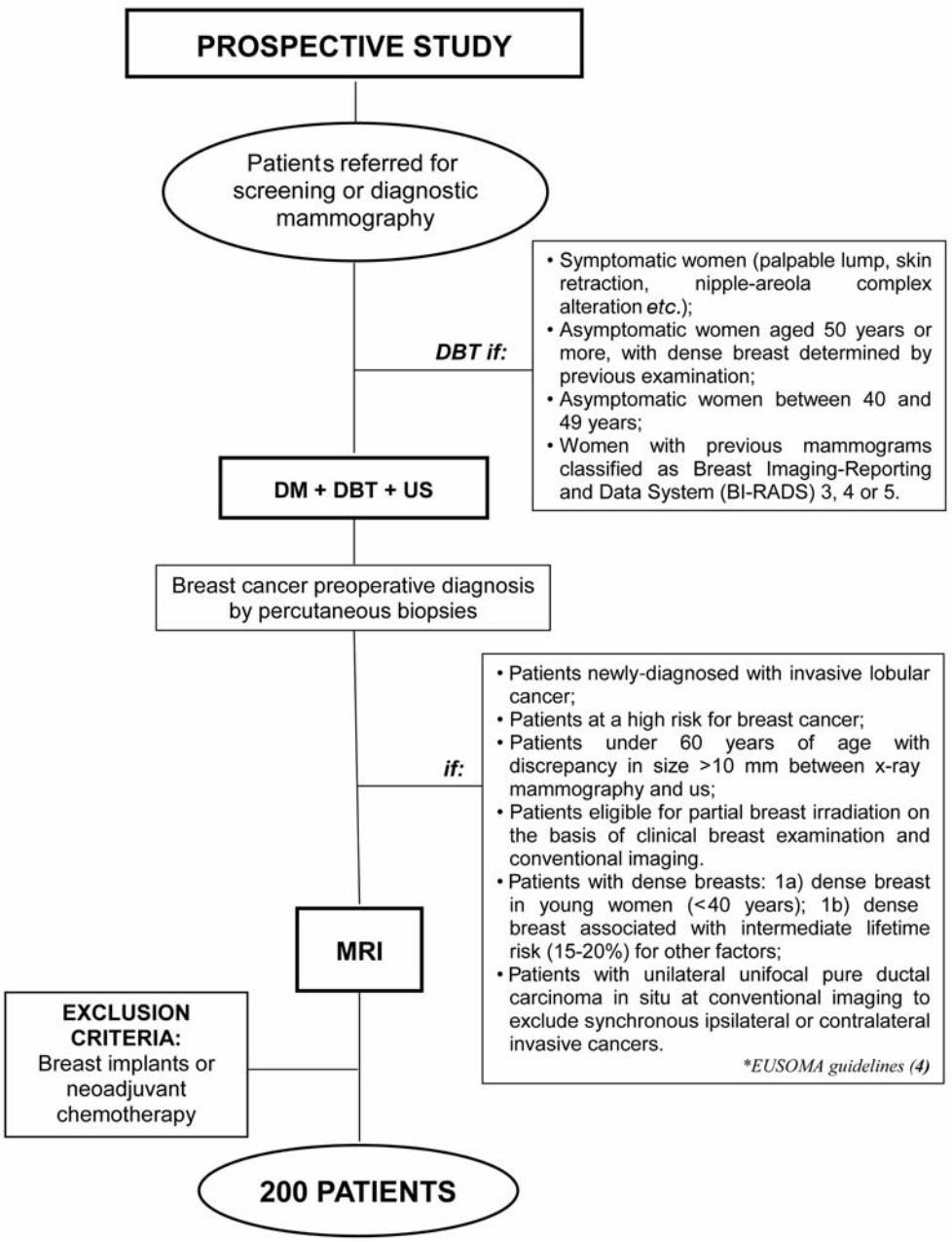

Figure 1. *Study outline and protocol for performing additional imaging.*

Ethics Committee approval was obtained (Prat. N. CEI/493), and all participating patients provided their written informed consent before undergoing diagnostic examinations as part of the study.

Study population. We considered women who had either screening or diagnostic mammography and had the full sequence of breast imaging indicated in the algorithm shown in Figure 1, and were found to have histologically-proven breast cancer. Criteria for undergoing DBT were: symptomatic women (palpable lump, skin retraction, nipple-areola complex alteration, *etc.*); asymptomatic women aged 50 years or more, with dense breast determined by previous examination; asymptomatic women between 40 and 49 years; women with previous mammograms classified as Breast Imaging-Reporting and Data System (BI-RADS) 3, 4 or 5. MRI was also performed using the pre-defined criteria recommended by the European Society of Breast Cancer Specialists guidelines (4), shown in Figure 1. Patients who had breast implants or who underwent neoadjuvant chemotherapy were ineligible for the study (Figure 1).

Preoperative diagnosis was based on core biopsy or fine-needle aspiration cytology; and all carcinomas were further characterized through definitive histology (as the gold standard).

Imaging examination and interpretation. Bilateral mammography was performed with a Full Field Digital Mammography unit with integrated tomosynthesis acquisition (Hologic Selenia Dimensions; Hologic, Bedford, MA, USA). Bilateral two views (cranio-caudal and medio-lateral oblique) were obtained in Combo mode: hence DM and DBT images were acquired with a single breast compression for each projection (3). DBT images were viewed as 1 mm reconstructed sections. One of two interpreting radiologists (one with eight years, the other with 23 years of experience in mammography, and both with three years of experience in DBT) interpreted mammographic examinations by viewing first the DM (2D) images alone, followed by the DBT images (therefore the latter interpretation was with knowledge of the 2D-imaging findings).

Bilateral whole-breast US was performed using one of two dedicated units (Hitachi or Esaote) with a 10-18 MHz linear-array probe. The same radiologist who interpreted the mammograms performed the US examination and was therefore aware of the findings on DM and DBT.

MRI was performed on a 1.5-T instrument (Achieva Intera, Philips), on days 7-14 of the menstrual cycle if the woman was pre-menopausal. Patients were placed prone with the breasts properly positioned in a dedicated seven-channel breast coil. The dynamic study was performed with 3D T1-weighted gradient recalled echo (GRE) acquisition in the axial plane obtained before and for five times after intravenous bolus injection of 0.2 ml/kg body weight gadobenate dimeglumine (Gd-BOPTA) at a rate of 2 ml/s. A dedicated radiologist with 9 years' experience in breast MRI interpreted the MR images without blinding to DM, DBT and US images and the clinical findings, therefore MRI reporting was with full knowledge of all other available imaging results.

We used the BI-RADS lexicon to classify imaging results, and also BI-RADS for density classification (5, 6). For each imaging modality, a BI-RADS score of 4 or 5 for suspicion of malignancy was considered a true-positive (TP) if the final histological diagnosis confirmed breast malignancy, otherwise it was a false positive (FP). Conversely, BI-RADS scores of 1, 2 or 3 were considered as true negatives (TN) if the final diagnosis was negative for cancer, or false-negatives (FN) if the final diagnosis was positive for malignancy.

If additional MRI-enhancing lesions *i.e.* additional foci considered if >5 mm and separated by at least 1 cm of intervening normal-appearing tissue from the index lesion (7) not identified on conventional preoperative imaging were detected, then the mammographic images (DM and DBT) were reviewed and targeted US was performed for a second look. If the additional malignancy was seen only at second-look US or DM-DBT as directed by MRI findings, it was classified as FN for that modality.

All suspicious additional MRI findings were verified preoperatively by imaging-guided fine-needle or core biopsy, or by surgical excision. All malignant lesions on needle biopsy were excised. When uncertain cytological or histological results [C1, B1, C3 and B3 according to European Guidelines (8)] were obtained, surgical excision was recommended. Lesions with benign findings underwent additional imaging follow-up.

Pathological examination. All patients underwent surgical excision of the primary tumour and sentinel lymph node biopsy/axillary dissection.

Breast specimens were sent to the Pathology Department at our Institution after verifying the presence of the lesion(s) in the surgical specimen by mammography.

Each excised sample was reduced on multiple levels of 4 mm thickness, for pathological evaluation and also for correlation with imaging findings.

Statistical analysis. Accuracy of imaging modalities was evaluated using a lesion-by-lesion analysis with respect to unifocal cancer, multifocal/multicentric cancer and bilateral cancer, and for all carcinomas.

We calculated the following parameters for accuracy: sensitivity, specificity and overall accuracy, positive and negative predictive values (PPV, NPV). For each of these, we computed the 95% confidence intervals (95% CI). Comparisons were carried out using the chi-square test applied to cross-correlation tables; for 2×2 tables, we used Yates correction. Statistical significance was set at $p<0.05$.

We evaluated the accuracy of DM alone, DM combined with DBT, DM combined with DBT and US, and MRI alone (but interpreted with knowledge of all other imaging). Accuracy measures, for combined DM, DBT and US, were computed using the following rules: TP and FP corresponded to at least one positive (or negative) result of three imaging tests and TN required three concordant negative results.

We also calculated the sensitivity of each imaging test for detection of malignant lesions, lesion-by-lesion, according to breast density, and patient-based estimates sensitivity of the modalities to identify multicentric or multifocal and bilateral cancer disease.

Results

There were 200 patients with breast cancer with a mean age of 55 (range=26-79) years who had preoperatively undergone all four breast imaging modalities. Amongst these 200 patients, 350 lesions were identified on imaging (based on any imaging test): 257 of these lesions were confirmed as malignant on histology, whereas 93 were benign. Out of the malignant lesions, 156 (60.7%) were unifocal, 59 (23.0%) were multifocal or multicentric in 24 women, and 42 (16.3%) were bilateral in 20 women. Lesion-based distribution of the final pathological findings is reported in Table I.

Breast tissue density was classified as dense in 94/200 (47%) patients, whereas 106/200 (53%) patients had non-dense breasts.

Table Il reports the results of sensitivity, specificity, overall accuracy, and PPV and NPV values. The results are lesion-based estimates and are shown according to whether unifocal, multifocal or multicentric, bilateral, and also for all carcinomas for the four imaging modalities.

DBT had a higher sensitivity than DM alone (90.7% *vs*. 85.2%) for detection of malignant lesions and although MRI had the highest sensitivity (98.8%), there was no statistically significant difference between MRI alone and the combination of DM with DBT and US (97.7%, $p=1$). Similarly, overall accuracy did not significantly differ between MRI-alone and the combination of DM, DBT and US (92.3% *vs*. 93.7%, $p=0.29$)

Table I. *Histology distribution of lesions (n=350) found on imaging in 200 patients with breast lesions.*

Malignant lesions (n=257)		Benign lesions (n=93)	
IDC	67 (26.1%)	Fibroadenoma	21 (22.6%)
IDC+DCIS	73 (28.4%)	Fibrocystic change	55 (59.1%)
ILC	40 (15.6%)	Fibrosis	7 (7.5%)
DCIS	32 (12.4%)	Radial scar	8 (8.6%)
LIN grade 3	3 (1.2%)	Papilloma	2 (2.2%)
ILC+LIN	15 (5.8%)		
Other invasive	27 (10.5%)		

IDC, Invasive ductal carcinoma; ILC, invasive lobular carcinoma; DCIS, ductal carcinoma *in situ*; LIN, lobular intraepithelial neoplasia.

Table II also shows results of the comparisons between DM and DBT and between DM combined with DBT and US and MRI.

In Table III, we report the sensitivity of each imaging test for detection of malignant lesions, lesion-by-lesion, according to breast density. These data show that breast density does not affect the sensitivity of MRI, whereas the sensitivity of DM and DBT is higher in non-dense breasts, although the difference was statistically significant only for DM (sensitivity in non-dense breast 91.3% *vs.* 78.9% in dense breast; p=0.009). US sensitivity is higher in dense breasts.

If we consider the patient-based estimated accuracy of each imaging modality in identifying multicentric or multifocal disease, the results indicated that MRI and US had the highest sensitivity (24/24=100%), significantly different from that of DM (18/24=75%) (p=0.002) and only borderline statistically significant compared to DBT (19/24=79%) (p=0.049).

MRI had the highest patient-based sensitivity (19/20=95%) in identifying synchronous bilateral cancer, followed by DBT (15/20=75%) (p=0.18) and was significantly different from DM (12/20=60%) (p=0.02) and US (9/20=45%) (p=0.01).

Discussion

We report a study on the accuracy of imaging in women with newly-diagnosed breast cancer who have undergone standard mammography, DBT, US, and MRI. Our study focuses on imaging assessment beyond the initial diagnosis of breast cancer, whereby additional imaging is performed to determine disease extent prior to surgical treatment. To date, this has been performed by adding MRI to conventional imaging (mammography and US) because MRI detects additional disease occult on conventional breast imaging in a substantial number of women (9, 10). Our work is, to the best of our knowledge, the first to investigate how the evolution of mammography into its derivative DBT might warrant re-consideration of the current breast imaging pathway in patients with breast cancer. Our results indicate that in general, and based on the results for all detected lesions, there is little to no gain in sensitivity, and no gain in overall accuracy, by performing MRI in women who have already been evaluated with DM with integrated DBT in combination with US. In other words, further addition of MRI (to the combination of conventional imaging with DBT) did not statistically contribute to detection yield.

On this regard, it could be argued that it might not be reasonable to compare MRI with combined imaging (mammography integrating DBT, and US), however it should be noted that MRI in preoperative assessment of women with breast cancer is interpreted with knowledge of all the information from conventional imaging and is usually the last imaging process to be performed in preoperative breast work-up. Therefore, the data we report for MRI are based on MRI interpreted with knowledge of the image-detected lesions from mammography with DBT and US, as practiced in clinical reality in our setting. Hence, the issue our study addresses is whether the addition of preoperative MRI (as part of the imaging algorithm outlined in the Patients and Methods section) is associated with substantial additional detection of disease not identified on conventional imaging inclusive of DBT. We found that there was limited additional TP detection achieved by adding MRI to mammography with DBT and US, and the limited additional MRI detection was off-set by additional FP detection from MRI. Hence the net effect is that very similar measures of accuracy are achieved with preoperative imaging assessment based on mammography/integrated DBT and US, or using the same imaging but including preoperative MRI. The implications of our findings may not be immediately relevant to those involved in breast cancer diagnostics and preoperative work-up, given that DBT is not yet routinely integrated with mammographic imaging. However, it is anticipated that this will evolve considerably in the coming years, particularly if mammographic screening shifts to integrate DBT (11-14). Therefore the implications of our findings will only be realized if the future transition of mammography to include DBT becomes evident and widespread. Our study aims to inform clinicians as well as for research planning, rather than to advocate an immediate change in preoperative imaging assessment.

Table II. *Breast imaging accuracy measurements (based on 350 lesions) amongst 200 patients with breast cancer.*

	Number estimate% (95% CI)				
	Sensitivity	Specificity	Overall accuracy	PPV	NPV
Unifocal (M=156, B=81)					
DM	142/156=91.0	74/81=91.4	216/237=91.1	142/149=95.3	74/88=84.1
	(85.5-94.6)	(83.3-95.8)	(86.8-94.1)	(90.6-97.7)	(75.1-90.3)
DBT	149/156=95.5	71/81=87.7	220/237=92.8	149/159=93.7	71/78=91.0
	(95.0-97.8)	(78.7-93.2)	(88.8-95.5)	(88.8-96.6)	(82.6-95.6)
p_1	0.17	0.61	0.61	0.82	0.27
DM+DBT+US	156/156=100	68/81=84.0	224/237=94.5	156/169=92.3	68/68=100
	(97.6-100)	(74.5-90.4)	(90.8-96.8)	(87.3-95.5)	(94.7-100)
MRI	156/156=100	59/81=72.8	215/237=90.7	156/178=87.6	59/59=100
	(97.6-100)	(62.3-81.3)	(86.4-93.8)	(82.0-91.7)	(93.9-100)
p_2	1	0.13	0.16	0.21	1
Multifocal or multicentric (M=59, B=10)					
DM	43/59=72.9	9/10=90.0	52/69=75.4	43/44=97.7	9/25=36.0
	(60.4-82.6)	(59.6-98.2)	(64.0-84.0)	(88.2-99.6)	(20.3-55.5)
DBT	47/59=79.7	9/10=90.0	56/69=81.2	47/48=97.9	9/21=42.9
	(67.7-88.0)	(59.6-98.2)	(70.4-88.7)	(89.1-99.6)	(24.5-63.5)
p_1	0.52	1	0.53	0.51	0.86
DM+DBT+US	56/59=94.9	7/10=70.0	63/69=91.3	56/59=94.9	7/10=70.0
	(86.1-98.3)	(39.7-89.2)	(82.3-96.0)	(86.1-98.3)	(39.7-89.2)
MRI	57/59=96.6	8/10=80.0	65/69=94.2	57/59=96.6	8/10=80.0
	(88.5-99.1)	(49.0-94.3)	(86.0-97.7)	(88.5-99.1)	(49.0-94.3)
p_2	>0.99	>0.99	0.74	>0.99	>0.99
Bilateral (M=42, B=2)					
DM	34/42=80.9	2/2=100	36/44=81.8	34/34=100	2/10=20.0
	(66.7-90.0)	(34.2-100)	(68.0-905)	(90.6-100)	(5.7-51.0)
DBT	37/42=88.1	2/2=100	39/44=88.6	37/37=100	2/7=28.6
	(75.0-94.8)	(34.2-100)	(76.0-95.1)	(90.6-100)	(8.2-64.1)
p_1	0.54	1	0.55	1	>0.99
DM+DBT+US	39/42=92.9	2/2=100	41/44=93.2	42/42=100	2/5=40.0
	(81.0-97.5)	(34.2-100)	(81.8-96.9)	(91.6-100)	(11.8-76.9)
MRI	41/42=97.6	2/2=100	43/44=97.7	41/41=100	2/3=67.0
	(87.7-99.6)	(34.2-100)	(88.2-99.6)	(91.4-100)	(20.8-93.9)
p_2	>0.99	1	>0.99	1	>0.99
All lesions (M=257, B=93)					
DM	219/257=85.2	85/93=91.4	304/350=86.9	219/227=96.5	85/123=69.1
	(80.5-89.2)	(84.3-95.9)	(83.0-901)	(93.2-98.2)	(60.5-76.6)
DBT	233/257=90.7	82/93=88.2	315/350=90.0	233/244=95.5	82/106=77.4
	(86.6-93.8)	(80.4-93.6)	(86.5-92.8)	(92.1-97.5)	(68.5-84.3)
p1	0.08	0.63	0.24	0.76	0.21
DM+DBT+US	251/257=97.7	77/93=82.8	328/350=93.7	251/267=94.0	77/80=96.3
	(95.0-98.9)	(73.9-83.1)	(90.7-95.8)	(90.5-96.3)	(89.6-98.7)
MRI	254/257=98.8	69/93=74.2	323/350=92.3	254/278=91.4	69/72=95.8
	(96.9-99.7)	(64.6-82.3)	(89.1-94.8)	(87.5-94.1)	(88.5-98.6)
p_2	1	0.21	0.29	0.88	0.76

M, Malignant lesion in breast cancer patient; B, benign lesion in breast cancer patient; PPV, positive predictive value; NPV, negative predictive value; p_1 is *p*-value for comparison between DM and DBT; p_2 is for comparison between DM+DBT+US and MRI.

The findings on the effect of breast tissue density (Table III) highlight that both mammography and its derivative technology, DBT, have less sensitivity for detection of malignant lesions in dense breast tissue relative to non-dense tissue. However, there was a relatively modest reduction in sensitivity in dense breast tissue for DBT (compared to that shown for standard DM), most likely because the 3-D nature of DBT helps reduce some of the masking caused by

Table III. *Sensitivity according to breast density.*

Lesion		DM	DBT	US	MRI
Unifocal	D1-D2	80/82=97.6% (92.2-99.6)	82/82=100% (96.4-100)	67/82=81.7% (72.2-89.0)	82/82=100% (96.4-100)
	D3-D4	63/74=85.1% (75.6-91.9)	68/74=91.9% (83.9-96.7)	71/74=95.9% (89.4-99.0)	74/74=100% (96.0-100)
	p-Value	0.01	0.03	0.01	1
Multifocal or multicentric	D1-D2	25/32=78.1% (61.5-89.9)	27/32=84.3% (68.7-94.0)	28/32=87.5% (72.6-95.9)	31/32=96.9% (85.5-99.8)
	D3-D4	18/27=66.7% (47.6-82.4)	20/27=74.1% (55.3-87.9)	25/27=92.6% (77.6-98.7)	26/27=96.3% (83.1-99.8)
	p-Value	0.49	0.51	0.83	0.55
Bilateral	D1-D2	21/24=87.5% (69.6-96.7)	21/24=87.5% (69.6-96.7)	19/24=79.2% (59.7-91.9)	24/24=100% (88.3-100)
	D3-D4	13/18=72.2% (48.7-89.0)	16/18=88.9% (67.9-98.1)	13/18=72.2% (48.7-89.0)	17/18=94.4% (75.5-99.7)
	p-Value	0.39	0.73	0.87	0.88
All lesions	D1-D2	126/138=91.3 (85.7-95.2)	130/138=94.2 (89.3-97.3)	114/138=82.6 (75.6-88.3)	137/138=99.3 (96.5-100)
	D3-D4	94/119=78.9 (1.0-85.6)	104/119=87.4 (80.5-92.5)	109/119=91.6 (85.5-95.7)	117/119=98.3 (94.6-99.7)
	p-Value	0.009	0.09	0.05	0.80

Fibroglandular density based on BI-RADS categories (5): D1=0-25%, D2=26-50%, D3=51-75% and D4=76-100%.

overlapping tissue density (15-19); therefore DBT maintains good sensitivity even in dense breast tissue. In contrast, and as expected, US had significantly better sensitivity in dense breast tissue. The sensitivity of MRI did not differ according to breast tissue density category, typifying the robust detection capability of breast MRI (20, 21).

Our study is limited by the defined eligibility criteria in that we only included patients who had undergone all four breast imaging modalities – we acknowledge that this means that our results may not translate to the broader population of patients with breast cancer. However, we have provided details of the clinical criteria applied to perform additional breast imaging (Figure 1) to allow clinicians to judge whether or not this concords with their clinical practice. Importantly, ours is a first exploratory study, and its findings should be used to support planning of future imaging studies with broader patient eligibility criteria. Another limitation is that our analyses by strata (for multifocal, or bilateral lesions) were based on small numbers, hence comparisons are statistically limited for these stratified analyses. For this reason, we based our interpretations and conclusions predominantly on analyses of all lesions in all patients, however, we also reported the stratified analyses because these data and the estimated accuracy measures may be of clinical interest.

Our study was not designed to assess the clinical utility or impact of adding either MRI or DBT to preoperative imaging assessment of patients newly-diagnosed with breast cancer. Investigation of clinical end-points is important, however, our study was primarily designed to examine accuracy measures for additional disease detection, hence examination of clinical endpoints was beyond the scope of the present exploratory work.

Our study evaluated the accuracy of DM, DBT, US, and MRI in preoperative assessment of breast cancer. In our setting, DM and US constitute routinely performed imaging in women with abnormal findings; DBT and MRI are performed according to predefined criteria including for preoperative assessment. In this clinical context, we found that the combination of conventional imaging (DM and US) with DBT performed as part of mammographic imaging in patients newly diagnosed with breast cancer provided similar accuracy to that achieved with the inclusion of preoperative MRI. Therefore further adding MRI did not improve the accuracy of preoperative imaging assessment. The evidence provided in this study may assist the development of new research studies on preoperative breast imaging to guide future practice.

References

1 Houssami N and Hayes DF: Review of preoperative magnetic resonance imaging (MRI) in breast cancer: Should MRI be performed on all women with newly diagnosed, early-stage breast cancer? CA Cancer J Clin *59*: 290-302, 2009.

2 Houssami N, Turner R and Morrow M: Preoperative magnetic resonance imaging in breast cancer: Meta-analysis of surgical outcomes. Ann Surg *257*: 249-255, 2013.

3 Houssami N and Skaane P: Overview of the evidence on digital breast tomosynthesis in breast cancer detection. Breast *22*: 101-108, 2013.

4 Sardanelli F, Boetes C, Borisch B, Decker T, Federico M, Gilbert FJ, Helbich T, Heywang-Köbrunner SH, Kaiser WA, Kerin MJ, Mansel RE, Marotti L, Martincich L, Mauriac L, Meijers-Heijboer H, Orecchia R, Panizza P, Ponti A, Purushotham AD, Regitnig P, Del Turco MR, Thibault F and Wilson R: Magnetic resonance imaging of the breast: Recommendations from the EUSOMA working group. Eur J Cancer *46*: 1296-1316, 2010.

5 American College of Radiology (ACR): Breast Imaging Reporting and Data System, Breast Imaging Atlas (BI-RADS Atlas). Fourth Edition. Reston, VA: American College of Radiology, 2003.

6 Tardivon AA, Athanasiou A, Thibault F and El Khoury C: Breast imaging and reporting data system (BIRADS): Magnetic resonance imaging. Eur J Radiol *61*: 212-215, 2007.

7 Liberman L, Morris EA, Dershaw DD, Abramson AF and Tan LK: MR imaging of the ipsilateral breast in women with percutaneously proven breast cancer. Am J Roentgenol *180*: 901-910, 2003.
8 Perry N, Broeders M, de Wolf C, Törnberg S, Holland R, von Karsa L: European Guidelines for Quality Assurance in Breast Cancer Screening and Diagnosis (Fourth Edition). Office for Official Publications of the European Communities, Luxembourg, 2006.
9 Brennan ME, Houssami N, Lord S, Macaskill P, Irwig L, Dixon JM, Warren RM and Ciatto S: Magnetic resonance imaging screening of the contralateral breast in women with newly diagnosed breast cancer: Systematic review and meta-analysis of incremental cancer detection and impact on surgical management. J Clin Oncol *27*: 5640-5649, 2009.
10 Houssami N, Ciatto S, Macaskill P, Lord SJ, Warren RM, Dixon JM and Irwig L: Accuracy and surgical impact of magnetic resonance imaging in breast cancer staging: systematic review and meta-analysis in detection of multifocal and multicentric cancer. J Clin Oncol *26*: 3248-3258, 2008.
11 Ciatto S, Houssami N, Bernardi D, Caumo F, Pellegrini M, Brunelli S, Tuttobene P, Bricolo P, Fantò C, Valentini M, Montemezzi S and Macaskill P: Integration of 3D digital mammography with tomosynthesis for population breast-cancer screening (STORM): A prospective comparison study. Lancet Oncol *14*: 583-589, 2013.
12 Skaane P, Bandos AI, Gullien R, Eben EB, Ekseth U, Haakenaasen U, Izadi M, Jebsen IN, Jahr G, Krager M, Niklason LT, Hofvind S and Gur D: Comparison of digital mammography alone and digital mammography plus tomosynthesis in a population-based screening program. Radiology *267*: 47-56, 2013.
13 Rose SL, Tidwell AL, Bujnoch LJ, Kushwaha AC, Nordmann AS and Sexton R Jr.: Implementation of breast tomosynthesis in a routine screening practice: An observational study. Am J Roentgenol *200*: 1401-1408, 2013.
14 Caumo F, Bernardi D, Ciatto S, Macaskill P, Pellegrini M, Brunelli S, Tuttobene P, Bricolo P, Fantò C, Valentini M, Montemezzi S and Houssami N: Incremental effect from integrating 3D-mammography (tomosynthesis) with 2D-mammography: Increased breast cancer detection evident for screening centres in a population-based trial. Breast *23*: 76-80, 2014.
15 Dobbins JT 3rd.: Tomosynthesis imaging: at a translational crossroads. Med Phys *36*: 1956-1967, 2009.
16 Baker JA and Lo JY: Breast tomosynthesis: state-of-the-art and review of the literature. Acad Radiol *18*: 1298-1310, 2011.
17 Helvie MA: Digital mammography imaging: Breast tomosynthesis and advanced applications. Radiol Clin North Am *48*: 917-929, 2010.
18 Baldwin P: Digital breast tomosynthesis. Radiol Technol *81*: 57M-74M, 2009.
19 Tingberg A and Zackrisson S: Digital mammography and tomosynthesis for breast cancer diagnosis. Expert Opin Med Diag *5*: 517-526, 2011.
20 Pediconi F, Catalano C, Roselli A, Dominelli V, Cagioli S, Karatasiou A, Pronio A, Kirchin MA and Passariello R: The challenge of imaging dense breast parenchyma: is magnetic resonance mammography the technique of choice? A comparative study with x-ray mammography and whole-breast ultrasound. Invest Radiol *44*: 412-421, 2009.
21 Biglia N, Bounous VE, Martincich L, Panuccio E, Liberale V, Ottino L, Ponzone R and Sismondi P: Role of MRI (magnetic resonance imaging) versus conventional imaging for breast cancer presurgical staging in young women or with dense breast. Eur J Surg Oncol *37*: 199-204, 2011.

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