

Comparative Diagnostic Efficacy of CBBCT, MRI, Ultrasound and Combined Modalities for Mass Enhancement Breast Lesions

fang he

The Eighth Medical Center of Chinese PLA

Yu zhang

Beijing Jingmei Group General Hospital

Bai he

The First Medical Center of Chinese PLA General Hospital

Yanning fu

The First Medical Center of Chinese PLA General Hospital

Yan-Jun zhang

The First Medical Center of Chinese PLA General Hospital

Ying li

liying301fsk@163.com

The First Medical Center of Chinese PLA General Hospital

Research Article

Keywords: Breast, Magnetic resonance imaging, Cone-beam breast CT, Ultrasound, Diagnosis efficacy

Posted Date: July 3rd, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10052373/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

Background

Breast cancer has become the leading disease threatening women's health worldwide. Improving the detection rate of breast cancer is a crucial task in clinical practice. To explore the diagnostic value of cone-beam breast CT (CBBCT), magnetic resonance imaging (MRI), ultrasound (US), and their combined methods for breast mass enhancement lesions, with pathological results as the gold standard, 85 cases of lesions (32 benign and 53 malignant) were selected from June 2020 to April 2023. The detection rates and diagnostic accuracy rates of the two groups were compared.

Methods

This study prospectively collected data from patients who underwent CBBCT examination at our hospital from June 2020 to April 2023. CBBCT imaging was performed using the KBCT-1000 system (manufactured by Corning Inc., USA, produced in Tianjin, China). Patients lay in a prone position on the examination table, with their breasts naturally suspended within the imaging aperture. MRI examinations were conducted using a GE 3.0T magnetic resonance scanner (provided by GE Healthcare) equipped with an 8-channel dedicated breast coil, and patients were in a prone position.

Results

The detection rates of US and MRI were 100%, while the detection rate of CBBCT enhancement (CE-CBBCT) was 92.94%. The combined methods, especially CBBCT + US, outperformed single US in terms of sensitivity, specificity, and AUC, and their efficacy was comparable to that of MRI + US.

Conclusions

CBBCT has good diagnostic performance. Combined with US, it can serve as a potential alternative to MRI, providing crucial imaging evidence for the treatment of breast cancer.

1.Introduction

Breast cancer has become the leading disease threatening the health of women worldwide. According to the global cancer statistics released by the International Agency for Research on Cancer (IARC) in February 2024, breast cancer ranks first in female cancer incidence. In 2022, there were 2.309 million new cases of breast cancer globally, and the number of deaths exceeded 665,684 cases^[1]. In recent years, the incidence of breast cancer has shown a continuous upward trend. In 2024, there were 369,769 new cases of breast cancer in China, and 77,959 people died from this disease.^[2] Effective, convenient, and economical screening methods to improve breast cancer detection rates and diagnostic accuracy, combined with effective treatments, are crucial measures to reduce mortality rates. Currently, mammography (MG) and ultrasonography (US) are the primary screening methods for breast diseases, while magnetic resonance imaging (MRI) serves as an important supplementary diagnostic tool^[3]. Cone beam breast computed tomography (CBBCT), a novel 3D breast imaging technology, offers advantages such as high patient comfort, rapid scanning speed, and high spatial resolution^[4]. Existing studies predominantly compare

CBBCT with MG, while comparative research involving US and MRI remains limited. This study evaluates the clinical value of CBBCT, MRI, and US using pathological results as the "gold standard."

2. Materials and Methods

2.1 Patient selection

This study prospectively collected data from patients who underwent CBBCT examinations at our hospital between June 2020 and April 2023. The inclusion and exclusion criteria are presented in the flowchart of Fig. 1.

Ultimately, 66 female patients with 85 lesions were enrolled. The malignant group comprised 53 lesions (patient age range: 21–67 years, median age: 47 years; left breast: 23 lesions, right breast: 30 lesions). The benign group included 32 lesions (age range: 27–61 years, median age: 40.5 years; left breast: 18 lesions, right breast: 14 lesions).

This study was performed following the Declaration of Helsinki. The study has been approved by the Ethics Committee of the Chinese People's Liberation Army General Hospital (Approval No.: S2020-221-01). We confirm that all methods were carried out in accordance with the guidelines and regulations of the Ethics Committee of the Chinese People's Liberation Army General Hospital. All patients provided written informed consent prior to the examinations.

2.2 CBBCT

CBBCT imaging was performed using the KBCT-1000 system (Koning Corporation, USA; manufactured in Tianjin, China). Patients were positioned prone on the examination table, with the breast naturally suspended within the imaging aperture. The X-ray tube voltage was set to 49 kVp, and the tube current was automatically adjusted based on breast volume and density. The X-ray tube and detector rotated 360° synchronously around the breast, acquiring 300 two-dimensional projection images within 10 seconds. Axial, sagittal, coronal, and three-dimensional images were reconstructed (matrix: 1024×1024; voxel size: 0.273 mm³). All cases underwent both non-contrast and contrast-enhanced scans. For contrast-enhanced imaging, Iohexol (Omnipaque® 300, GE Healthcare) was administered intravenously at a dose of 2 mL/kg (maximum 100 mL) with an injection rate of 2 mL/s. Scanning was initiated 120 seconds post-injection using identical parameters. Examination time: Ranged from 8 to 10 minutes.

2.3 MRI

MRI examinations were performed using a GE 3.0T MR scanner (GE Healthcare) with an 8-channel dedicated breast coil, with patients positioned prone. The imaging protocol included the following sequences: T1-weighted imaging (T1WI), fat-suppressed T2-weighted imaging (T2WI), diffusion-weighted imaging (DWI), and dynamic contrast-enhanced (DCE) MRI. (1) Fat-suppressed T2WI: TR 4600–5000 ms, TE 68–85 ms, matrix 320 × 256. (2) Diffusion-weighted imaging (DWI): TR 5000–8000 ms, TE 60–85 ms, b-values of 0 and 1000 s/mm². Consistent slice orientation with T2WI; slice thickness 4 mm, slice gap 1 mm, total slices 36. (3) T1WI and DCE-MRI: Sequence: Volume imaging for breast assessment (VIBRANT). T1WI: Without fat suppression; TR 4.5–4.8 ms, TE 2.2–2.4 ms, FOV 320 mm × 320 mm, slice thickness 1 mm, total slices 176, covering the breast and axilla. Dynamic enhancement: Six consecutive phases (120 s per phase). The first phase served as the pre-contrast scan. Gadopentetate dimeglumine (Magnevist®) was administered via intravenous bolus injection at 2 mL/s (dose: 0.1 mmol/kg), followed by an equivalent volume of saline flush at the same injection rate. Examination time: Approximately 30 minutes.

2.4US

US included conventional grayscale imaging and color Doppler flow imaging (CDFI). Some patients underwent contrast-enhanced ultrasonography (CEUS) using SonoVue® (Bracco). For CEUS, 25 mg of lyophilized powder was reconstituted with 5 mL of saline to form a sulfur hexafluoride (SF₆) microbubble suspension. After manual agitation, 2.4–4.8 mL of the suspension was administered as an intravenous bolus via the antecubital vein, followed by a 5–10 mL saline flush. Examination time: Highly operator-dependent.

2.5Image Analysis

Observation and Measurement of Imaging Features: The number of lesions detected on NC-CBBCT, CE-CBBCT, US, and MRI was recorded separately. Based on the 5th edition of the Breast Imaging Reporting and Data System (BI-RADS) [5], the following characteristics were evaluated: lesion location, shape, margins, and internal enhancement patterns, and involvement of the nipple, skin, or pectoralis major muscle.

Measurement of Lesion Dimensions: For CBBCT, US, and MRI, the maximum diameters of lesions in three orthogonal planes (anterior-posterior, transverse, and craniocaudal) were measured.

Region of Interest (ROI) Analysis: ROIs were placed in the area of highest enhancement, avoiding blood vessels, hemorrhage, liquefaction, necrosis, cystic changes, and calcifications.

CT value analysis: Non-contrast and post-contrast CT values were measured at identical lesion locations. $\Delta\text{CT} = \text{Post-contrast CT value} - \text{Non-contrast CT value}$. Enhancement ratio (%) = $(\Delta\text{CT} / \text{Non-contrast CT value}) \times 100\%$.

MRI Enhancement Kinetics: Early enhancement rate (%) = $[(\text{Post-contrast signal intensity (SI)} - \text{Pre-contrast SI}) / \text{Pre-contrast SI}] \times 100\%$. Time-intensity curve types: Type I (persistent), Type II (plateau), Type III (washout).

Diagnosis of Benign vs. Malignant Breast Lesions

Two radiologists (one attending physician and one senior physician) independently performed blinded reviews of CBBCT and MRI images, with evaluations separated by a one-month interval and randomized image order. Discrepancies in diagnoses were resolved through consensus. For US, an attending physician and a senior sonologist jointly conducted examinations and classifications.

BI-RADS Classification Criteria: CBBCT and MRI: Due to the lack of established BI-RADS criteria for CBBCT, classifications were adapted from the MRI BI-RADS standards. Malignant: BI-RADS categories 4–5. Benign: BI-RADS categories ≤ 3. US: Malignant: BI-RADS categories 4B–5. Benign: BI-RADS categories ≤ 4A.

Discordant Cases: When conventional US and CEUS classifications conflicted, the CEUS result was prioritized.

Combined Diagnostic Approach: A parallel testing method was employed, where results from multiple modalities (CBBCT, MRI, US) were analyzed independently, and any positive result for malignancy triggered further evaluation.

2.6Statistical Analysis

Statistical analyses were performed using SPSS 26.0. Using pathological results as the gold standard, the agreement of imaging features across different modalities was analyzed. Categorical data were compared between groups using the chi-square test or Fisher's exact test. The Kruskal-Wallis H test was used to compare lesion sizes, and the independent samples t-test was applied to compare ΔCT values between benign and malignant groups.

Sensitivity and specificity of individual and combined examination methods were calculated. Receiver operating characteristic (ROC) curves were constructed, and the area under the curve (AUC) was computed to evaluate diagnostic efficacy, with inter-group comparisons of AUC performed accordingly. For sensitivity and specificity calculations, benign lesions were classified as negative, and malignant lesions as positive. Statistical significance was defined as $P < 0.05$.

3. Results

3.1 Pathological result

Pathological findings revealed 85 lesions, including 32 benign and 53 malignant lesions. Benign lesions consisted of 15 fibroadenomas, 11 cases of adenosis (2 nodular adenosis and 1 complex sclerosing adenosis), 4 intraductal papillomas, 1 benign phyllodes tumor, and 1 radiation-induced sclerotic lesion. Malignant lesions included 46 invasive carcinomas, 3 ductal carcinoma in situ, 1 lobular carcinoma in situ, 1 mixed mucinous carcinoma (50% mucinous and 50% micropapillary components), 1 pure mucinous micropapillary carcinoma, and 1 borderline phyllodes tumor (categorized as malignant for statistical purposes due to its potential for malignant transformation). Pathological diagnoses were obtained via fine-needle aspiration biopsy in 23 cases and postoperative histopathological examination in 62 cases.

3.2 Detection Rates

The detection rates of US and MRI for 85 lesions were both 100% (85/85). NC-CBBCT achieved a detection rate of 70.59% (60/85), while CE-CBBCT demonstrated a higher detection rate of 92.94% (79/85). In the benign subgroup, detection rates were 56.25% (18/32) for NC-CBBCT and 84.38% (27/32) for CE-CBBCT. In the malignant lesion subgroup, the corresponding detection rates were 79.25% (42/53) for NC-CBBCT and 98.11% (52/53) for CE-CBBCT. Statistically significant differences were observed in the detection rates among US, MRI, NC-CBBCT, and CE-CBBCT. Notably, the detection rate of NC-CBBCT was significantly lower than that of US, MRI, and CE-CBBCT. Although the detection rate of CE-CBBCT was slightly lower than that of US and MRI, this difference was not statistically significant. Furthermore, the detection rates of both NC-CBBCT and CE-CBBCT were lower in the benign group compared to the malignant group. (Table 1)

Table 1
Comparison of Detection Rates of NC- and CE-CBBCT, US and MRI

Modality	Total (n = 85)		Benign (n = 32)		Malignant (n = 53)		P value
	Detected (n, %)	Not Detected (n, %)	Detected (n, %)	Not Detected (n, %)	Detected (n, %)	Not Detected (n, %)	
US	85 (100)	0 (0)	32 (100)	0 (0)	53 (100)	0 (0)	< 0.001
MRI	85 (100)	0 (0)	32 (100)	0 (0)	53 (100)	0 (0)	< 0.001
NC-CBBCT	60 (70.59)*	25 (29.41)*	18 (56.25)*	14 (43.75)*	42 (79.25)*	11 (20.75)*	< 0.001
CE-CBBCT	79 (92.94)	6 (7.06)	27 (84.38)#	5 (15.62)#	52 (98.11)	1 (1.89)	< 0.001

Note: * indicates statistically significant differences compared with other modalities ($P < 0.05$); # indicates no statistically significant differences compared with US/MRI ($P > 0.05$) but significant differences compared with NC-CBBCT ($P < 0.05$).

3.3 Imaging Features

Given the relatively high rate of missed diagnoses in NC-CBBCT observed in this study, its diagnostic efficacy was not further evaluated. In the CE-CBBCT group, six lesions were missed: five benign lesions (all adenosis) and one malignant lesion (mucinous micropapillary carcinoma). This study focused on the imaging features of 79 detected lesions, with CE-CBBCT imaging characteristics described by referencing MRI and BI-RADS terminology consolidated for straightforward comparison with US (Table 2).

Table 2

Comparative Analysis of Imaging Features and Diagnostic Accuracy between CE-CBBCT and MRI for Different Types of Cystic Lesions

Characteristics	Benign(n = 27)			P value	Malignant(n = 52)			P value
	CBBCT	US	MRI		CBBCT	US	MRI	
Shape				0.006				0.01
-Regular	22	12*	21		17	2*	15	
-Irregular	5	15*	6		35	50*	37	
Margin				0.742				0.141
-Circumscribed	22	20	22		7	11	4	
-Uncircumscribed (Irregular, Spiculated)	5	7	5		45	41	48	
Internal enhancement pattern				0.054				0.487
-Homogeneous	10	/	3		4	/	2	
-Heterogeneous	17	/	23		45	/	44	
-Rim	/	/	∅		3	/	6	
-Dark internal septaions	∅	/	1		/	/	∅	
CDFI (positive)	/	10	/		/	39	/	
CEUS (hyper/hypovascularity)	/	Hyper-7, hypo-5	/		/	hyper-3	/	
Maximum diameter(cm)M(Q1-Q3)	1.4(1.1–1.6)	1.4(1.2–1.8)	1.4(1.1–1.9)	0.941	2.1(1.5–3.0)	2.0(1.5–2.6)	2.2(1.5–3.2)	0.712
Other signs								
-Skin thickening	/	/	∅		3	3	3	
-Nipple retraction	/	/	/		/	/	/	
-Chest wall invasion	∅	/	∅		2	/	3	
-Suspicious calcification	∅	/	∅		7	7	/	
-Positive vascular sign	/	/	/		31		27	
△CT(HU),mean ± SD	65.3 ± 30.7	/	∅		106.9 ± 43.0	/	∅	< 0.001
Early enhancement rate				< 0.001				< 0.001
-<90%	24*	/	9*		29	/	6	
Note: * denotes a statistically significant difference between this group and all other groups; / indicates not applicable.								

Characteristics	Benign(n = 27)			P value	Malignant(n = 52)			P value
	CBBCT	US	MRI		CBBCT	US	MRI	
-90-120%	2	/	7		9	/	6	
->120%	1	/	11		14*	/	40*	
TIC								
- Type I (Persistent)	☒	/	13		/	/	1	
- Type II (Plateau)	☒	/	10		☒	/	11	
- Type III (Washout)	☒	/	4		☒	/	40	
Note: * denotes a statistically significant difference between this group and all other groups; / indicates not applicable.								

3.4 Lesion Location

The location of 79 breast lesions was consistently identified across CE-CBBCT, US, and MRI: 35 lesions in the left breast and 44 in the right breast. Among these, 35 lesions were located in the outer upper quadrant, 8 in the outer lower quadrant, 9 in the inner upper quadrant, 8 in the inner lower quadrant, 5 in the upper quadrant, 4 in the inner quadrant, 5 in the outer quadrant, and 5 in the central area.

3.5 Key Imaging Feature Comparisons

Shape: Statistically significant differences were observed in the shape classification of benign and malignant lesions between US and CE-CBBCT/MRI (benign: $P = 0.006$; malignant: $P = 0.01$). US more frequently classified benign lesions as irregular and malignant lesions as regular compared with CE-CBBCT and MRI.

Margins and Size: High consistency was noted in the assessment of lesion margins (benign: $P = 0.742$; malignant: $P = 0.141$) and size measurements (benign: $P = 0.941$; malignant: $P = 0.712$) across the three modalities.

Internal Enhancement: Although no statistically significant difference was found in internal enhancement feature interpretation between CE-CBBCT and MRI (benign: $P = 0.054$; malignant: $P = 0.487$), a notable discrepancy existed in the benign group. The mean ΔCT value of the benign group (65.3 ± 30.7 HU) was significantly lower than that of the malignant group (106.9 ± 43.0 HU) ($P < 0.001$). Additionally, a statistically significant difference was observed in the early enhancement rate between CE-CBBCT and MRI ($P < 0.001$) (Table 2).

3.6 Diagnostic Efficacy

Among the 79 detected lesions, the number of misdiagnosed cases in the malignant group using CBBCT, MRI, US, CBBCT + US, MRI + US, and CE-CBBCT + US+MRI was 4, 0, 6, 1, 0, and 0, respectively. In the benign group, the corresponding numbers were 7, 14, 6, 3, 5, and 3, respectively. Sensitivity values were 92.31%, 100%, 88.46%, 98.07%, 100%, and 100%, while specificity values were 74.07%, 48.15%, 77.78%, 88.89%, 81.48%, and 88.89%, respectively. ROC curve analysis revealed AUC values of 0.934, 0.952, 0.891, 0.958, 0.960, and 0.965 (all $P < 0.05$). Statistically significant differences were observed between US alone and the combined examination groups ($P = 0.019, 0.038, 0.024$) (Table 3, Fig. 2). Figure 3 and Fig. 4 show good diagnostic value and illustrate typical imaging features of malignant breast lesions.

Table 3
Comparative Analysis of Diagnostic Performance for 79 Breast Lesions Using CBBCT, MRI, US, and Combined Modalities

Imaging modalities	Pathology(n)		Sensitivity %(n/N)	Specificity %(n/N)	AUC
	Malignant	Benign			
CBBCT			92.31(48/52)	74.07(20/27)	0.934
≥BI-RADS 4	48	7			
≤BI-RADS 3	4	20			
MRI			100(52/52)	48.15(13/27)	0.952
≥BI-RADS 4	52	14			
≤BI-RADS 3	0	13			
US			88.46(46/52)	77.78(21/27)	0.891*
≥BI-RADS 4b	46	6			
≤BI-RADS 4a	6	21			
CBBCT⊗US			98.07(51/52)	88.89(24/27)	0.958
≥BI-RADS 4/4b	51	3			
≤BI-RADS 3/4a	1	24			
MRI⊗US			100 (52/52)	81.48(22/27)	0.960
≥BI-RADS 4/4b	52	5			
≤BI-RADS 3/4a	0	22			
CBBCT⊗US + MRI			100(52/52)	88.89(24/27)	0.965
≥BI-RADS 4/4b	52	3			
≤BI-RADS 3/4a	0	24			

Note: * denotes a statistically significant difference between the individual group and the combined examination group.

4.Discussion

In contrast to Western countries' reliance on mammography (MG) for breast screening, US is more widely adopted in China due to its cost-effectiveness, operational flexibility, and minimal interference from patient positioning or breast tissue density. Some patients in our institution had prior MG at local hospitals, but poor acceptance—attributed to compression-related discomfort^[6]—led to incomplete data, so MG was excluded. Notably, CBBCT has been shown to outperform MG in coverage, patient comfort, and diagnostic performance^[6]. While breast MRI offers high accuracy, sensitivity, and specificity^[7, 8], an unmet need exists for alternatives in patients with claustrophobia or intolerance to prolonged prone positioning.

CBBCT is a specialized breast imaging technique based on cone-beam X-rays and flat-panel detectors^[9]. It acquires 300 projection images within 10 seconds via 360° synchronous rotation of the emitter and detector, reconstructing

isotropic high-resolution 3D images that eliminate tissue overlap and avoid breast compression. Compared to MG, CBBCT improves comfort[6]; relative to MRI, it provides faster scanning and lower costs^[10]. Although prior studies confirm CBBCT's superiority over US and MG^[11, 12], simultaneous comparative data with MRI and US remain scarce—this study addresses this critical gap.

This study enrolled 85 lesions (32 benign, 53 malignant). US and MRI achieved 100% detection rates, while contrast-enhanced CBBCT (CE-CBBCT) had a significantly higher detection rate than non-contrast CBBCT (NC-CBBCT) (92.94% vs. 70.59%), consistent with previous reports^[11, 13]. Missed diagnoses in CBBCT primarily stemmed from low lesion-glandular tissue contrast, especially for small non-calcified lesions and dense breasts—enhanced imaging mitigates this by improving tissue contrast. Uhlig et al^[14] reported CE-CBBCT matches dual-phase (plain + enhanced) scanning in accuracy while reducing radiation dose by approximately 50%, aligning with our findings on its efficiency.

Six lesions were missed in CE-CBBCT (five benign adenosis, one malignant mucinous micropapillary carcinoma), mainly due to small size, dense glandular tissue, insufficient enhancement, minimal density differences, or limited axillary-tail coverage (a technical constraint^[15]). Notably, 13.46% (7/52) of malignant lesions showed microcalcifications on CBBCT, consistent with US findings. CBBCT's strengths—shorter scan time, improved comfort, reduced motion artifacts, and high microcalcification detection^[16, 17]—collectively enhance its clinical utility.

Statistically significant differences in lesion shape interpretation were observed between US and CE-CBBCT/MRI. This discrepancy arises because US provides operator-dependent, subjective 2D localized imaging, whereas CE-CBBCT and MRI use prone-position enhanced scanning—enabling natural breast suspension without compression and ensuring high consistency in assessing lesion location, shape, margins, and size. Benign lesions typically present as round/oval with well-defined margins, while malignant lesions are irregular with ill-defined/spiculated margins (some involving the chest wall or skin)—findings consistent with prior literature^[3, 18, 19].

Although CEUS can objectively reflect the microperfusion of breast lesions and serves as an important supplementary examination, features such as high enhancement, expanded enhancement range, heterogeneous enhancement, irregular lesion morphology after enhancement, and the crab-claw sign are associated with a higher probability of malignancy^[20, 21]. All three single modalities showed diagnostic significance, but CBBCT and MRI outperformed US (moderate efficacy). Following Uhlig et al.^[22], who validated 2-minute post-contrast scanning for benign/malignant differentiation, we adopted this protocol (consistent with MRI) and found benign lesions had a significantly lower ΔCT value (65.3 ± 30.7 HU) than malignant lesions (106.9 ± 43.0 HU, $P < 0.001$). This difference reflects vascular structural variations: malignant tumors have higher microvascular density, immature endothelial cells, and reduced basement membranes (increasing permeability), while benign lesions show reactive vascular hyperplasia with intact endothelium and basement membranes (lower permeability)^[23, 24]. Inconsistencies in early enhancement rates between CE-CBBCT and MRI may reflect contrast permeability differences or measurement errors.

CBBCT uses self-shielding technology, limiting radiation exposure to the target breast with an average glandular dose of 5.73 mGy—within the FDA-validated safe range^[25]. This favorable dose profile, combined with rapid scanning, supports its use in routine screening and follow-up. Due to radiation minimization concerns and patient informed consent constraints, multi-phase scanning was not performed, precluding analysis of CE-CBBCT enhancement curve types.

CBBCT's sensitivity (92.31%) was slightly lower than MRI's (100%), potentially due to limited CBBCT interpretation experience and suboptimal patient positioning (e.g., incomplete breast adherence to the bed from shoulder/cervical discomfort). Compared with MRI, the resolution of posterior breast lesions is reduced, and near-chest wall artifacts are more likely to occur^[26]. Future radiologist training and optimized positioning protocols (e.g., adjustable bed height, supportive cushions) may mitigate these issues. Conversely, MRI had lower specificity than CBBCT and US (48.15% vs. 74.07% and 77.78%), possibly due to benign lesions' abundant blood supply, lobulated morphology, or internal degeneration—this may lead to unnecessary biopsies.

Comprehensive imaging is critical for breast-conserving surgery planning. Recent studies validate CBBCT's utility in measuring tumor size and glandular/breast volume to guide surgical strategies^[27]. At our institution, MRI is routinely used preoperatively to exclude multifocal lesions and assess breast-conserving eligibility. Our data show combining CBBCT + US, MRI + US, or all three modalities enhances sensitivity and specificity—with CBBCT + US achieving efficacy comparable to MRI + US (AUC: 0.958 vs. 0.960). This makes CBBCT + US an ideal preoperative alternative for patients with MRI contraindications (e.g., claustrophobia, renal impairment precluding contrast use).

This study has limitations. First, the small sample size (85 lesions) may limit generalizability, especially for rare benign/malignant subtypes. Since all lesions were preselected by ultrasound, this selection bias should be considered when interpreting the high detection rate of ultrasound. Second, only mass-type lesions were included, and parallel diagnostic testing (all patients underwent all three modalities) may introduce verification bias. Third, the absence of MG comparison prevents assessing CBBCT's utility relative to Western screening standards, warranting multi-center investigation. Fourth, lack of multi-phase CE-CBBCT data limits evaluation of enhancement kinetics, a feature that improves MRI specificity.

In conclusion, our study—among the first to simultaneously compare CBBCT with MRI and US—confirms both modalities exhibit high diagnostic performance for malignant breast lesions. Combining CBBCT with US significantly enhances sensitivity and overall efficacy, yielding results non-inferior to MRI + US. This combination offers a valuable alternative for patients with MRI contraindications, and its favorable radiation profile and rapid scanning support routine clinical application. Future large-scale, multi-center studies with diverse lesion types and long-term follow-up are needed to further validate CBBCT's role in breast cancer screening, preoperative assessment, and neoadjuvant therapy monitoring.

Abbreviations

CBBCT

Cone-beam breast CT

NC-CBBCT

Non-contrast cone-beam breast CT

CE-CBBCT

Contrast-enhanced cone-beam breast CT

MRI

Magnetic resonance imaging

DCE-MRI

Dynamic contrast-enhanced MRI

T1WI

T1-weighted imaging

T2WI
T2-weighted imaging
DWI
Diffusion-weighted imaging
VIBRANT
Volume imaging for breast assessment
US
Ultrasonography
CEUS
Contrast-enhanced ultrasonography
CDFI
Color Doppler flow imaging
BI-RADS
Breast Imaging Reporting and Data System
ROI
Region of Interest
AUC
Area Under the Curve
SI
Signal intensity
TIC
Time-intensity curve
MG
Mammography
SF₆
Sulfur hexafluoride
FOV
Field of view
TR
Repetition time
TE
Echo time
ADC
Apparent diffusion coefficient
HU
Hounsfield unit

Declarations

6. Conflict of Interest

The authors declare no conflict of interest.

7. Author Contributions

Ying Li and Yan Jun Zhang led study design and prepared the manuscript; Yu Zhang carried out the experiments and performed statistical analysis; Fang He and Bai He performed data analysis and interpretation; Yan ning Fu provided data collection. All authors read and approved the final manuscript.

8.Availability of data and materials

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

9. Acknowledgments

We acknowledge the assistance from the Chinese PLA General Hospital.

10.Ethics approval and consent to participate

This study was approved by the Ethics Committee of the Chinese PLA General Hospital(Approval No.: S2020-221-01). All patients provided written informed consent prior to the examinations.

11. Funding

This study was not supported by any funds.

References

1. Bray F, Laversanne M, Sung H, et al. Global cancer statistics 2022: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. *CA Cancer J Clin.* 2024;74:229–63.
2. Wu Y, He S, Cao M, et al. Comparative analysis of cancer statistics in China and the United States in 2024. *Chin Med J (Engl).* 2024;137:3093–100.
3. Zhang H, Guo LL, Tao WJ, et al. Comparison of the clinical application value of mo-targeted X-ray, color doppler ultrasound and MRI in preoperative comprehensive evaluation of breast cancer. *Saudi J Biol Sci.* 2019;26:1973–7.
4. Zhu Y, O'Connell AM, Ma Y, et al. Dedicated breast CT: state of the art—Part I. Historical evolution and technical aspects. *Eur Radiol.* 2022;32:1579–89.
5. Morris EA, Comstock CE, Lee CH, et al. ACR BI-RADS® magnetic resonance imaging/ACR BI-RADS atlas, breast imaging reporting and data system. Reston, VA: American College of Radiology; 2013.
6. Li H, Yin L, He N, et al. Comparison of comfort between cone beam breast computed tomography and digital mammography. *Eur J Radiol.* 2019;120:108674.
7. Liu G, Li Y, Chen SL, et al. Non-mass enhancement breast lesions: MRI findings and associations with malignancy. *Ann Transl Med.* 2022;10:357.
8. Zhu X, Cao Y, Li R, et al. Diagnostic performance of mammography and magnetic resonance imaging for evaluating mammographically visible breast masses. *J Int Med Res.* 2021;49:300060520973092.
9. Wienbeck S, Lotz J, Fischer U. Review of clinical studies and first clinical experiences with a commercially available cone-beam breast CT in Europe. *Clin Imaging.* 2017;42:50–9.
10. Uhlig J, Uhlig A, Biggemann L, et al. Diagnostic accuracy of cone-beam breast computed tomography: a systematic review and diagnostic meta-analysis. *Eur Radiol.* 2019;29:1194–202.

11. He N, Wu YP, Kong Y, et al. The utility of breast cone-beam computed tomography, ultrasound, and digital mammography for detecting malignant breast tumors: a prospective study with 212 patients. *Eur J Radiol.* 2016;85:392–403.
12. Wienbeck S, Uhlig J, Luftner-Nagel S, et al. The role of cone-beam breast-CT for breast cancer detection relative to breast density. *Eur Radiol.* 2017;27:5185–95.
13. Wienbeck S, Fischer U, Luftner-Nagel S, et al. Contrast-enhanced cone-beam breast-CT (CBBCT): clinical performance compared to mammography and MRI. *Eur Radiol.* 2018;28:3731–41.
14. Uhlig J, Fischer U, Biggemann L, et al. Pre- and post-contrast versus post-contrast cone-beam breast CT: can we reduce radiation exposure while maintaining diagnostic accuracy. *Eur Radiol.* 2019;29:3141–8.
15. O'Connell A, Conover DL, Zhang Y, et al. Cone-beam CT for breast imaging: radiation dose, breast coverage, and image quality. *AJR Am J Roentgenol.* 2010;195:496–509.
16. Aminololama-Shakeri S, Abbey CK, Gazi P, et al. Differentiation of ductal carcinoma in-situ from benign micro-calcifications by dedicated breast computed tomography. *Eur J Radiol.* 2016;85:297–303.
17. O'Connell AM, Kawakyu-O'Connor D. Dedicated Cone-beam Breast Computed Tomography and Diagnostic Mammography: Comparison of Radiation Dose, Patient Comfort, And Qualitative Review of Imaging Findings in BI-RADS 4 and 5 Lesions. *J Clin Imaging Sci.* 2012;2:7.
18. Ma D, Lu F, Zou X, et al. Intravoxel incoherent motion diffusion-weighted imaging as an adjunct to dynamic contrast-enhanced MRI to improve accuracy of the differential diagnosis of benign and malignant breast lesions. *Magn Reson Imaging.* 2017;36:175–9.
19. Malich A, Fischer DR, Wurdinger S, et al. Potential MRI interpretation model: differentiation of benign from malignant breast masses. *AJR Am J Roentgenol.* 2005;185:964–70.
20. Boca Bene I, Dudea SM, Ciurea AI. Contrast-Enhanced Ultrasonography in the Diagnosis and Treatment Modulation of Breast Cancer. *J Pers Med.* 2021;11:2.
21. Wang B, Yang D, Zhang X, et al. The diagnostic value of contrast-enhanced ultrasonography in breast ductal abnormalities. *Cancer Imaging.* 2023;23:25.
22. Uhlig J, Fischer U, Surov A, et al. Contrast-enhanced cone-beam breast-CT: analysis of optimal acquisition time for discrimination of breast lesion malignancy. *Eur J Radiol.* 2018;99:9–16.
23. Kang W, Zhong W, Su D. The cone-beam breast computed tomography characteristics of breast non-mass enhancement lesions. *Acta Radiol.* 2021;62:1298–308.
24. Leach MO. Application of magnetic resonance imaging to angiogenesis in breast cancer. *Breast Cancer Res.* 2001;3:22–7.
25. Zhu Y, Zhang Y, Ma Y, et al. Cone-beam breast CT features associated with HER2/neu overexpression in patients with primary breast cancer. *Eur Radiol.* 2020;30:2731–9.
26. Vedantham S, Tseng HW, Konate S, et al. Dedicated cone-beam breast CT using laterally-shifted detector geometry: quantitative analysis of feasibility for clinical translation. *J Xray Sci Technol.* 2020;28:405–26.
27. Li J, Zhong G, Wang K, et al. Tumor-to-Gland Volume Ratio versus Tumor-to-Breast Ratio as Measured on CBBCT: possible predictors of Breast-Conserving Surgery. *Cancer Manag Res.* 2021;13:4463–71.

Figures

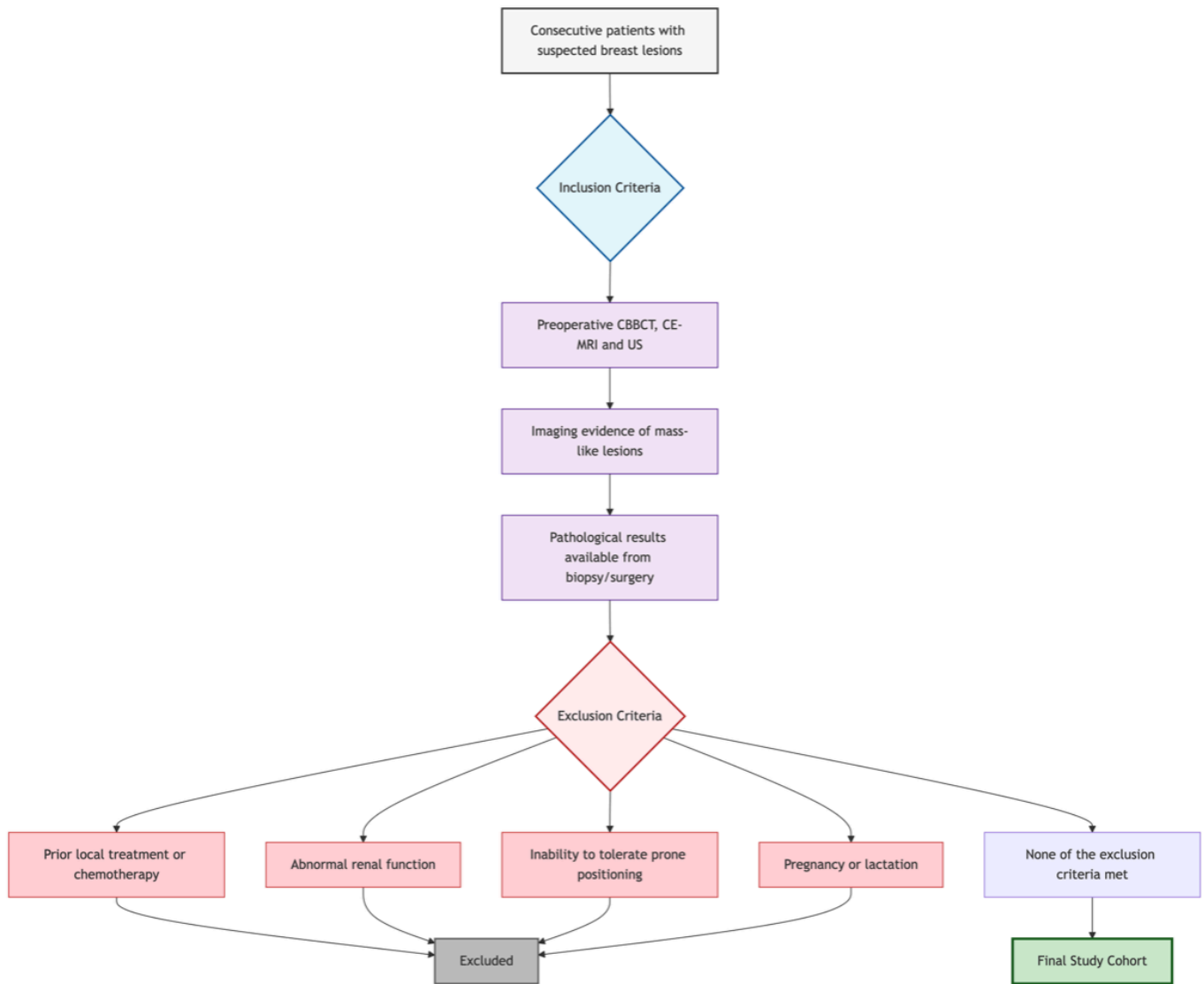


Figure 1

Flowchart of the inclusion and exclusion criteria.

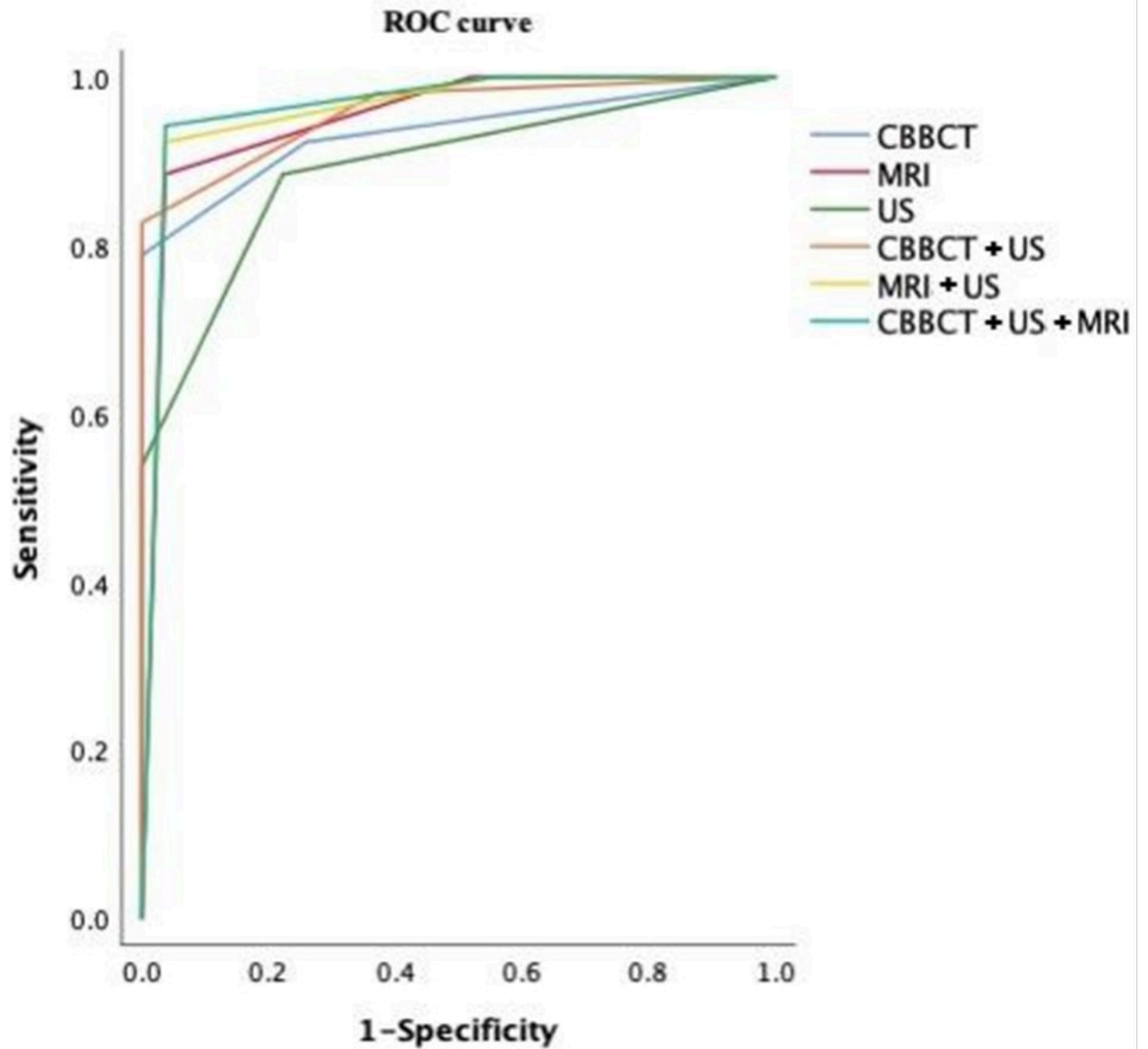


Figure 2

Receiver Operating Characteristic (ROC) Curves for CBBCT, MRI, US, and Combined Diagnostic Approaches

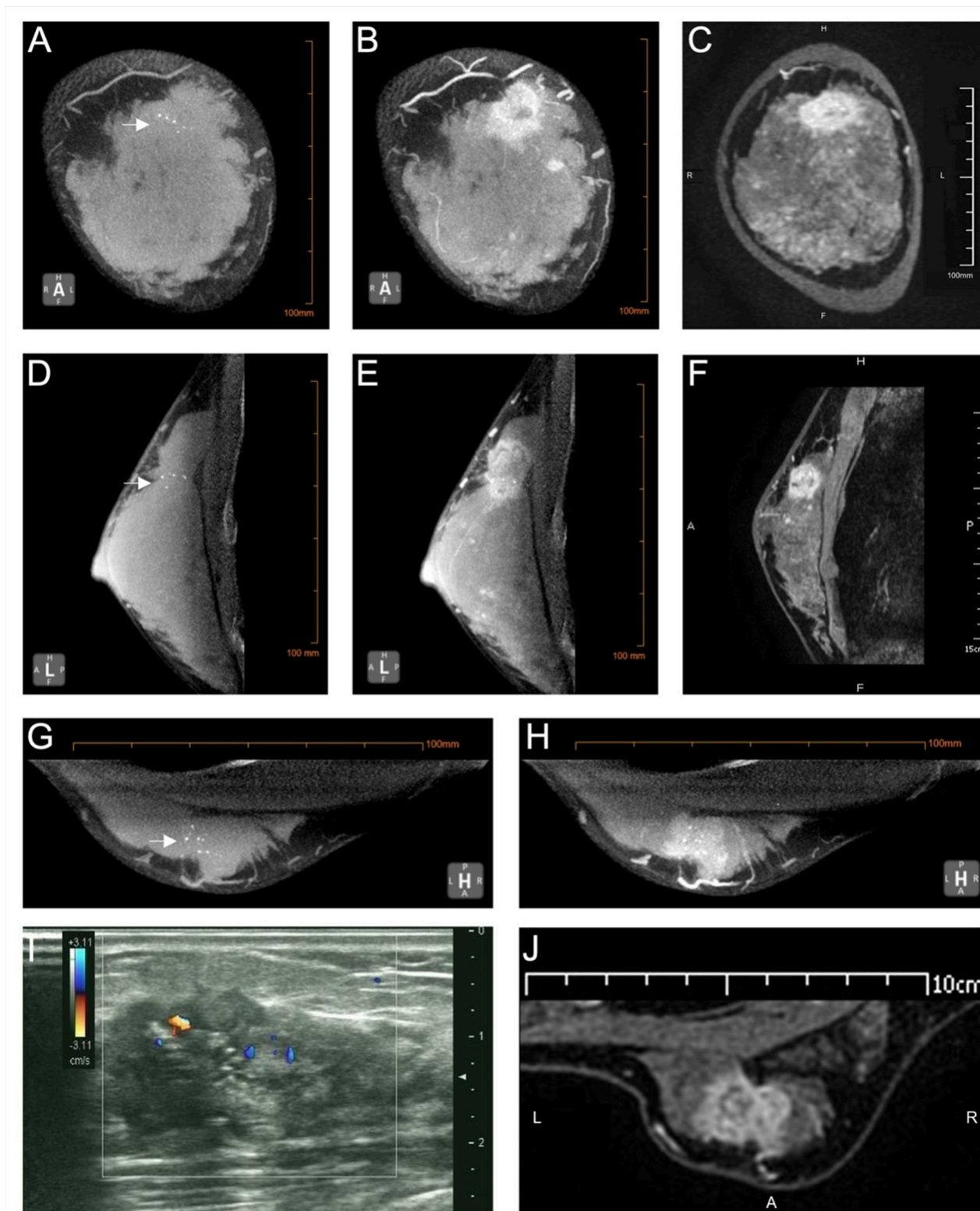


Figure 3

shows a patient with invasive breast cancer in the right breast. Figures A, D, and G are plain CBBCT images, with an arrow indicating an irregular slightly high-density shadow and microcalcifications. Figures B, E, and H and C, F, and J are CBBCT and MRI enhanced sagittal, coronal, and axial images, respectively. Figure I is an US image. The imaging findings are consistent. The lesion is mass-like, with an irregular shape and margin, heterogeneous enhancement, $ADC_{min} = 0.92 \times 10^{-3} \text{mm}^2/\text{s}$, and type III curve. Spotty hyperechoic foci are visible in the US, and blood flow signals are seen in the CDFI. The BI-RADS classification is all category 5.

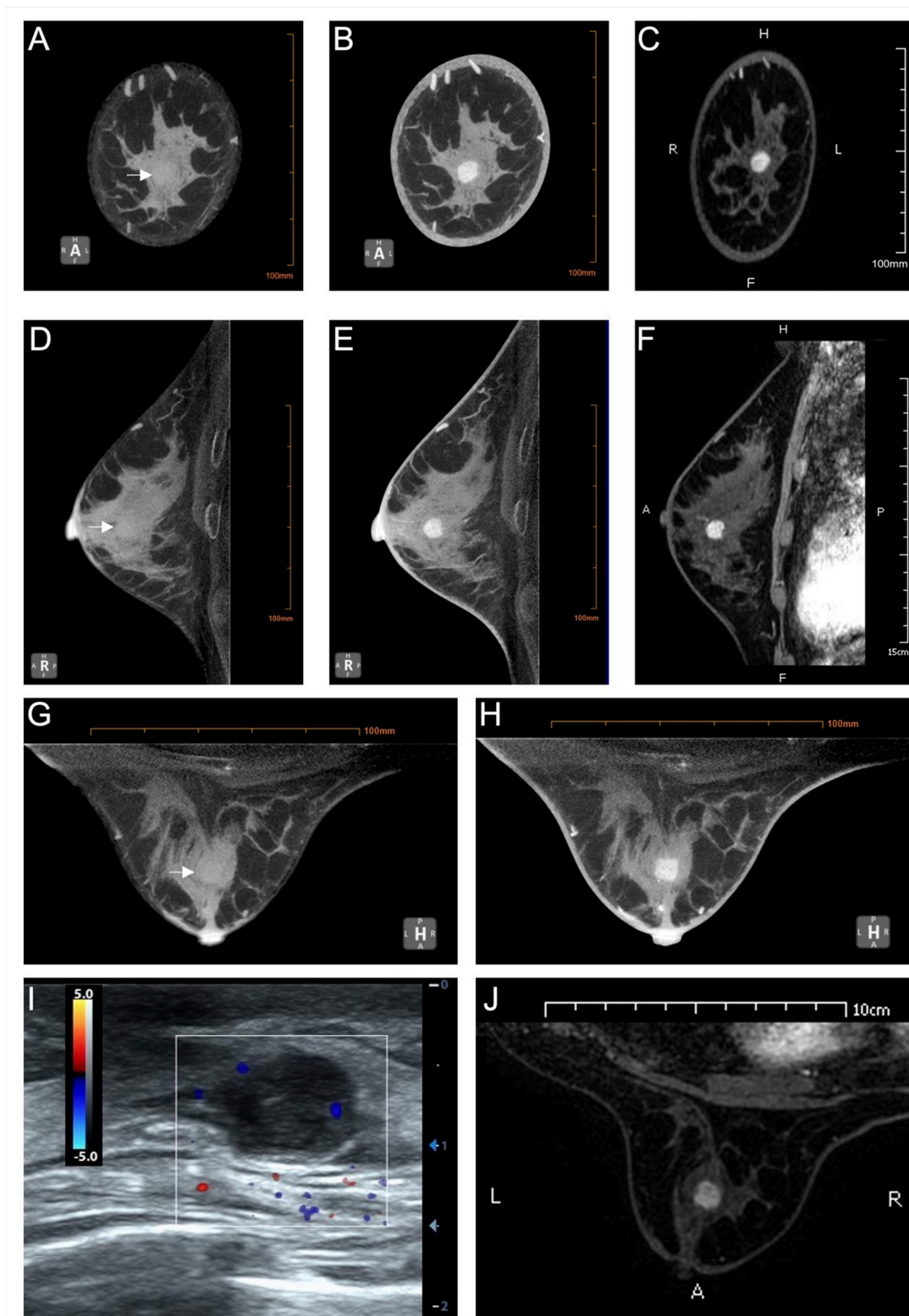


Figure 4

shows a patient with invasive breast cancer in the left breast. Figures A, D, and G are plain CBBCT images, with arrows indicating a slightly high-density, round-like shadow. Figures B, E, and H and C, F, and J are CBBCT and MRI enhanced sagittal, coronal, and axial images, respectively. Figure I is an US image. The imaging findings are consistent. The lesion is mass-like, round-like, with an irregular margin, heterogeneous enhancement, $ADC_{min} = 1.02 \times 10^{-3} \text{mm}^2/\text{s}$, type III curve, and CDFI shows blood flow signals. BI-RADS classification: CBBCT 4, MRI 5, and US 4b.

