



# Simultaneous comparison between strain and shear wave elastography of breast masses for the differentiation of benign and malignant lesions by qualitative and quantitative assessments

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## Abstract

**Purpose** To compare the addition of diagnostic strain elastography (SE) and shear wave elastography (SWE) values to the conventional B-mode ultrasonography in differentiating between benign and malignant breast masses by qualitative and quantitative assessments.

**Materials and methods** B-mode ultrasound, SE, and SWE were simultaneously performed using one ultrasound system in 148 breast masses; 88 of them were malignant. The breast imaging reporting and data system category in the B-mode, Tsukuba score ( $SE_{Tsu}$ ), Fat-Lesion-Ratio ( $SE_{FLR}$ ) in SE, and five-point color assessment ( $SWE_{col}$ ) and elasticity values ( $SWE_{ela}$ ) in SWE were assessed. The results were compared using the area under the receiver-operating characteristic curve (AUC).

**Result** The AUC for B-mode and each elastography were similar (B-mode, 0.889;  $SE_{Tsu}$ , 0.885;  $SE_{FLR}$ , 0.875;  $SWE_{col}$ , 0.881;  $SWE_{ela}$ , 0.885;  $P > 0.05$ ). The combined sets between B-mode and either of the elastography technique showed good diagnostic performance (B-mode +  $SE_{Tsu}$ , 0.903; B-mode +  $SE_{FLR}$ , 0.909; B-mode +  $SWE_{col}$ , 0.919; B-mode +  $SWE_{ela}$ , 0.914). B-mode +  $SWE_{col}$  and B-mode +  $SWE_{ela}$  showed a higher AUC than B-mode alone ( $P = 0.026$  and  $0.029$ ), and B-mode +  $SE_{Tsu}$  and B-mode +  $SE_{FLR}$  showed comparable AUC to B-mode alone ( $P = 0.196$  and  $0.085$ ). There was no significant difference between qualitative and quantitative assessments for the combined sets of B-mode and elastography ( $P > 0.05$ ).

**Conclusion** The addition of both SE and SWE to B-mode ultrasound improved the diagnostic performance with increased AUC, and especially SWE was more useful than SE, and no significant difference was found between qualitative and quantitative assessments.

**Keywords** Breast imaging · Ultrasound · Elastography · Strain elastography · Shear wave elastography

## Introduction

Breast cancer is the most common cancer and second leading cause of cancer-related deaths in women [1]. When an abnormality is found by the other imaging modalities or clinical examination, ultrasound is used to detect and characterize the lesion [2]. The ultrasound guidance intervention

procedure has recently increased, and ultrasound is the main biopsy guidance technology currently used in many breast imaging centers [3].

The breast imaging reporting and data system (BI-RADS) lexicon was developed by the American College of Radiology [4], which is used to standardize the description of breast imaging terminology, predict malignancy of lesions, allow automated data collection, and promote communication with physicians and radiologists throughout facilities [5]. However, morphologic features overlap between benign and malignant lesions, and the radiologists subjectively decide the final BI-RADS assessment. Therefore, potential interobserver variability is unavoidable [6].

It is known that cancer tissue is hard, and the possibility of tumor malignancy can be estimated by evaluating tissue elasticity. Ultrasonic elastography is an imaging method

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that measures tissue elasticity based on the “displacement inside the tissue by external force” or “velocity of elastic wave.” Strain elastography (SE) and shear wave elastography (SWE) are the two main methods to measure mammary elasticity in the ultrasound [7]. Many reports have shown that combining one of these two with the conventional B-mode ultrasound improves the diagnostic performance of distinguishing between benign and malignant breast masses [8–19]. However, direct comparison between both types of elastography in the same population is rare [16–19]. Especially, studies that simultaneously performed both SE and SWE using one ultrasound system are rare [18]. In addition, although some qualitative and quantitative evaluation methods for ultrasonic elastography already existed, comparison between them has not been sufficiently done.

Therefore, this study aimed to simultaneously compare the diagnostic values of two types of breast ultrasound elastography added to the conventional B-mode ultrasonography in differentiating between benign and malignant breast masses by qualitative and quantitative assessments using one ultrasound system.

## Materials and methods

### Patients

This retrospective study was approved by the medical ethics committee of our institution, which waived the requirement for written informed consent.

The inclusion criteria of enrolling patients in this study were as follows: (a) those who had breast masses and underwent each of the B-mode ultrasound, SE, and SWE at our Medical Hospital (Tokyo, Japan), from March 2016 to June 2017; (b) those whose masses were diagnosed as benign or malignant by pathology or > 1-year follow-up. The following patients were excluded: (a) those who were treated with hormonal therapy, chemotherapy, or radiation therapy and (b) those whose masses with > 50% necrosis or cystic component for the reason these therapy and abundant necrosis or cystic components may affect the elasticity of the tumor. The percentage of necrosis or cystic component was visually measured. A medical student (A.K.) selected breast masses categorized as BI-RADS  $\geq 3$  for this study, after reviewing the radiology report database and clinical records at our institute. In case of bilateral lesions, both sides were targeted, whereas, in multiple lesions, a maximum of two lesions with the highest BI-RADS category were evaluated.

### Diagnosis

Lesions were cytologically or histologically diagnosed as malignant or benign through biopsy or surgical resection.

However, the mass without interval changes for > 1-year observation was clinically diagnosed as benign.

## Ultrasound examinations

Ultrasound examinations were performed by one of three radiologists with 5–20-year experiences in breast ultrasound using only one ultrasound system, the Aplio 500 scanner (Toshiba Medical Systems Corp, Tochigi, Japan) with an 8.0-MHz linear probe (PLT-805AT). First, the radiologist performed a B-mode examination and then simultaneously performed SE and SWE examinations without changing the patient’s position.

### B-mode examination

The radiologists obtained transverse and longitudinal static images and measured the maximum diameter of the masses by B-mode. The investigator was aware of the clinical and mammographic findings at the time of ultrasound examination.

### SE examination

SE images were generated by the transducer under vertical light manual compression of 1–2 cycle/s. A rectangular region of interest (ROI) was concentrated on the target and fixed to include the superficial portion of the pectoralis muscle layer to the subcutaneous fat layer. After the pressure and speed coordination of the handheld compression to reveal the subcutaneous fat as a mixture of red and green area, a representative SE image was obtained. Two additional 2-mm circle ROIs were placed at the highest stiffness part of the target mass and subcutaneous fat. The ratio of strain in fat tissue and target lesion [Fat–Lesion Ratio ( $SE_{FLR}$ )] within ROIs was automatically calculated. In this study, we applied  $SE_{FLR}$  as a quantitative assessment.

### SWE examination

SWE images were generated with minimal pressure from the transducer. After a few seconds of fixation to stabilize the SWE image, the image was frozen and stored. SWE images were displayed as a color map, ranging from dark blue to red (0–180 kPa). An additional 2-mm circle ROI was positioned at the visually stiffest part of the target mass. The mean elasticity value ( $SWE_{cla}$ ) within the ROI was automatically calculated.

### Image analysis

Image findings of B-mode, SE and SWE examination were retrospectively evaluated through a consensus reading by a

medical student (A.K.) and a breast radiologist (T.F. with 8 years of experience in breast imaging) without knowing the benign and malignant results. Sequential readings of the three procedures were performed using three data sets, i.e., B-mode, SE, and SWE. We left more than 2 weeks between reading sessions. For B-mode ultrasound images, the masses were classified as category 3, 4a, 4b, 4c, or 5 based on BI-RADS 5th edition [4]. For SE, the mass was visually classified into score 1, 2, 3, 4, or 5 by Tsukuba Score ( $SE_{Tsu}$ ) [9]. The readers also selected  $SE_{FLR}$  of the mass. For SWE images, the mass was evaluated by five-point color assessment ( $SWE_{col}$ ): dark blue as score 1, light blue as score 2, green as score 3, orange score 4, and red as score 5. The score was taken at the visually highest stiffness part of the mass. The readers also chose  $SWE_{ela}$  of the mass.

In this study, an evaluation method was devised, combining the B-mode BI-RADS category with each elastography image in Table 1. Using this method, if the mass was downgraded or upgraded, then the masses were reclassified into a new category.

**Table 1** Evaluation method combining B-mode BI-RADS category with elastography images

B-mode BI-RADS category	Elastography images	Modified category
3	$SE_{Tsu} \geq \text{Score}4$	4a
3	$SE_{FLR} \geq 3.0$	4a
3	$SWE_{col} \geq \text{Score}4$	4a
3	$SWE_{ela} \geq 100 \text{ kPa}$	4a
4a	$SE_{Tsu} \leq \text{Score}2$	3
4a	$SE_{FLR} \leq 2.0$	3
4a	$SWE_{col} \leq \text{Score}2$	3
4a	$SWE_{ela} \leq 50 \text{ kPa}$	3

BI-RADS breast imaging reporting and data system,  $SE_{Tsu}$  Tsukuba score,  $SE_{FLR}$  fat-lesion ratio,  $SWE_{col}$  color assessment,  $SWE_{ela}$  elasticity value

**Table 2** Patient’s age, size with ultrasound, Fat-Lesion Ratio, and elasticity value

	Malignant ( $n=88$ ) range Mean $\pm$ SD	Benign ( $n=60$ ) range Mean $\pm$ SD	Total ( $n=148$ ) range Mean $\pm$ SD	P value
Age (years)	29–85 58.4 $\pm$ 12.7	25–74 47.5 $\pm$ 12.1	25–85 54.0 $\pm$ 13.6	<0.001
Size with ultrasound (mm)	6–46 17.0 $\pm$ 8.2	5–56 16.4 $\pm$ 12.2	5–56 16.7 $\pm$ 10.0	0.732
$SE_{FLR}$	0.51–81.29 8.8 $\pm$ 13.8	0.15–8.38 1.7 $\pm$ 1.5	0.15–81.29 5.9 $\pm$ 11.2	<0.001
$SWE_{ela}$ (kPa)	4.10–168.90 105.7 $\pm$ 39.3	5.20–170.00 41.7 $\pm$ 39.3	4.10–170.00 79.7 $\pm$ 50.3	<0.001

SD standard deviation,  $SE_{FLR}$  fat-lesion ratio,  $SWE_{ela}$  elasticity value

### Statistical analysis

Each analysis in this study was demonstrated using the EZR software package version 1.31 (Saitama Medical Center, Jichi Medical University, Saitama, Japan) [20] and the Visualizing Categorical Data package version 1.4-4 with graphical user interface for R software package (version 3.5.1; R Development Core Team, Vienna, Austria). For each evaluation method, sensitivity, specificity, and accuracy of differentiating benign masses from malignant masses were analyzed. Receiver-operating characteristic analyses were performed to calculate the area under the receiver-operating characteristic curve (AUC) for performance. Data are presented as mean  $\pm$  standard deviation. Student’s *t* test was performed if characteristics were quantitative. Furthermore, we considered  $P < 0.05$  as statistically significant.

### Results

#### Clinicopathological characteristics of patients

A total of 153 consecutive masses in 148 patients were identified. Among them, five were excluded because of poor image quality. Thus, 148 masses (60 benign and 88 malignant) were finally identified in 143 patients in this study. Malignant lesions comprised ductal carcinoma in situ ( $n=9$ ), invasive ductal carcinomas ( $n=60$ ), mucinous carcinoma ( $n=5$ ), invasive lobular carcinoma ( $n=9$ ), apocrine carcinoma ( $n=3$ ), and metaplastic carcinoma ( $n=2$ ). Benign lesions comprised fibroadenoma ( $n=26$ ), papilloma ( $n=8$ ), mastopathy ( $n=7$ ), abscess ( $n=4$ ), hamartoma ( $n=2$ ), adenoma ( $n=2$ ), fibrosis ( $n=2$ ), and pseudoangiomatous stromal hyperplasia ( $n=1$ ). Eight masses were clinically diagnosed as benign after > 1 year observation.

Table 2 shows patient’s age, mass size with ultrasound, and  $SE_{FLR}$  and  $SWE_{ela}$  of the masses.  $SE_{FLR}$  and  $SWE_{ela}$  of the masses are significantly larger than benign masses, and patients with malignant masses are significantly older than those with benign masses.

## Diagnostic performance of B-mode and elastography

Table 3 summarizes the BI-RADS categories,  $SE_{Tsu}$ , and  $SWE_{col}$  of the masses. Table 4 shows the diagnostic performance of B-mode and each elastographic image. Sensitivity, specificity, accuracy, and AUC were 97.7%, 35.0%, 72.3%, and 0.889 by B-mode (cut-off value, Category  $\geq 4a$ ); 96.6%, 40.0%, 73.6%, and 0.885 by  $SE_{Tsu}$  (cut-off value, Score  $\geq 2$ ); 90.9%, 53.3%, 75.7%, and 0.875 by  $SE_{FLR}$  (cut-off value,  $\geq 1.5$ ), 94.3%, 55.0%, 78.4%, and 0.881 by  $SWE_{col}$  (cut-off

value, Score  $\geq 2$ ); and 90.9%, 66.7%, 81.1%, and 0.885 by  $SWE_{ela}$  (cut-off value,  $\geq 50$  kPa), respectively. No significant differences were observed between B-mode and each elastographic image.

## Diagnostic performance of combined sets of B-mode and elastography

Table 3 also summarizes the modified category combined sets of B-mode and elastography of the masses. Table 4 also shows the diagnostic performance of combined sets

**Table 3** BI-RADS categories, Tsukuba score, and color assessment

B-mode			Elastography images					
BI-RADS			$SE_{Tsu}$			$SWE_{col}$		
Category	Malignant (n = 88)	Benign (n = 60)	Score	Malignant (n = 88)	Benign (n = 60)	Score	Malignant (n = 88)	Benign (n = 60)
3	2	21	1	3	24	1	5	33
4a	13	30	2	14	29	2	3	12
4b	17	5	3	9	2	3	6	5
4c	33	4	4	44	5	4	10	4
5	23	0	5	18	0	5	64	6

Modified category combined B-mode and elastography								
Modified category	B-mode + $SE_{Tsu}$		B-mode + $SE_{FLR}$		B-mode + $SWE_{col}$		B-mode + $SWE_{ela}$	
	Malignant (n = 88)	Benign (n = 60)						
3	7	48	4	42	2	42	3	42
4a	8	3	11	9	13	9	12	9
4b	17	5	17	5	17	5	17	5
4c	33	4	33	4	33	4	33	4
5	23	0	23	0	23	0	23	0

BI-RADS breast imaging reporting and data system,  $SE_{Tsu}$  Tsukuba score,  $SE_{FLR}$  fat-lesion ratio,  $SWE_{col}$  color assessment,  $SWE_{ela}$  elasticity value

**Table 4** Diagnostic performance of B-mode, elastography, and combined sets

	Sensitivity (%)	Specificity (%)	Accuracy (%)	Cut-off value	AUC [95% CI]	<i>P</i> value vs B-mode
B-mode	97.7	35.0	72.3	$\geq$ Category 4a	0.889 [0.839–0.939]	
$SE_{Tsu}$	96.6	40.0	73.6	$\geq$ Score 2	0.885 [0.833–0.936]	0.874
$SE_{FLR}$	90.9	53.3	75.7	$\geq 1.5$	0.875 [0.817–0.932]	0.647
$SWE_{col}$	94.3	55.0	78.4	$\geq$ Score 2	0.881 [0.824–0.938]	0.813
$SWE_{ela}$	90.9	66.7	81.1	$\geq 50.0$ kPa	0.885 [0.786–0.924]	0.353
B-mode + $SE_{Tsu}$	92.0	80.0	87.2	$\geq$ Category 4a	0.903 [0.855–0.951]	0.196
B-mode + $SE_{FLR}$	95.5	70.0	85.1	$\geq$ Category 4a	0.909 [0.862–0.956]	0.085
B-mode + $SWE_{col}$	97.7	70.0	86.5	$\geq$ Category 4a	0.919 [0.874–0.963]	0.026
B-mode + $SWE_{ela}$	96.6	70.0	85.8	$\geq$ Category 4a	0.914 [0.868–0.959]	0.029

Statistically significant *P* values ( $P < 0.05$ ) are in italics

AUC area under the receiver-operating characteristic curve, CI confidence interval,  $SE_{Tsu}$  Tsukuba score,  $SE_{FLR}$  fat-lesion ratio,  $SWE_{col}$  color assessment,  $SWE_{ela}$  elasticity value

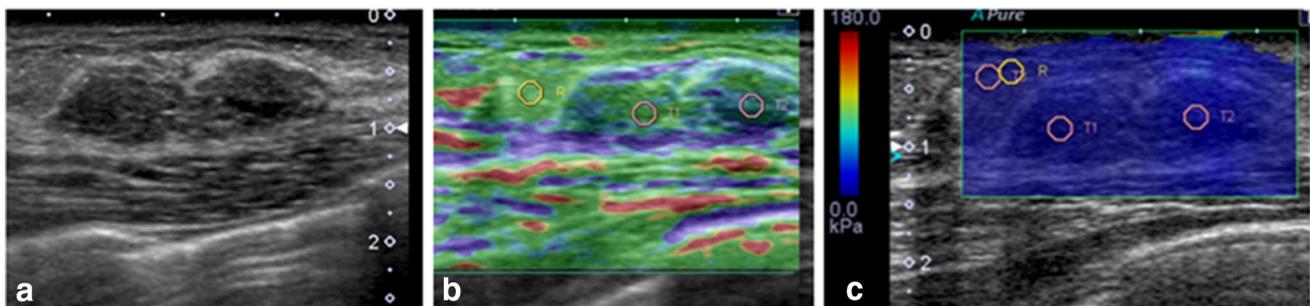
of B-mode and elastography. Sensitivity, specificity, accuracy, and AUC were 92.0%, 80.0%, 87.2%, and 0.903 by B-mode +  $SE_{Tsu}$  (cut-off value, Category  $\geq 4a$ ); 95.5%, 70.0%, 85.1%, and 0.909 by B-mode +  $SE_{FLR}$  (cut-off value, Category  $\geq 4a$ ); 97.7%, 70.0%, 86.5%, and 0.919 by B-mode +  $SE_{col}$  (cut-off value, Category  $\geq 4a$ ); and 96.6%, 70.0%, 85.8%, and 0.914 by B-mode +  $SWE_{ela}$  (cut-off value, Category  $\geq 4a$ ). Addition of either elastography to B-mode ultrasound tends to increase the specificity and AUC. B-mode +  $SWE_{col}$  and B-mode +  $SWE_{ela}$  showed a higher AUC than B-mode ultrasound alone ( $P=0.026$  and  $0.029$ ), and B-mode +  $SE_{Tsu}$  and B-mode +  $SE_{FLR}$  showed comparable AUCs to B-mode ultrasound alone ( $P=0.196$  and  $0.085$ ). There was no statistically significant difference between B-mode +  $SE_{Tsu}$  and B-mode +  $SE_{FLR}$  ( $P=0.930$ ), and between B-mode +  $SWE_{col}$  and B-mode +  $SWE_{ela}$  ( $P=0.914$ ).

The positive predictive value in category 4a increased from 32.5% for B-mode ultrasound alone to 72.7, 55.0, 59.1, and 57.1% for combined sets of  $SE_{Tsu}$ ,  $SE_{FLR}$ ,  $SWE_{col}$ , and  $SWE_{ela}$ , respectively. Figure 1 summarizes the representative case in this study.

Table 5 shows nine cases of false-negative malignancies in size, BI-RADS category in B-mode, modified category of B-mode combined with elastography, histological type, nuclear grade, estrogen receptor (ER), and human epidermal growth factor receptor 2 (HER2).

## Discussion

Cancerous tissues become harder as the blood vessel and cell density increases, and stiffness is associated with tumor progression [21]. Elastography is a noninvasive



**Fig. 1** Images of fibroadenoma in a 35-year-old woman. **a** B-mode ultrasound showed a 22-mm oval lobulated hypo-echoic mass categorized as breast imaging and reporting data system (BI-RADS) category 4a. **b** Strain elastography (SE) showed the entire lesion corresponding to B-mode ultrasound as green, indicating a soft lesion with a Tsukuba score of 1 and a Fat-Lesion Ratio of 1.30. **c** Shear

wave elastography (SWE) showed the mass and surrounding tissue as very homogeneous and dark blue, indicating a soft lesion with a color assessment score of 1 and a mean elasticity value of 28.2 kPa. With combined sets of B-mode and elastographic images, category 4a lesion was upgraded to category 3 by both SE and SWE and by qualitative and quantitative assessments

**Table 5** False-negative cases of combined sets of B-mode and elastography

No	B-mode ultrasound		Combined Sets of B-mode and elastography				Pathology			
	Size (mm)	BI-RADS Category	+ $SE_{Tsu}$	+ $SE_{FLR}$	+ $SWE_{col}$	+ $SWE_{ela}$	Histological type	NG	ER	HER2
1	23	4a	3	4a	4a	4a	MBC	1	Positive	Negative
2	14	4a	3	4a	4a	4a	MBC	1	Positive	Negative
3	20	4a	3	4a	4a	4a	DCIS	1	Positive	Negative
4	7	3	3	3	4a	3	IDC	1	Positive	Negative
5	7	4a	4a	3	3	3	MBC	1	Positive	Negative
6	16	4a	3	3	4a	4a	IDC	1	Positive	Negative
7	8	4a	3	3	4a	4a	IDC	1	Positive	Negative
8	15	3	3	4a	4a	4a	IDC	1	Positive	Negative
9	15	4a	4a	4a	3	3	DCIS	2	Positive	Negative

BI-RADS breast imaging reporting and data system,  $SE_{Tsu}$  Tsukuba score,  $SE_{FLR}$  fat-lesion ratio,  $SWE_{col}$  color assessment,  $SWE_{ela}$  elasticity value, MBC mucinous breast carcinoma, DCIS ductal carcinoma in situ, IDC invasive ductal carcinoma, NG nuclear grade, ER estrogen receptor, HER2 human epidermal growth factor receptor 2

technique to measure tissue hardness and is used to distinguish between benign and malignant breast masses [8–19].

In this study, the added diagnostic values of two breast ultrasound elastography to the conventional B-mode ultrasound were simultaneously evaluated to differentiate between benign and malignant breast masses by qualitative and quantitative assessments using one ultrasound system. The addition of SE or SWE to the B-mode improved the diagnostic performance with increased specificity and AUC, and SWE was especially more useful than SE; however, no significant difference was found between qualitative and quantitative assessments.

Several reports have shown that combining elastography technique with the conventional B-mode ultrasound improves the diagnostic performance in distinguishing between benign and malignant breast masses. Studies that directly compare SE with SWE in the same patients were limited [16–19]. Chang et al. compared the elasticity score on SE using EUB-8500 (Hitachi Aloka, Tokyo, Japan) and mean elasticity value (kPa) on SWE using Aixplorer (Supersonic Imagine, Aix en Provence, France), in 150 breast lesions [16]. Youk et al. compared the elasticity score and strain ratio on SE using HiVision Ascendus (Hitachi Aloka, Tokyo, Japan) and visual color score, homogeneity of elasticity, maximum and mean elasticity values (kPa), and elasticity ratio on SWE using Aixplorer in 79 breast lesions [17]. Kim et al. compared the elasticity score and strain ratio on SE using RS80A (Samsung Medison, Seoul, Korea) and visual color score, maximum elasticity values (kPa), and elasticity ratio on SWE using Aixplorer in 108 breast lesions [19]. These three studies use two ultrasound systems provided by different vendors. They demonstrated the addition of SE or SWE showed similar diagnostic performance in differentiating benign from malignant masses, but no significant difference was observed between qualitative and quantitative assessments.

In this study, only one ultrasound system Aplio 500 was used to simultaneously obtain SE and SWE images. A study used the equipment similar to ours. Seo et al. compared the strain ratio on SE and mean elasticity value (kPa) and elasticity ratio on SWE by quantitative assessment only on 108 breast lesions. They also reported that both elastography and B-mode US improved the diagnostic performance [18]. To the best of our knowledge, this is the first study to evaluate the comparison of SE and SWE to qualitatively and quantitatively assess breast masses using one ultrasound system. In this study, the addition of SE or SWE to B-mode ultrasound improved the diagnostic performance; however, SWE was more useful than SE. This may be because the proportion of malignant masses ( $88/148 = 59.5\%$ ) in our study is higher than that in the previous studies, and elastographic protocols are vendor specific for ultrasound systems. Further studies are needed

to set a unified evaluation method and to achieve a standard cut-off value for elastography systems.

In this study, the positive predictive value of category 4a increased from 32.5% for B-mode ultrasound alone to 72.7, 55.0, 59.1, and 57.1% for combined sets of  $SE_{Tsu}$ ,  $SE_{FLR}$ ,  $SWE_{col}$ , and  $SWE_{ela}$ , respectively. This result suggests that the combined use of elastography may help patients with BI-RADS category 4a mass to avoid unnecessary biopsies.

A total of nine cases had false-negative malignancies on combined sets of B-mode and elastography in this study, including two ductal carcinoma in situ (DCIS), four invasive ductal carcinoma, and three mucinous breast carcinoma (MBC). Regarding the nuclear grade, eight lesions were grade 1 and one was grade 2. Regarding the ER status, all nine lesions were positive. Furthermore, regarding the HER2 status, all nine lesions were negative. Two of the four IDC cases were small lesions of 8 and 7 mm, respectively. The histological type of DCIS, MBC, small size, and low histological grade and subtype of ER-positive have been reported to show low aggressive malignant cancer [22–24]. Malignancies in false-negative cases tended to have low aggressive features; thus, their elastographic images may show low stiffness, resulting in false-negative results. Some reports also demonstrated that tumor stiffness values in ultrasound elastography correlated with aggressive prognostic breast cancer features [25–27]. Chang et al. reported that high stiffness values by SWE correlated with large tumor size, high histological grade, and tumor subtype (triple negative and HER2 positive) in breast cancer [22]. Their findings were consistent with the results in this study. Therefore, low aggressive tumors may be considered to have low stiffness values on ultrasound elastography even if the tumor is malignant.

This study has several limitations. First, this is a retrospective study conducted at a single institution. Therefore, further extensive, multicenter studies are warranted to validate its findings. Second, not all recurrent lesions were diagnosed using cytological or histological diagnosis. Third, SE and SWE were performed after the B-mode ultrasound examination, and the information on the B-mode ultrasound could affect the examiner's performance.

In conclusion, the addition of both SE and SWE to B-mode ultrasound improved the diagnostic performance with increased specificity and AUC in distinguishing benign from malignant breast masses, and especially SWE was more useful than SE; however, no significant difference was observed between qualitative and quantitative assessments. This study suggests that the combined use of elastography may help patients with BI-RADS category 4a mass to avoid unnecessary biopsies.

## Compliance with ethical standards

**Conflict of interest** This manuscript has not been published and is not under consideration for publication elsewhere. All the authors have read the manuscript and have approved this submission. All the authors and their institution have no conflicts of interest.

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