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ORIGINAL ARTICLE – BREAST ONCOLOGY

Shear-Wave Elastography for the Detection of Residual Breast Cancer After Neoadjuvant Chemotherapy

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ABSTRACT

Objective. This study was designed to evaluate the accuracy of shear-wave elastography (SWE) in the detection of residual breast cancer after neoadjuvant chemotherapy (NAC).

Methods. Seventy-one women with stage II-III breast cancers who underwent B-mode ultrasound (US), SWE, and magnetic resonance imaging (MRI) after NAC were included. The presence of residual cancer was determined on B-mode US and MRI, and the maximum elasticity of residual lesions was assessed on SWE. The sensitivity, specificity, accuracy, and area under the receiver operating characteristic curve (AUC) of B-mode US, SWE, and MRI were compared.

Results. Sixty-one of 71 women (86 %) had residual cancer and showed higher maximum elasticity values (mean 116.0 ± 74.1 kPa) than those without residual cancer (26.4 ± 21.0 kPa; $p < 0.001$). B-mode US showed 72.1 % (44/61) sensitivity, 50.0 % (5/10) specificity, and 69.0 % (49/71) accuracy. The sensitivity, specificity, and accuracy of SWE were 83.6 % (51/61), 80.0 % (8/10), and 83.1 % (59/71) when a maximum elasticity value of >30 kPa was considered to indicate the presence of residual cancer. The combined AUC of B-mode US and SWE (0.877) was significantly higher than that of B-mode US (0.702) ($p = 0.014$) and comparable to that of MRI (0.939) ($p = 0.147$).

Conclusions. SWE allowed relatively accurate assessment for the presence of residual lesion after NAC and improved the diagnostic performance of B-mode US.

Neoadjuvant chemotherapy (NAC) has been established as the standard treatment option in patients with locally advanced breast cancer as it can render inoperable tumors resectable and increase the rate of breast-conserving therapy in operable cases.[1–4] It has been shown that patients who achieve pathological complete response, defined as the lack of microscopic evidence of residual viable tumor cells after NAC, have longer disease-free and overall survival compared with nonresponders.[5–8] Therefore, accurate preoperative imaging evaluation of the residual tumor extent following NAC can provide important information necessary for the selection of the most appropriate surgical planning and in the prediction of patient's prognosis. Until now, dynamic contrast-enhanced magnetic resonance imaging (MRI) is known to enable the most accurate assessment of tumor response after NAC.[9–14] However, MRI is limited, because it is not amenable to all patients due to cost, the need for IV contrast injection, and other contraindications, including renal insufficiency, claustrophobia, and presence of a ferromagnetic metal in proximity to a vital structure.

Shear-wave elastography (SWE) is an imaging technique that can visualize and quantify tissue stiffness in vivo. High mean stiffness values of breast cancers were reported to be significantly correlated with large tumor size, lymph node involvement, high histologic grade, and

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aggressive subtypes.[15–17] SWE can play a complementary role to conventional B-mode ultrasound (US) in identifying high-grade, aggressive invasive breast cancers, which can appear as oval circumscribed masses without suspicious features on B-mode US but stiff on elastography.[18] In addition, baseline stiffness measurements of breast cancers assessed on US elastography have been correlated with the subsequent response to NAC in previous studies.[19,20] However, as of yet, to our knowledge, there have been no studies evaluating the value of US elastography for the evaluation of residual breast cancers after NAC nor its additional diagnostic value when used in combination with conventional B-mode US.

Therefore, the purpose of our study was to evaluate the accuracy of SWE in detecting residual breast cancer after NAC and to determine whether the addition of SWE can improve the diagnostic performance of conventional B-mode US.

MATERIALS AND METHODS

Patients and Lesions

This retrospective study was approved by our institutional review board and the requirement for written, informed consent was waived. A search of our database between January 2012 and February 2013 revealed a total of 104 women with stage II or III breast cancers who underwent preoperative B-mode US, MRI, and SWE after completion of NAC. Twenty-four patients with multifocal diffuse cancers were excluded due to the difficulty in correlating US and pathologic results. Nine patients with a residual lesion size of larger than 4 cm were excluded as those lesions were not able to be fully included in the maximum range of the SWE color overlay. Finally, 71 women (mean age 45 years; age range 25–67 years) with 71 lesions constituted our study population. All patients underwent either breast US or MRI in our hospital prior to NAC according to surgeon's decision. Initial mammographic findings of 71 lesions were mass or asymmetry ($n = 41$), mass or asymmetry with microcalcification ($n = 21$), microcalcification only ($n = 6$), and occult ($n = 3$). All available demographic and clinical information of the study population are summarized in Table E1 (online).

Preoperative Imaging Techniques

US Examinations US images were obtained using the Aixplorer system (SuperSonic Imagine, Aix en Provence, France) equipped with a 4–15 MHz linear-array transducer 1 day prior to surgery by one of five breast radiologists with knowledge of the clinical and mammographic findings. At least two orthogonal images were obtained for residual lesions depicted on B-mode US and the maximum diameter of residual lesions was measured.

SWE images were acquired at a plane showing the largest diameter of the residual lesion. Customized presets of SWE parameters were used and a color-coded map of tissue elasticity representing the elastic modulus in kilopascals (kPa) at each pixel was obtained with a default color scale ranging from just over 0 (dark blue; soft) to +180 kPa (red; stiff). Quantitative elasticity values were measured using a 2-mm-sized circular quantification region of interest (Q-box^{TM}) placed at the stiffest portion of the mass or immediately adjacent tissue. The data acquisition procedure took approximately 2–3 min per case.

Breast MRI

All patients underwent preoperative breast MRI using a 1.5-T scanner (Signa; GE Medical Systems, Milwaukee, WI) and a dedicated breast coil in the prone position. MRI was performed mean 9 (range 1–29) days before surgery. After obtaining a bilateral transverse localizer image, fat-suppressed, T2-weighted, fast spin-echo sagittal images were obtained (repetition time [TR]/echo time [TE], 5500-7150/85.2; image matrix, 256 × 160; field of view, 200 × 200 mm^2; and section thickness/gap, 1.5/0 mm). A three-dimensional, T1-weighted, fast spoiled, gradient-echo sequence also was performed with bilateral sagittal imaging, for one precontrast and five postcontrast dynamic series after 91, 180, 360, 449, and 598 s (TR/TE, 6.5/2.5; flip angle, 10°; image matrix, 256 × 160; field of view, 200 × 200 mm^2; and section thickness/gap, 1.5/0 mm). The acquisition time of each postcontrast series was 76 s. In all patients, gadobutrol (Gadovist; Bayer Schering Pharma, Berlin, Germany) was injected into an antecubital vein using an automated injector (Spectris Solaris; Medrad Europe, Maastricht, Netherlands) at a dose of 0.1 mmol/kg, at a rate of 2 mL/s, followed by a 20-mL saline flush.

Residual Lesion Evaluation on Preoperative Imaging

B-mode US and MRI Preoperative B-mode US and MR images were retrospectively evaluated by two different pairs of radiologists (7 and 11 years of experience and 7 and 9 years of experience in breast imaging, respectively) in consensus blinded to the histopathologic, clinical, and mammographic findings. B-mode US or MR images of the initial tumor prior to chemotherapy were provided to the readers when evaluating the residual lesions. Residual lesion size was measured on preoperative B-mode US and MRI, respectively. In addition, residual lesions were classified into three categories according to the probability of residual cancer presence by using morphologic changes.

On B-mode US, category 1 was defined as having low probability (<10 %) of residual cancer and having post-treatment fibrotic change, with overall decrease in the tumor size and iso- to hyperechoic residual lesions parallel to the chest wall. When there are irregular hypoechoic masses with nonparallel orientation regardless of any size change, we used category 2 or 3 according to the residual cancer probability. Category 2 was used to indicate intermediate probability (10–95 %) of residual cancer and category 3, high probability (≥95 %) of residual cancer.

On MRI, category 1 was defined as having low probability (<10 %) of residual cancer, with decreased lesion size and no residual contrast enhancement. Residual irregular enhancing masses or nonmass enhancements with segmental distribution were considered as category 2 or 3. Also, category 2 was used to indicative of intermediate probability (10-95 %) of residual cancer and category 3, high probability (≥95 %) of residual cancer.

Shear-Wave Elastography

Representative SWE images of residual lesions were reviewed by two radiologists with 5 and 7 years of experience in breast imaging in consensus blinded to the histopathologic, clinical, and mammographic findings. B-mode US images were assessed as shown below. Maximum stiffness of residual lesions was quantitatively measured in kilopascal units (E_{max}) and visually assessed according to the stiffest colors of the lesion (E_{col}): dark blue (very soft), light blue (soft), green to yellow (intermediate), and orange to red (hard).[20,21]

Histopathologic Evaluation

Histopathologic evaluation was performed by one pathologist with 20 years of experience in breast pathology. Surgical specimens were sliced into 5-mm-thick sections that were formalin-fixed, paraffin-embedded, and stained with hematoxylin–eosin for microscopic evaluation. Pathologic complete response (pCR) was defined as the absence of residual invasive cancer and ductal carcinoma in situ.[5] In cases of non-pCR, the largest histopathologic diameters of residual tumors were measured.

Data Analysis

SWE features and categories of residual lesions on B-mode US and MRI were compared between the pCR and non-pCR groups using Fisher's exact test and independent samples *t* test, respectively. Sensitivity, specificity, and accuracy of preoperative imaging modalities for the detection of residual breast cancers were calculated using various cutoff points and compared using the McNemar test. Receiver operating characteristic (ROC) curves for the B-mode US, SWE, and MRI were analyzed to evaluate the overall diagnostic performance for detecting residual breast cancer. Logistic regression model was used to evaluate the combined diagnostic performance when SWE was added to B-mode US. The area under the curve (AUC) was calculated and compared between the modalities. Pearson correlation analysis was used to compare the image-measured and pathologic tumor sizes.

Two-tailed p values <0.05 were considered to indicate a statistically significant difference. All statistical analyses were performed using commercially available software (SAS system for Windows, version 9.2; SAS Institute, Cary, NC).

RESULTS

Quantitative and Qualitative Imaging Features of Residual Lesions

Of the 71 women, 10 (14 %) achieved pCR and 61 (86 %) had residual cancers (non-pCR group). Thirteen patients underwent mastectomy (13/71, 18 %), and the others underwent breast-conserving surgery. Two of 71 underwent reexcision due to involvement of resection margin by invasive cancer. The residual cancers were composed of invasive cancers with or without ductal carcinoma in situ (DCIS) in 56 women and DCIS only in 5 women. The mean size of residual tumors was 2.5 ± 1.4 cm (median 2.4 cm; range 0.5–7.7 cm) on histopathologic examination. The size and categories of residual lesions on B-mode US and MRI for both pCR and non-pCR groups are listed in Table 1. There were significant differences in mean lesion size between pCR and non-pCR group on both B-mode US ($p = 0.006$) and MRI ($p < 0.001$). In addition, the distribution of our categorization according to size and imaging characteristics also showed significant differences between pCR and non-pCR groups on both B-mode US ($p = 0.032$) and MRI ($p < 0.001$).

On SWE, women with residual cancers showed significantly higher E_{max} (mean 116.0 ± 74.1 kPa; median 106.2 kPa; range 10.2–300 kPa) than women who achieved pCR (mean 26.4 ± 21.0 kPa; median 19.9 kPa; range 7.8–73.8 kPa; $p < 0.001$). In addition, E_{max} value showed a significant correlation with residual tumor size on histopathologic examination (correlation coefficient = 0.455, $p < 0.001$), i.e., women with larger residual tumor size showed significantly higher E_{max} values. On visual assessment, most women (90 %, 9/10) with pCR showed soft colors (E_{col} of dark blue in 80 % [8/10] and light blue in 10 % [1/10]). None of pCR group showed hard colors,

TABLE 1 Quantitative and qualitative imaging features of residual lesions after neoadjuvant chemotherapy in 71 breast cancer patients according to histopathologic groups

	Non-pCR group ($N = 61$)	pCR group ($N = 10$)	p value
B-mode US			
Size of residual lesion (cm)[a]	1.9 ± 0.8	1.2 ± 0.5	0.006
Category of residual lesion			0.032
Category 1	17 (28 %)	5 (50 %)	
Category 2	13 (21 %)	4 (40 %)	
Category 3	31 (51 %)	1 (10 %)	
SWE (E_{max}) (kPa)[a]	116.0 ± 74.1	26.4 ± 21.0	<0.001
≤30	10 (16.4 %)	8 (80 %)	
>30 to ≤80	12 (19.7 %)	2 (20 %)	
>80 to ≤140	18 (29.5 %)	0 (0 %)	
>140 to ≤180	6 (9.8 %)	0 (0 %)	
>180	15 (24.6 %)	0 (0 %)	
SWE (E_{col})			<0.001
Dark blue (very soft)	11 (18.0 %)	8 (80 %)	
Light blue (soft)	10 (16.4 %)	1 (10 %)	
Green to yellow (intermediate)	10 (16.4 %)	1 (10 %)	
Orange to red (hard)	30 (49.2 %)	0 (0 %)	
MRI			
Size of residual lesion (cm)[a]	2.3 ± 1.2	0.6 ± 0.6	<0.001
Category of residual lesion			<0.001
Category 1	5 (8.2 %)	9 (90 %)	
Category 2	20 (32.8 %)	1 (10 %)	
Category 3	36 (59.0 %)	0 (0 %)	

Residual lesions were classified into three categories on B-mode US and MRI: category 1 (low probability of residual cancer), category 2 (intermediate probability of residual cancer), and category 3 (high probability of residual cancer)

SWE shear-wave elastography, E_{max} maximum stiffness value, E_{col} maximum stiffness color

[a] Data are mean ± standard deviations. Otherwise, data are numbers of women with percentages in parentheses

whereas 49.2 % (30/61) of non-pCR group showed hard colors ($p = 0.001$; Table 1). E_{max} of residual lesions after NAC according to other clinical factors are summarized in Table E1 (online). Women with clinical complete response (CR) showed significantly lower E_{max} of residual lesions than those with partial response (PR) or stable disease (SD) ($p = 0.005$). E_{max} of residual lesions was not different according to the patient's age, breast density, initial clinical stage of breast cancers, or molecular subtype. Women with clinical complete response (CR) show E_{max} of residual lesions was lower in women who underwent breast-conserving surgery than those received mastectomy without statistically significant difference ($p = 0.112$).

Sensitivity, Specificity, and Accuracy of B-mode US, SWE, and MRI

The sensitivity, specificity, and accuracy of preoperative imaging modalities for the detection of residual breast cancers using various cutoff points are shown in Table 2. B-mode US showed 72.1 % (44/61) sensitivity, 50.0 % (5/10) specificity, and 69.0 % (49/71) accuracy when a cutoff point of >category 1 was used for indicating present residual cancer. For SWE, the optimal cutoff point yielding the highest diagnostic accuracy was >30 kPa for E_{max} and >dark blue for E_{col}, respectively. SWE showed higher sensitivity with statistically significant difference (83.6 % [51/61], $p = 0.016$ for E_{max}; 82.0 % [50/61], $p = 0.031$ for E_{col}) (Fig. 1) and also showed a tendency for higher specificity (Fig. 2) and accuracy compared with those of B-mode US.MRI showed the highest sensitivity (91.8 % [56/61]), as well as diagnostic accuracy (91.5 % [65/71]) of all preoperative imaging modalities when a cutoff point of >category 1 was used for indicating present residual cancer. However, the differences in sensitivity, specificity, and accuracy between MRI and SWE were not statistically significant ($p > 0.05$).

TABLE 2 Sensitivity, specificity, and accuracy of B-mode US, SWE, and MRI for the detection of residual breast cancers

	Sensitivity	*p* value	Specificity	*p* value	Accuracy	*p* value
B-mode US						
>Category 1[a]	72.1 (44/61)	N/A	50.0 (5/10)	N/A	69.0 (49/71)	N/A
SWE (E_{max}) (kPa)						
>30[a]	83.6 (51/61)	0.016	80.0 (8/10)	0.250	83.1 (59/71)	0.076
>80	63.9 (39/61)	0.437	100 (10/10)	0.032	69.0 (49/71)	0.999
>100	59.0 (36/61)	0.182	100 (10/10)	0.032	64.8 (46/71)	0.721
SWE (E_{col})						
>Dark blue[a]	82.0 (50/61)	0.031	80.0 (8/10)	0.250	81.7 (58/71)	0.118
>Light blue	65.6 (40/61)	0.289	90.0 (9/10)	0.125	69.0 (49/71)	0.999
>Green	49.2 (30/61)	0.001	100 (10/10)	0.063	56.3 (40/71)	0.165
MRI						
>Category 1[a]	91.8 (56/61)	0.004	90.0 (9/10)	0.125	91.5 (65/71)	0.001

All *p* values were calculated in comparison with B-mode US

N/A not applicable

[a] Optimal cutoff points showing the highest diagnostic accuracy for each modality. Residual lesions were classified into three categories on B-mode US and MRI: category 1 (low probability of residual cancer), category 2 (intermediate probability of residual cancer), and category 3 (high probability of residual cancer)

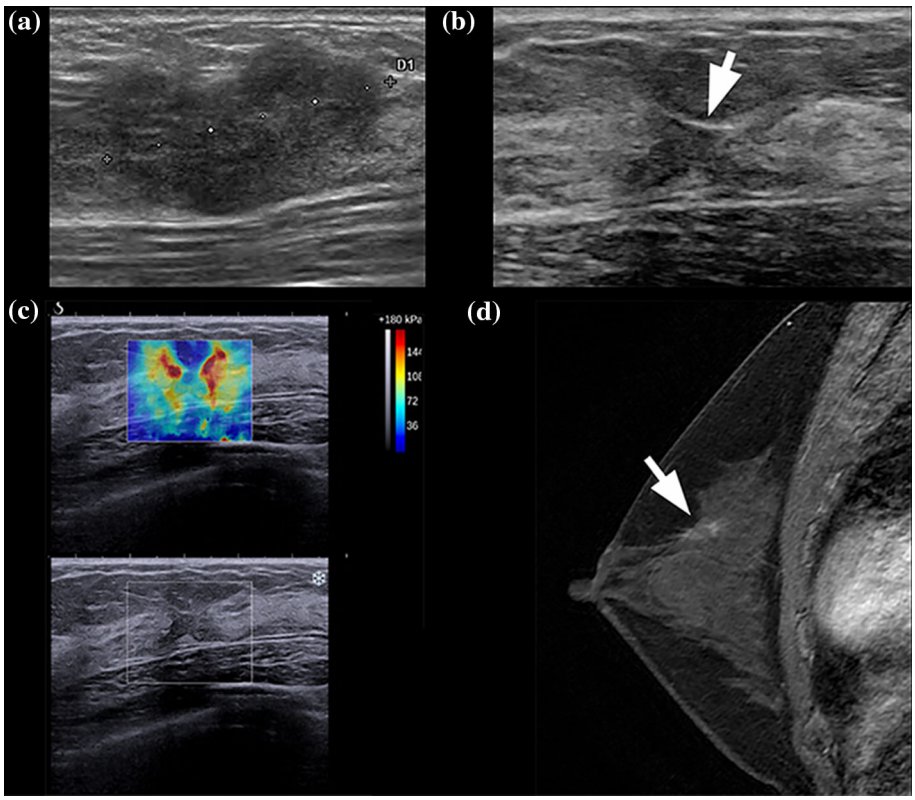

FIG. 1 Conventional B-mode US image of the initial tumor and preoperative images of residual lesion in a 39-year-old woman with an invasive ductal carcinoma (cT2N0) who underwent 8 cycles of NAC. **a** The initial tumor was a 2.7-cm palpable mass in the left breast in the 1 o'clock location. **b** Preoperative B-mode US image shows a 1.5-cm isoechoic lesion with a concave contour (*arrow*). The lesion was considered to indicate a posttreatment fibrotic change and was assigned a category of 1 (low probability of residual cancer). **c** SWE image of the residual lesion shows a high maximum elasticity color of *red* (E_{col} score of 5) and a maximum elasticity value (E_{max}) of 184 kPa, suspicious for residual tumor. **d** Preoperative MRI shows a 1.8-cm irregular enhancing mass (*arrow*) that was assigned a category of 3 (high probability of residual cancer). On histopathologic examination, there was a 0.5-cm invasive cancer associated with a 2.0 cm DCIS

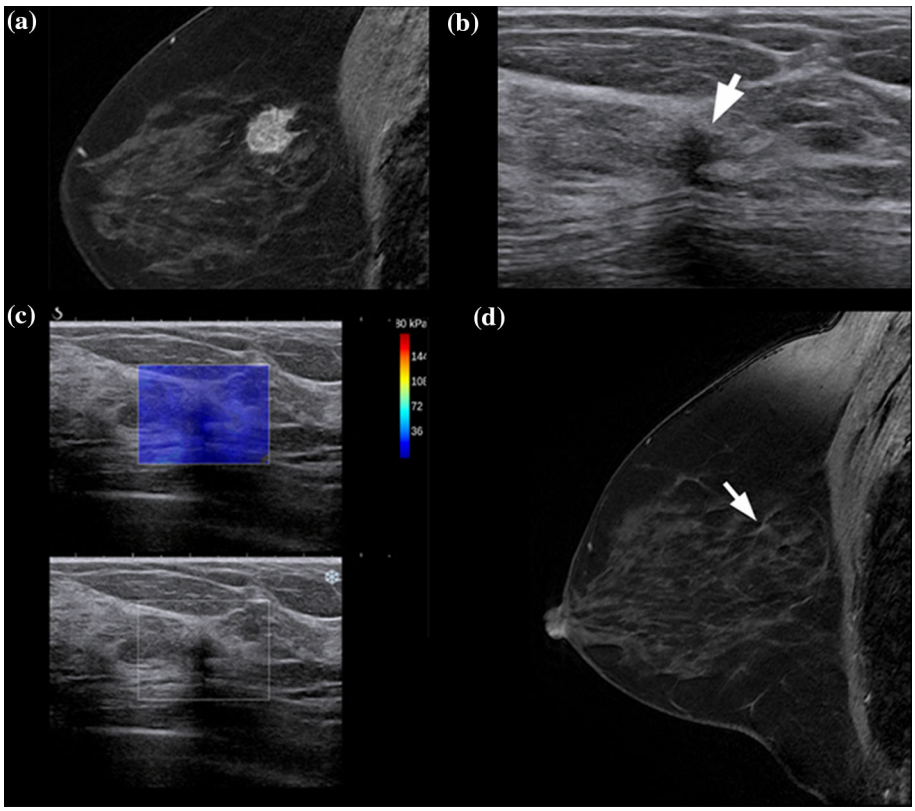

FIG. 2 MR image of the initial tumor and preoperative images of residual lesion in a 50-year-old woman with an invasive ductal carcinoma (cT2N1) who underwent 8 cycles of NAC. **a** The initial tumor was a 2.1-cm mass in the left breast in the 1 o'clock location detected on screening examination. **b** Preoperative B-mode US image shows a 0.7-cm irregular nonparallel hypoechoic mass (*arrow*), which was assigned a category of 2 (intermediate probability of residual cancer) for the presence of residual cancer. **c** SWE image of the residual lesion shows a low maximum elasticity color of *dark blue* (E_{col} score of 1) and a maximum elasticity value (E_{max}) of 16 kPa, suggesting no residual cancer. **d** Preoperative MRI shows no residual enhancement (*arrow*) and was assigned a category of 1 (low probability of residual cancer). On histopathologic examination, there was no residual invasive or noninvasive cancer (pCR)

Combined Diagnostic Performance of B-mode US and SWE in the Detection of Residual Breast Cancer

The AUC of SWE E_{max} was 0.880 (95 % confidence interval [CI] 0.781–0.945) and was higher than that of SWE E_{col} (0.859; 95 % CI 0.756–0.930; $p = 0.380$). The AUC of B-mode US was 0.702 (95 % CI 0.581–0.804) and was significantly lower than SWE (E_{max} or E_{col}, $p < 0.030$). MRI showed the highest AUC value of 0.939 (95 % CI 0.855–0.982) among the three modalities; however, the differences in AUC between MRI and SWE were not statistically significant ($p = 0.305$ for E_{max} vs. MRI and $p = 0.136$ for E_{col} vs. MRI).

When the qualitative SWE feature (E_{col}) was combined with B-mode US by logistic regression model, the AUC increased from 0.702 to 0.847 (95 % CI 0.713–0.981) with marginal statistical significance ($p = 0.086$). The AUC of B-mode US significantly increased from 0.702 to 0.877 (95 % CI 0.787–0.967) by addition of quantitative SWE feature (E_{max}) ($p = 0.014$).The difference in AUC between B-mode US combined with SWE and MRI was not statistically significant ($p = 0.147$; Fig. 3).

Comparison of Residual Tumor Size Measurements by Imaging and Pathology

The mean size of residual tumors was 1.8 ± 0.8 cm (range 0.5–4.0 cm) by B-mode US and 2.0 ± 1.3 cm (range 0–5.4 cm) by MRI. MRI showed better correlation with pathologic residual tumor size than B-mode US ($r = 0.755$ and $r = 0.571$, respectively; Table E2 [online]). B-mode US predicted the residual tumor size more accurately when SWE was combined (i.e., $E_{col} \leq$ dark blue or $E_{max} \leq 30$ kPa was considered to indicate no residual cancer): the correlation coefficients increased from 0.571 to 0.633 and 0.645, respectively.

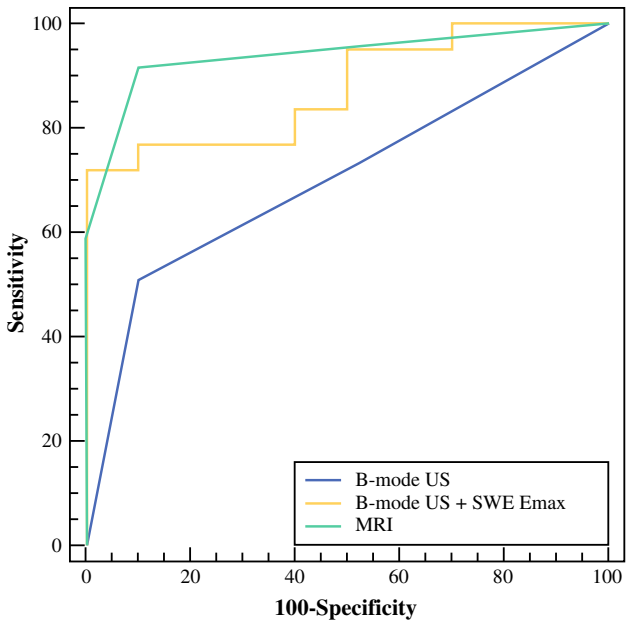

FIG. 3 ROC curves to compare the performance of B-mode US, MRI, and SWE E_{max} feature added to each modality. The AUC of B-mode US significantly increased from 0.702 to 0.877 by addition of SWE ($p = 0.014$). The AUC of MRI (0.939) was higher than B-mode US combined with SWE; however, the difference was not statistically significant ($p = 0.147$)

DISCUSSION

In our study, we found that SWE allowed accurate assessment of residual lesions after NAC. The AUC of SWE was significantly higher than that of B-mode US. MRI showed the highest diagnostic performance among the three preoperative imaging modalities in our study, concordant with the results of previous studies.[21–25] However, the difference between SWE and MRI was not statistically significant. Furthermore, we also found that the diagnostic performance of conventional B-mode US in the detection of residual breast cancers was significantly improved with the addition of SWE.

Previous studies have noted that the accuracy of residual tumor extent measurements following NAC showed only a moderate correlation between pathology and B-mode US.[21,22,24,26,27] Likewise, the diagnostic performance of B-mode US was the lowest in this study. It often is difficult to differentiate post-treatment fibrosis and residual cancer using findings of morphology or size change, particularly on B-mode US compared with MRI which also can evaluate the vascularity of residual lesions. According to our study results, SWE showed the potential to discriminate pCR from residual cancers, and by addition of SWE to B-mode US, the AUC of B-mode US for the detection of residual breast cancers was significantly improved. Lower SWE elasticity values were observed in patients who underwent breast-conserving surgery than those who received mastectomy (96.6 ± 72.2 vs. 133.7 ± 86.8 kPa), albeit without statistical significance ($p = 0.112$) probably due to the small number of our study population. Until now, US elastography has not been indicated for patients who had undergone NAC; however, it may be a useful tool for the evaluation of residual lesions as NAC changes the stiffness of breast cancers by decreasing cancer cellularity and vascularity as well as by inducing fibrotic changes in the tumor stroma.[28–31] To the best of our knowledge, this is the first study to investigate the diagnostic performance of SWE for the detection of residual breast cancers.

As for the optimal cutoff points used for SWE indicating present residual cancer (>30 kPa for E_{max} and >dark blue for E_{col}), a relatively low elasticity value or color was used in our study as we included patients who underwent a NAC regimen of more than 4 cycles in most cases. It is well known that tumors that have responded to treatment are more difficult to palpate owing to the softening of the tumor stroma and that small residual cancers might have lower elasticity values.[31] Therefore, it may be reasonable to have lower criteria of elasticity on SWE for residual lesion evaluation after NAC than in pretreatment breast tumor evaluation in the diagnostic setting.[15,18] E_{max} showed slightly higher accuracy (83.1 % [59/71]) than E_{col} (81.7 % [58/71]) for the detection of residual cancer after neoadjuvant chemotherapy. However, E_{col} is still a useful parameter, because it correlates well with E_{max} and less time-consuming without process of quantitative measurement for elastic modulus on SWE image.

In many previous studies that have evaluated residual lesions after NAC, the authors mainly compared the size of the lesions on preoperative imaging to those on histopathologic examination.[12,21,22,26,32,33] However, not only the size but the characterization of residual lesions also would be of great importance, because not all residual lesions represent residual cancer or ductal carcinoma in situ and they can include posttreatment fibrotic change or other benign conditions. In cases of pCR with large fibrotic change, the size of the residual lesion can be overestimated on B-mode US hampering correlation with pathology. Thus, in our study, we used a three-point category system for the characterization of residual lesions representing the probability of residual cancers on B-mode US and MRI evaluated by experienced breast radiologists. According to our results, category 3 indeed showed high probability of residual cancer (97 % [31/32] for B-mode US and 100 % [36/36] for MRI) and category 2 showed relatively high probability of residual cancer (76 % [13/17] for B-mode US and 95 % [20/21] for MRI). However, the probability of residual cancer for category 1 on preoperative imaging was

higher than our expectation especially for B-mode US (77 % [17/22]) which can be lowered by addition of SWE; soft residual lesions (E_{max} of residual E_{col} of dark blue) showed 56 % (10/18) and 58 % (11/19) probability of residual cancer presence for E_{max} and E_{col}, respectively. Even with MRI, 36 % (5/14) of patients with category 1 had residual cancers on pathology. Thus, surgery still seems necessary even though pCR is suggested on imaging.

Our study has several limitations. First, this study was a retrospective study with a relatively small sample size. Second, SWE was not performed prior to NAC: baseline stiffness value of breast cancers was not available, because most of our study population were referred from primary or secondary care center after being diagnosed by core needle biopsy and started chemotherapy without undergoing additional US examinations in our hospital. Therefore, evaluation of the interval changes of tumor stiffness was not possible. However, the purpose of our study was focused on the detection of residual cancers on preoperative imaging, not on the prediction of the response to NAC. Third, tumors with greater than 4 cm of residual lesions were excluded given limitations of the SWE technology and SWE image was assessed in one plane showing the largest diameter of lesion. Two-orthogonal view or 3-dimensional SWE may be more accurate in the evaluation of residual lesion.[34,35] Fourth, mammographic finding was not taken into account when assessing presence of residual cancer. Lastly, simple qualitative categories were used to describe residual lesion on each image modality. Using quantitative criteria in studies with larger study population is warranted to apply the results in clinical setting and possibly aid in surgical decision making.

CONCLUSIONS

SWE allowed relatively accurate discrimination between pCR and residual cancers and a combination of conventional B-mode US findings and SWE features improved the diagnostic performance of breast US for residual lesion assessment after NAC. Our results demonstrate that B-mode US combined with SWE can potentially be used instead of MRI to accurately assess the presence of residual cancer or pCR in breast cancer patients following treatment with NAC.

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