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Second-Look Ultrasound Using Shear-Wave Elastography in MRI-Suspected Locoregional Recurrence of Breast Carcinoma

Second-Look-Ultraschall mittels Scherwellen-Elastografie bei Verdacht auf lokoregionales Rezidiv des Mammakarzinoms im MRT

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ABSTRACT

Purpose To investigate if second-look US using shear-wave elastography (SWE) can help to differentiate between benign and malignant changes in the postoperative breast after surgical treatment of breast carcinoma.

Materials and Methods SWE and related sonographic features were reviewed in 90 female patients with a history of surgical treatment of breast carcinoma and a suspicious lesion detected on a follow-up MRI scan. A single experienced radiologist performed all second-look US exams with SWE measurements placing a circular region of interest measuring 2 mm in diameter over the stiffest part of the lesion. Tissue samples for histopathological analysis were obtained during the same US examination via core-needle biopsy.

Results Out of 90 lesions, 39 were proven malignant on histopathological analysis. 50 % of malignant lesions had El_{max} values ranging from 128 to 199 kPa, and 50 % of benign lesions had El_{max} values ranging from 65 to 169 kPa. The cut-off value of 171.2 kPa for El_{max} shows a sensitivity of 59 % and specificity of 78.4 % for carcinoma recurrence, area under the curve 0.706 (CI95 % 0.6–0.81), P = 0.001. In univariate logistic models, restricted diffusion and stiffness on SWE, El_{max} > 171.2 kPa, were shown as significant recurrence predictors. In the multivariate model, restricted diffusion remains significant independent recurrence predictor. With a recurrence prevalence of 43 %, the test sensitivity is 95 % (CI95 % 81–99 %) and the specificity is 75 % (CI95 % 60–85 %).

Conclusion Stiffer lesions should be considered suspicious on second-look US in the postoperative breast and SWE can be a helpful tool in identifying malignant lesions, especially if this is related to restricted diffusion on MRI exam. Lesion stiffness, however, should not be considered as an independent predictor of lesion malignancy in the postoperative breast, because of benign changes that can appear stiff on SWE, as well as carcinoma recurrences that may appear soft.

ZUSAMMENFASSUNG

Ziel Es soll untersucht werden, ob der Second-Look-US mittels Scherwellen-Elastografie (SWE) nützlich ist, um zwischen benignen und malignen Veränderungen in der postoperativen Brust nach der operativen Therapie des Mammakarzinoms zu differenzieren.

Material und Methoden SWE und die damit verbundenen sonografischen Merkmale wurden bei 90 Patientinnen mit Anamnese einer operativen Therapie des Mammakarzinoms und einer bei der MRT-Nachuntersuchung entdeckten verdächtigen Läsion überprüft. Ein einziger erfahrener Radiologe führte alle Second-Look-US-Untersuchungen mit SWE-Messungen durch, indem er eine kreisförmige Region of Interest von 2 mm Durchmesser über dem steifsten Teil der Läsion legte. Gewebeproben für die histopathologische Untersuchung wurden dabei durch Stanzbiopsie entnommen.

Ergebnisse Von 90 Läsionen erwiesen sich 39 als maligne in der histopathologischen Untersuchung. Von den malignen Läsionen zeigten 50 % El_{max}-Werte im Bereich von 128 bis 199 kPa, und 50 % der benignen Läsionen hatten El_{max}-Werte von 65 bis 169 kPa. Ein Cut-off-Wert von 171,2 kPa für El_{max} zeigt eine Sensitivität von 59 % und eine Spezifität von 78,4 % für das Karzinomrezidiv und eine AUC von 0,706 (95 %-KI 0,6–0,81; p = 0,001). In univariaten logistischen Modellen erwiesen sich eingeschränkte Diffusion und Steifigkeit bei SWE, El_{max} > 171,2 kPa, als signifikante Rezidiv-Prädiktoren. Im multivariaten Modell bleibt die eingeschränkte Diffusion ein signifikanter unabhängiger Rezidiv-Prädiktor. Bei einer Rezidiv-Prävalenz von 43 % liegt die Testsensitivität bei 95 % (95 %-KI 81–99 %) und die Spezifität bei 75 % (95 %-KI 60–85 %).

Schlussfolgerung Steifere Läsionen in der postoperativen Brust sollten im Second-Look-Ultraschall als suspekt angesehen werden. SWE kann eine hilfreiche Methode zur Identifizierung maligner Läsionen sein, insbesondere im Zusammenhang mit einer eingeschränkten Diffusion in der MRT-Untersuchung. Die Steifigkeit der Läsion sollte jedoch nicht als unabhängiger Prädiktor für die Läsionsmalignität in der postoperativen Brust angesehen werden, da in der SWE benigne Veränderungen steif, Karzinomrezidive hingegen weich erscheinen können.

Introduction

Although primary breast carcinoma is still the most common malignancy in women, management of this disease has changed in the last two decades, with the multidisciplinary approach leading to a decrease in local recurrence (LR) incidence rates [1, 2]. Reported rates vary depending on the advancement of the primary tumor as well as administration of adjuvant therapy: 3–5 % 10-year incidence rate is reported for early breast carcinoma with adjuvant radiotherapy, while 5-year incidence rates of around 35 % were reported in patients who did not receive adjuvant radiotherapy [3, 4]. The reported 10-year incidence of LR for patients who underwent mastectomy was 3–8 % [2, 5]. Although LR incidence rates are decreasing, postoperative changes in the breast after oncoplastic surgery as well as changes due to adjuvant radiation or systemic therapy can present a challenge in differentiating carcinoma recurrence from iatrogenic breast changes, both on physical exam [6, 7] and imaging methods [8–10]. Although magnetic resonance imaging (MRI) has high sensitivity and specificity in LR detection, annual screening after breast-conserving surgery (BCS) is not routinely recommended [11]. However, a recent survey by the European Society of Breast Imaging (EUSOBI) has shown that approximately 45 % of participants use MRI for the detection of LR after BCS [12]. This can lead to an increased number of false-positive findings, due to postoperative changes which may result in post-contrast enhancement on T1 sequences, such as early scarring, seroma, and fat necrosis [13, 14]. Suspicious lesions detected by breast MRI are commonly assessed and biopsied under guidance of a targeted ultrasound (US) examination ("second-look" US) [15, 16]. However, US is an operator-dependent method and lesion detection rates for second-look US vary between 22.6 % and 82.1 % [16]. Sonoelastography is a relatively new ultrasonographic method, which has been proven helpful in the detection and differentiation of benign and malignant breast lesions [17, 18]. This study aims to investigate whether second-look US using shear-wave elastography (SWE) can help differentiate between benign and malignant changes in the postoperative breast.

Materials and Methods

The design of this single-center study was prospective. This study was approved by our hospital's ethics committee and was performed according to the standards of good clinical practice. Written informed consent from the patients was waived, since SWE was performed during the routine second-look US examination after breast MRI. SWE and related sonographic features were reviewed in 90 female patients (29–83 years old, mean age: 57 years, median: 58 years). The inclusion criteria included adult female patients with a history of surgically treated breast carcinoma, who were scheduled for follow-up MRI, and a suspicious lesion requiring histopathological assessment detected on a follow-up MRI scan. The exclusion criteria included a history of previously detected breast carcinoma recurrence. The MRI scans were performed in an eight-year period (2011–2018) in our department. MRI scans were performed on two 1.5 T MRI scanners (Avanto, Siemens, Germany and Ingenia, Philips, Netherlands), using dedicated breast coils and a standard multiparametric protocol including T2-weighted imaging (T2WI), diffusion-weighted imaging (DWI) and dynamic contrast-enhanced (DCE)-MRI. Signal intensity (SI) on T2WI, signs of restricted diffusion on DWI and apparent diffusion coefficient (ADC) map as well as enhancement patterns and kinetics were observed. The lesion size and type of margins were also noted. If multiple lesions were present, the index lesion was chosen depending on the most suspicious MRI features (e. g. irregular mass with irregular edges showing contrast uptake, or new enhancing lesion not present on earlier MRI exams, or higher intensity of enhancement in a previous lesion) and size of the lesion (largest lesion). All patients underwent the SWE examination on the same state-of-the-art ultrasound scanner Aixplorer (Supersonic Imagine, Aix en Provence, France), with the same linear high-frequency 4–15 MHz transducer. All US examinations were performed by a single experienced breast radiologist with more than 25 years of breast US experience. The images were taken immediately prior to US-guided core biopsy and were stored on the device. The stiffness of the lesion expressed in kilopascals was measured using the built-in quantification region of interest (ROI) of the system (Q-Box). An ROI size of 2 mm was used in all measurements, placed by the investigator over the

stiffest part of the lesion, determined based on the color map generated by the scanner. The breast preset in the penetration mode was used for all measurements, with the highest stiffness set at ≥ 300 kPa. Quantitative SWE features were measured: mean (El_{mean}), maximum (El_{max}), and minimum (El_{min}) elasticity value of the stiffest portion of the lesion. US-guided core biopsy under local anesthesia was performed using a 14G needle and BARD MAGNUM Reusable Core Biopsy System (Bard biopsy, Arizona, USA) to obtain tissue samples for histopathological analysis.

Statistical analysis

The patients were divided into two groups based on histopathological findings (verified carcinoma recurrence and benign breast lesion). Normality of the distribution of quantitative variables (patient age, MRI lesion size and SWE measurements, months free from disease) was analyzed using the Kolmogorov Smirnov test. Distributions of quantitative variables were presented as median and Q1–Q3 range. Differences in the distribution of qualitative variables between the two groups were analyzed with the Mann-Whitney U-test and results were presented as adjusted z- and P-values. With the given sample size, the test had power 75 % to determine effect size d = 0.5.

The distribution of qualitative variables was presented in tables and differences in their distributions were analyzed with Pearson's χ^2 or Fisher's exact test. Pearson's χ^2 test with df = 1 had power 81 % to determine effect size w = 0.5 whereas the power of the test with df = 2 was 72 %.

The diagnostic accuracy and optimal cut-off value for SWE measurements between the two groups were obtained based on the value of the area under the ROC curve.

Logistic regression models were constructed to investigate the predictive values of MRI (SI on T2WI, enhancement patterns and kinetic curves as well as restricted diffusion) and SWE parameters (El_{mean}, El_{max} and El_{min}) on histopathological findings (carcinoma recurrence). All statistical analyses were performed using TIBCO Software Inc. (2018) Statistica (data analysis software system), version 13 (http://tibco.com).

Results

In 39 patients (43.3 %), breast carcinoma recurrence was proven by histopathological analysis of a tissue sample obtained by core biopsy. In 51 patient (56.7 %), scar tissue or another benign breast lesion was found. Statistical analyses (Mann-Whitney U-Test) revealed no difference between the two groups of patients regarding age, months free from disease and lesion size (▶ **Supplementary Table 1**).

The type of breast surgery patients underwent showed no difference regarding carcinoma recurrence, Fisher's exact test P = 0.547. (▶ **Supplementary Table 2**).

Carcinoma recurrences more often appeared as T2-hypointense. Almost all (37 out of 39, or 94.9 %) recurrences showed restricted diffusion on DWI and ADC maps, compared to only 13 of 51 benign lesions (25.5 %). In carcinoma recurrence, two thirds of participants (26 of 39, or 66.7 %) had a washout kinetic curve. In case of benign lesions, 19 of 51 (37.3 %) had a washout kinetic

curve, 21 (41.2 %) had a plateau kinetic curve and 11 (21.6 %) had a persistent kinetic curve (▶ **Supplementary Table 3**).

Carcinoma recurrences in general showed higher stiffness values on SWE when compared to benign lesions (distribution of El_{max}, El_{mean} and El_{min} between groups is shown in ▶ **Supplementary Table 4**). While 50 % of El_{max} values in malignant lesions ranged from 128 to 199 kPa. One carcinoma recurrence was very soft, measuring El_{max} of only 32.7 kPa.

ROC curve analysis was applied to analyze the diagnostic accuracy of measurements and the optimal cut-off values for El_{max} and El_{mean} values (▶ **Supplementary Fig. 1**) between verified recurrence and benign lesion.

An El_{max} value of 171.2 kPa shows a sensitivity of 59 % and a specificity of 78.4 % for carcinoma recurrence, area under the curve 0.706 (CI95 % 0.6–0.81), P = 0.001. An El_{mean} value of 148.5 kPa shows a sensitivity of 59 % and a specificity of 74.5 % for carcinoma recurrence, area under the curve 0.703 (CI95 % 0.59–0.81), P = 0.001.

Logistic regression models have shown that information about diffusion restriction obtained from MRI, exam, hypointensity, washout curve compared to persistent curve and SWE $El_{max} > 171.2$ kPa can serve as individual predictors for lesion malignancy. In the multivariate model, restricted diffusion remains a significant independent predictor of carcinoma recurrence (▶ **Supplementary Table 5**).

With a prevalence of carcinoma recurrence of 43 %, diffusion restriction has a sensitivity of 95 % (CI95 % 81–99 %) and a specificity of 75 % (CI95 % 60–85 %). The test is most valuable if the test result is negative. The probability of having disease if the test is positive is 74 % (CI95 % 64–82 %) and 5 % (CI95 % 2–17 %) if the test is negative.

Regarding SWE, for $El_{max} > 171.2$ kPa, with a prevalence of carcinoma recurrence of 43 %, the test sensitivity is 59 % (CI95 % 42–74 %) and the specificity is 78 % (CI95 % 64–88 %). The probability of true recurrence is 68 % (CI95 % 54–79 %) in the case of positive test results and 29 % (CI94 % 21–37 %) in the case of negative test results.

With a prevalence of carcinoma recurrence of 43 %, T2-hypointensity showed sensitivity for malignancy of 62 % (CI95 % 45–76 %) and specificity of 63 % (CI95 % 48–76 %). The probability of true recurrence is 56 % (CI95 % 45–66 %) if the test result is positive and 32 % (CI95 % 23–42 %) in the case of a negative test result.

Disscussion

SWE, unlike strain elastography, allows for quantification of lesion stiffness. Furthermore, it is highly reproducible for assessing elastographic features of breast masses within and across observers [17]. These were the main reasons for choosing SWE over strain elastography in our study. SWE is being widely used in clinical practice, especially in the characterization of breast lesions. However, evidence regarding the value of SWE in differentiating benign postoperative changes in the breast from local carcinoma recurrences is scarce. A PubMed search performed in October 2019 resulted in only one study that investigated the sensitivity and specificity of SWE in suspected recurrence of breast carcinoma
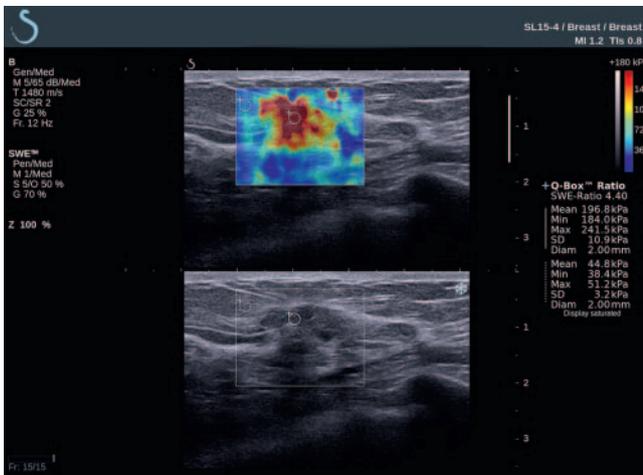
▶ **Fig. 1** A small, heterogeneous breast lesion occurring 14 years after breast segmentectomy. Lesion shows high stiffness on SWE, with El$_{max}$ value of 241.5 kPa. Histopathological analysis-proven locoregional recurrence of Luminal B Her2-negative carcinoma.
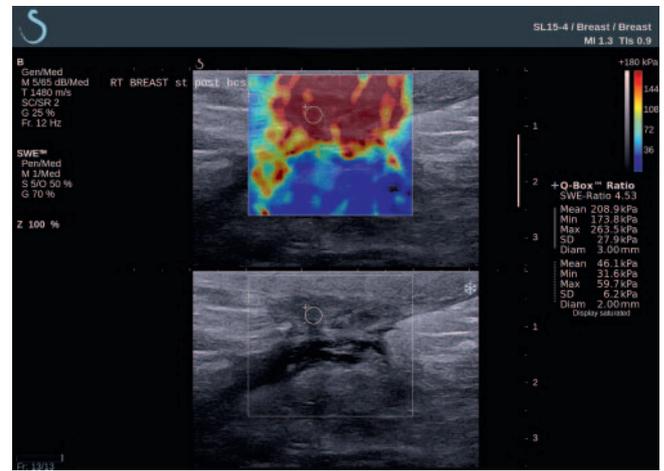
▶ **Fig. 3** A hypoechoic, irregular, spiculated breast lesion after breast-conserving surgery. The lesion showed post-contrast enhancement on MRI and high stiffness on SWE. Biopsy revealed scar tissue.
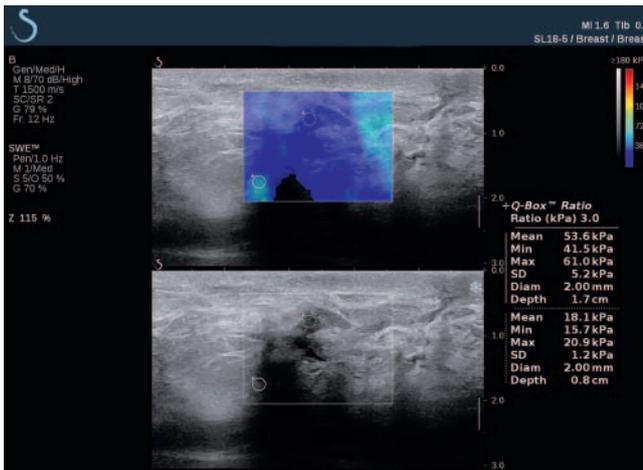
▶ **Fig. 2** A surgical scar in the postoperative breast presented as an irregular, spiculated enhancing lesion on follow-up MRI. Second-look US with SWE shows that the lesion is in fact soft, while biopsy revealed scar tissue.
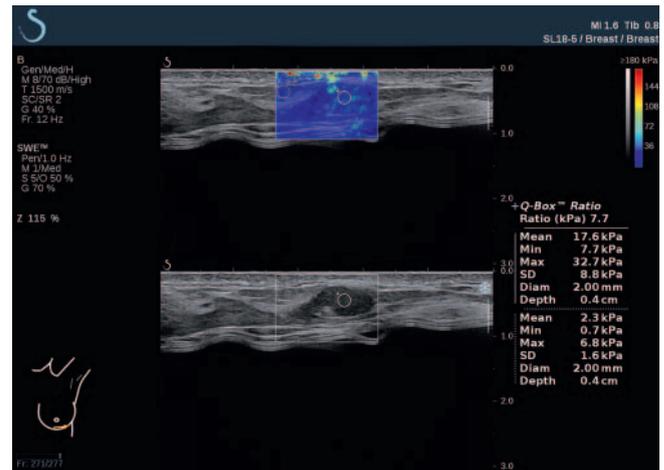

▶ **Fig. 4** A small, hypoechoic breast lesion after skin-and-nipple-sparing mastectomy and reconstruction using breast implant. While SWE showed very low El$_{max}$ values, biopsy revealed a carcinoma recurrence.

[19]. This study included 29 patients with 32 masses and although it was shown that SWE can discriminate between benign and malignant lesions, it was not recommended to perform biopsies based on SWE results only.

Our study included a larger number of patients, but is still limited by the relatively small pool of patients with suspected recurrence of breast carcinoma. Our results also show increased stiffness of malignant lesions (▶ **Fig. 1**) in comparison to benign postoperative changes (▶ **Fig. 2**), but with a significant overlap of SWE parameters between the two groups, probably due to increased stiffness of fibrotic changes present in the postoperative breast (▶ **Fig. 3**). In our study, the best-performing SWE parameter in diagnosing breast lesions was El$_{max}$, similar to evidence from earlier studies [17, 20–23]. Another parameter that could be useful is El$_{ratio}$ [21, 23–25], which requires comparison of lesion stiffness with the stiff-

ness of fat tissue. Due to postoperative changes, it was not always possible to capture fat tissue in the Q-Box, so the authors decided to focus on measurements of lesions alone. The cut-off value of 171.2 kPa for El$_{max}$ is significantly higher than the cut-off values that are reported in studies on primary carcinomas, which range from 46.7 to 93.8 kPa (median: 79.25 kPa) [23], although it is not uncommon for malignant lesions to show El$_{max}$ values above 130 kPa [26–28]. It is known that tumor stiffness is related to tumor size and immunohistochemical profile [27, 29]. Our study included relatively small lesions (median diameter of malignant lesions was 16 mm), and stiffness probably resulted from intrinsic tumor properties rather than size. Most of malignant lesions in our study had El$_{max}$ values between 128 and 199 kPa. However, we also encountered a soft carcinoma recurrence, with an El$_{max}$ value of only 32.7 kPa (▶ **Fig. 4**), possibly due to the small lesion size (8 mm in
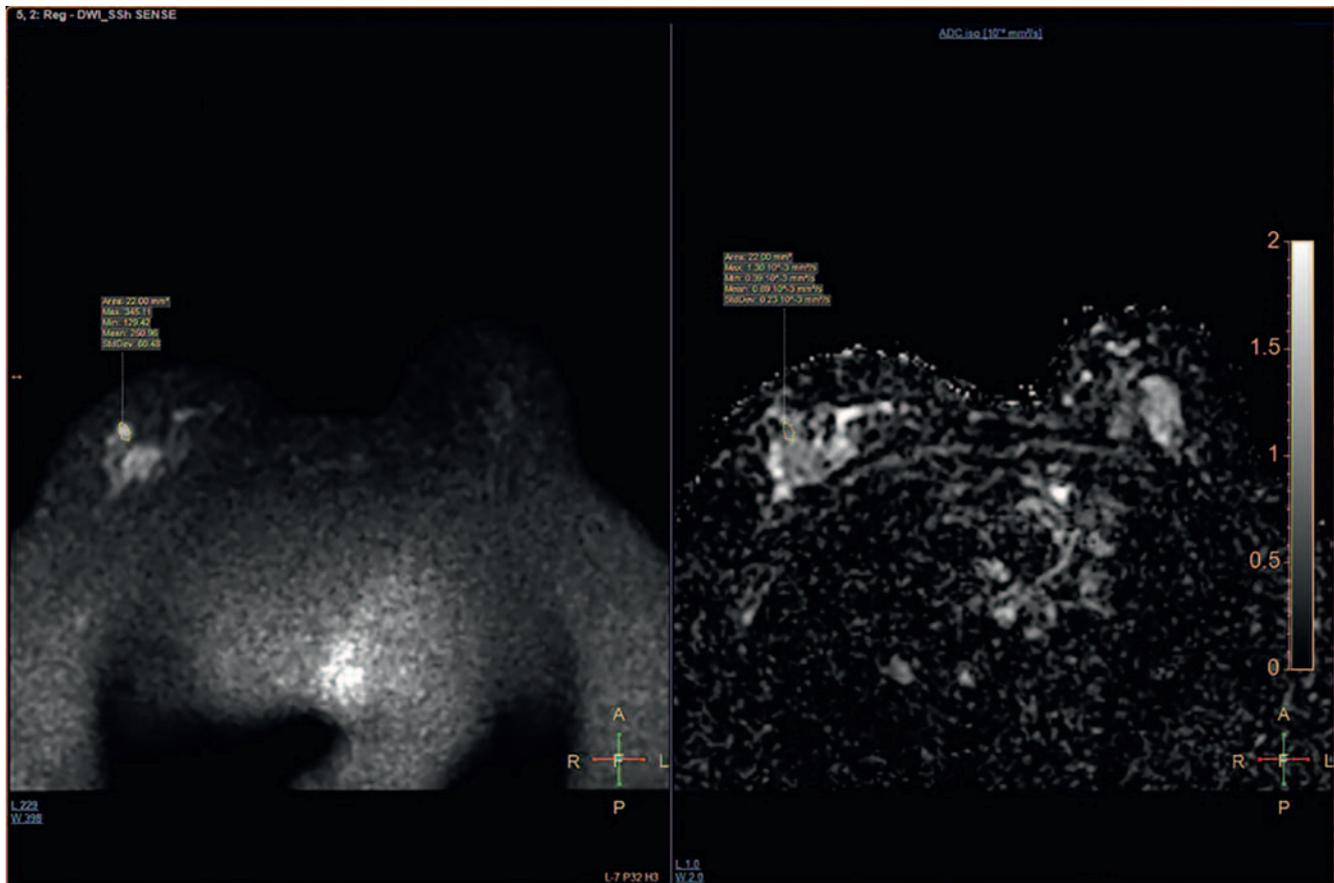
▶ Fig. 5 A DWI image (left) and ADC map (right) of a carcinoma recurrence in the right breast 21 years after a segmentectomy. Lesion is hyperintense on DWI and shows low ADC values on ADC map, which represents restricted diffusion.

diameter) and/or histopathological properties of the tumor. This served as a good reminder of the diverse appearance of breast carcinomas on SWE. The sensitivity of El_{max} with the proposed cut-off value was 59 % (CI95 % 42–74), while the specificity was 78 % (CI95 % 64–88).

Regarding MRI findings, two different MRI devices were used in the study, but both are state-of-the-art scanners with same MRI field strength (1.5 T) and the same protocols were used on both devices. Therefore, we believe this couldn't cause any significant bias in our data. Results have shown that restricted diffusion on DWI and ADC map can serve as an individual predictor for lesion malignancy (▶ **Fig. 5**), with a sensitivity of 95 % (CI95 % 81–99) and specificity of 75 % (CI95 % 60–85). Restricted diffusion remains a significant independent predictor of carcinoma recurrence in the multivariate model. Other MRI parameters, including DCE variables, have shown a lower predictive value for carcinoma recurrence, which can be explained by the tendency of postoperative changes (that as a rule include fibrous healing and inflammation) to show washout enhancement pattern and irregular shape [8, 30]. On the other hand, the value of DWI in breast carcinoma detection has become more prominent in recent studies and this technique is now being incorporated into MRI breast protocols more often [31, 32]. Not only can it give information about lesion hypercellularity, but there are also some indications that DWI could be applicable for morphological assessment [33].

In conclusion, stiffer lesions should be considered suspicious on second-look US in the postoperative breast and SWE can be a helpful tool for identifying malignant lesions, especially if this is related to restricted diffusion on MRI exam. Lesion stiffness, however, should not be considered as an independent predictor of lesion malignancy in the postoperative breast, because of benign changes that can appear stiff on SWE, as well as carcinoma recurrences that may appear soft.

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Conflict of Interest

The authors declare that they have no conflict of interest.

References

[1] Mamounas EP, Tang G, Liu Q. The importance of systemic therapy in minimizing local recurrence after breast-conserving surgery: the NSABP experience. J Surg Oncol 2014; 110: 45–50

[2] Frandsen J, Ly D, Cannon G et al. In the Modern Treatment Era, Is Breast Conservation Equivalent to Mastectomy in Women Younger Than 40 Years of Age? A Multi-Institution Study. Int J Radiat Oncol 2015; 93: 1096–1103

[3] Darby S, McGale P. Early Breast Cancer Trialists' Collaborative Group (EBCTCG) et al. Effect of radiotherapy after breast-conserving surgery on 10-year recurrence and 15-year breast cancer death: meta-analysis of individual patient data for 10801 women in 17 randomised trials. Lancet (London, England) 2011; 378: 1707–1716

[4] Wadasadawala T, Vadgaonkar R, Bajpai J. Management of Isolated Locoregional Recurrences in Breast Cancer: A Review of Local and Systemic Modalities. Clin Breast Cancer 2017; 17: 493–502

[5] Clarke M, Collins R, Darby S et al. Effects of radiotherapy and of differences in the extent of surgery for early breast cancer on local recurrence and 15-year survival: an overview of the randomised trials. Lancet 2005; 366: 2087–2106

[6] Montgomery DA, Krupa K, Cooke TG. Locoregional Relapse After Breast Cancer: Most Relapses Occur Late and are not Clinically Detected. Breast J 2009; 15: 163–167

[7] Montgomery DA, Krupa K, Cooke TG. Follow-up in breast cancer: does routine clinical examination improve outcome? A systematic review of the literature. Br J Cancer 2007; 97: 1632–1641

[8] Gutierrez R, Horst KC, Dirbas FM et al. Breast Imaging Following Breast Conservation Therapy. In: Breast Surgical Techniques and Interdisciplinary Management. New York, NY: Springer New York; 2010. [cited 2019 Jun 20] 975–995

[9] Khatcheressian JL, Hurley P, Bantug E et al. Breast cancer follow-up and management after primary treatment: American Society of Clinical Oncology clinical practice guideline update. J Clin Oncol 2013; 31: 961–965

[10] Emens LA, Davidson NE. The follow-up of breast cancer. Semin Oncol 2003; 30: 338–348

[11] Sardanelli F, Boetes C, Borisch B et al. Magnetic resonance imaging of the breast: Recommendations from the EUSOMA working group. Eur J Cancer 2010; 46: 1296–1316

[12] Clauser P, Mann R, Athanasiou A et al. A survey by the European Society of Breast Imaging on the utilisation of breast MRI in clinical practice. Eur Radiol 2018; 28: 1909–1918

[13] Lehman CD, Lee JM, DeMartini WB et al. Screening MRI in Women With a Personal History of Breast Cancer. J Natl Cancer Inst 2016; 108: djv349

[14] Gigli S, Amabile MI, Di Pastena F et al. Magnetic Resonance Imaging after Breast Oncoplastic Surgery: An Update. Breast Care 2017; 12: 260–265

[15] Kuhl C. The Current Status of Breast MR Imaging Part I. Choice of Technique, Image Interpretation, Diagnostic Accuracy, and Transfer to Clinical Practice. Radiology 2007; 244: 356–378

[16] Spick C, Baltzer PAT. Diagnostic Utility of Second-Look US for Breast Lesions Identified at MR Imaging: Systematic Review and Meta-Analysis. Radiology 2014; 273: 401–409

[17] Berg WA, Cosgrove DO, Doré CJ et al. Shear-wave Elastography Improves the Specificity of Breast US: The BE1 Multinational Study of 939 Masses. Radiology 2012; 262: 435–449

[18] Brkljačić B, Ivanac G. Ultrasonography of the Breast. Ultrasound Clin 2014; 9: 391–427

[19] Jales RM, Dória MT, Serra KP et al. Power Doppler Ultrasonography and Shear Wave Elastography as Complementary Imaging Methods for Suspected Local Breast Cancer Recurrence. J Ultrasound Med 2018; 37: 1493–1501

[20] Lee SH, Chang JM, Kim WH et al. Differentiation of benign from malignant solid breast masses: comparison of two-dimensional and three-dimensional shear-wave elastography. Eur Radiol 2013; 23: 1015–1026

[21] Cebi Olgun D, Korkmazer B, Kilic F et al. Use of shear wave elastography to differentiate benign and malignant breast lesions. Diagnostic Interv Radiol 2014; 20: 239–244

[22] Chen L, He J, Liu G et al. Diagnostic performances of shear-wave elastography for identification of malignant breast lesions: a meta-analysis. Jpn J Radiol 2014; 32: 592–599

[23] Youk JH, Gweon HM, Son EJ. Shear-wave elastography in breast ultrasonography: The state of the art. Ultrasonography 2017; 36: 300–309

[24] Youk JH, Gweon HM, Son EJ et al. Diagnostic value of commercially available shear-wave elastography for breast cancers: integration into BI-RADS classification with subcategories of category 4. Eur Radiol 2013; 23: 2695–2704

[25] Au FWF, Ghai S, Moshonov H et al. Diagnostic performance of quantitative shear wave elastography in the evaluation of solid breast masses: Determination of the most discriminatory parameter. Am J Roentgenol 2014; 202: E328–E336

[26] Tian J, Liu Q, Wang X et al. Application of 3D and 2D quantitative shear wave elastography (SWE) to differentiate between benign and malignant breast masses. Sci Rep 2017; 7: 41216

[27] Song EJ, Sohn YM, Seo M. Tumor stiffness measured by quantitative and qualitative shear wave elastography of breast cancer. Br J Radiol 2018; 91: 20170830

[28] Berg WA, Mendelson EB, Cosgrove DO et al. Quantitative Maximum Shear-Wave Stiffness of Breast Masses as a Predictor of Histopathologic Severity. Am J Roentgenol 2015; 205: 448–455

[29] Au FWF, Ghai S, Lu FI et al. Quantitative Shear Wave Elastography. Acad Radiol 2015; 22: 269–277

[30] Margolis NE, Morley C, Lotfi P et al. Update on imaging of the postsurgical breast. Radiographics 2014; 34: 642–660

[31] Partridge SC, Amornsiripanitch N. DWI in the Assessment of Breast Lesions. Top Magn Reson Imaging 2017; 26: 201–209

[32] Spick C, Bickel H, Pinker K et al. Diffusion-weighted MRI of breast lesions: a prospective clinical investigation of the quantitative imaging biomarker characteristics of reproducibility, repeatability, and diagnostic accuracy. NMR Biomed 2016; 29: 1445–1453

[33] Radovic N, Ivanac G, Divjak E et al. Evaluation of Breast Cancer Morphology Using Diffusion-Weighted and Dynamic Contrast-Enhanced MRI: Intermethod and Interobserver Agreement. J Magn Reson Imaging 2019; 49: 1381–1390