Differentiating Benign from Malignant Solid Breast Masses with US Strain Imaging

Purpose:
To prospectively evaluate the sensitivity and specificity of ultrasonographic (US) strain imaging for distinguishing between benign and malignant solid breast masses, with biopsy results as the reference standard.

Materials and Methods:
The study was institutional review board approved and HIPAA compliant. Informed consent was obtained from all participating patients. US strain imaging of 403 breast masses was performed. The 50 malignant and 48 benign lesions (in patients aged 19–83 years; mean age, 49 years ± 17 [standard deviation]) with the highest quality were selected for the reader study. Three observers blinded to the pathologic outcomes first described the B-mode image findings by using US Breast Imaging Reporting and Data System descriptors and derived a probability of malignancy. They then updated the probability by assessing strain images. Receiver operating characteristic (ROC) curves were constructed by using these probabilities. Areas under the ROC curve, sensitivities, and specificities were calculated and compared. Interobserver variability and the correlation between automated and subjective image quality assessment were analyzed.

Results:
The average area under the ROC curve for all three readers after US strain imaging (0.903) was greater than that after B-mode US alone (0.876, \( P = .014 \)). With use of a 2% probability of malignancy threshold, strain imaging—as compared with B-mode US alone—had improved average specificity (0.257 vs 0.132, \( P < .001 \)) and high sensitivity (0.993 vs 0.987, \( P > .99 \)). Significant interobserver variability was observed (\( P < .001 \)). The ability to assess strain image quality appeared to correlate with the highest observer performance.

Conclusion:
US strain imaging can facilitate improved classification of benign and malignant breast masses. However, interobserver variability and image quality influence observer performance.

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Supplemental material:
http://radiology.rsna.org/cgi/content/full/245/2/401/DC1
http://radiology.rsna.org/cgi/content/full/245/2/401/DC2
http://radiology.rsna.org/cgi/content/full/245/2/401/DC3
Breast biopsy, the current method used to distinguish between benign and malignant breast abnormalities seen at imaging, yields a benign result in more than 75% of patients, making it the most costly per capita component of a breast cancer screening program (1). A decade ago, physicians found that the imaging features on ultrasonographic (US) images could be used to classify benign and malignant solid breast masses and thus decrease the numbers of biopsies performed (2). The successes of these investigators, however, have been neither reliably confirmed nor widely applied. Furthermore, the Agency for Healthcare Research and Quality recently asserted that current US examinations are neither sufficiently sensitive nor adequately specific to be used in place of breast biopsy for the diagnosis of mammographically identified abnormalities (3). Thus, a method to reliably differentiate benign from malignant solid breast masses on US images would be valuable.

US strain imaging (also known as elastography) may aid in the differentiation of benign from malignant solid breast masses (4–19). This technique exploits the theory that benign and malignant breast lesions have inherent differences in firmness (20,21). Strain images display the relative stiffness of lesions compared with the stiffness of surrounding tissue. Stiffer areas deform less easily than do their surroundings and are depicted as dark on strain images, whereas softer areas deform more easily than do their surroundings and are depicted as light. Malignant masses typically appear dark and have high contrast with background breast tissue during deformation. Benign masses typically appear lighter and have lower contrast with background breast tissue during deformation (6). In addition, malignant lesions tend to be larger on US strain images than on corresponding B-mode US images, perhaps because of the desmoplastic reaction commonly associated with malignancy (5–7,9,14,18,22). The changes in contrast with deformation can only be appreciated in a sequence of images (Figs 1, 2). The appearance of masses on strain images and lesion size discrepancies between B-mode and strain images may be promising tools for distinguishing benign from malignant lesions.

In the past, various characteristics of strain imaging (e.g., strain lesion-to-B-mode lesion size ratio) have been used as isolated predictors of benign and malignant breast disease (Table E1, http://radiology.rsna.org/cgi/content/full/245/2/401/DC1) (5,6,9,18,23). In clinical practice, US strain imaging is more likely to be used as an adjunct to conventional US in lesion evaluation and management. In this experiment, we added US strain image findings to the cohort of evidence that radiologists used to determine the risk of malignancy. The purpose of our study was to prospectively evaluate the sensitivity and specificity of US strain imaging for distinguishing between benign and malignant solid breast masses, with biopsy results as the reference standard.

Materials and Methods

Patients and Reference Standard

Siemens Medical Solutions, Ultrasound Division (Issaquah, Wash), provided equipment and partial financial support for our study. Authors not supported by Siemens Medical Solutions had full control of the data and information submitted for publication. Approval for our study was obtained from the Mayo Foundation institutional review board, the Riverside research ethics committee, Chelsea & Westminster Hospital (NHS Trust, for Charring Cross Hospital), and the University of Wisconsin Health Sciences institutional review board. Informed consent was obtained from all enrolled patients. Our study was also compliant with the Health Insurance Portability and Accountability Act (data acquired at Mayo Clinic). Consecutive women with indeterminate breast masses who were candidates for US-guided percutaneous breast biopsy were eligible. We excluded patients with technically inadequate radiofrequency (RF) data—that is, no RF data were available, there was spurious electronic noise in the RF data, or the file was corrupted—and patients who did not undergo biopsy for pathologic outcome.

Two institutions participated in patient enrollment and imaging: Charing Cross Hospital and the Mayo Clinic. Two hundred forty-one patients aged 13–91 years (mean age, 42.9 years ± 15.7 [standard deviation]) who underwent imaging of 259 lesions at Charing Cross Hospital were enrolled between

Implication for Patient Care

The addition of elasticity (i.e., mechanical strain imaging data) to the cohort of information available through US has the potential to improve the diagnosis of breast abnormalities.
February 22, 2002, and April 8, 2004. Eleven of these 259 lesions were excluded because of inadequate RF data, and 11 were excluded because biopsy was not performed. One hundred fifty-six patients aged 20–83 years (mean age, 58.4 years ± 14.6) from the Mayo Clinic were enrolled between February 4, 2002, and May 25, 2004. Of the 186 lesions evaluated in these patients, 17 were excluded for inadequate RF data and three were excluded because biopsy was not performed. Thus, strain imaging of 445 breast masses was prospectively performed, and 42 of these lesions were excluded on the basis of our exclusion criteria, leaving a total of 403 (38.7% malignant, 61.3% benign) candidate lesions for our reader study (Fig 3).

Histopathologic results of percutaneous or excisional biopsy were considered the reference standard. Concordance between the imaging and histopathologic results was documented for each lesion to minimize the chance of sampling error.

US Strain Imaging
Lesions were imaged at Mayo Clinic by a mammography technologist with 10 years experience in breast US and at Charing Cross Hospital by a radiologist with 17 years experience in breast US (W.E.S.). These individuals chose the orientation (transverse or longitudinal) that best depicted the lesion for display on both the B-mode and the strain images. At both sites, US was performed by using the SONOLINE Elegra (Siemens Medical Solutions, Ultrasound Division) US machine, which operates with the 7.5L40 linear-array transducer at 7.2 MHz or the VFX13-5 multirow linear-array transducer at 10 MHz. The radiologist and technologist used the freehand compression technique (6), starting with the transducer barely in contact with the skin surface and then increasing the pressure in a cyclic manner over an approximately 10% strain range. A real-time strain imaging algorithm (24) was implemented on the US machine and used during RF echo signal acquisition (6).

B-mode images were obtained offline from the stored RF echo data by first computing the Hilbert transform of the zero-mean RF A-line. The transformed data were then downsampled axially to obtain square pixels. The resulting data were displayed with an 8-bit log-compressed color map similar to the maps used in clinical imaging systems.

US strain images were produced by comparing the US RF echo data obtained before with those obtained after a slight axial deformation of the breast to determine the tissue displacement at each location in the breast. Strain images were formed off-line by using custom software similar to that described in detail elsewhere (24,25). The primary modification made to the previously reported strain image formation algorithm was the use of three frames of RF data to form a single lower-noise strain image (26), which resulted in superior strain image quality compared with the quality of the image displayed in real time on the US machine. Because individual frames of B-mode and strain images were created from the same underlying RF data, the image plane, region of interest, and pixel dimensions were identical. B-mode and strain images were displayed side by side by using a cine-loop sequence of approximately 100 frames.

Reader Study and Final Patient Group
Two parameters were used to select the abnormalities that would be analyzed for our reader study: the distribution of diagnosed abnormalities and the quality of the strain images. First, to optimally represent the entire spectrum of breast abnormalities seen in clinical breast imaging practice, we determined the distribution of diagnosed abnormalities...
identified on our collected patient studies (Table E2, http://radiology.rsna.org/cgi/content/full/245/2/401/DC1). Image quality was measured by using the displacement quality measure (DQM) (Appendix E1, http://radiology.rsna.org/cgi/content/full/245/2/401/DC2).

Next, two individuals who did not participate in the reader study (T.J.H., A.M.S.) and are codevelopers of the DQM, used the DQM to select the highest-quality data sets for 50 malignant and 50 benign abnormalities while preserving the same distribution of diagnosed abnormalities in the malignant and benign categories. An error was found after our reader study was conducted: Two pairs of related examinations were revealed. Thus, the lower-quality image sequence of each pair was removed from our study, and this left 48 benign abnormalities in the final analysis. With this correction, we made sure that only one lesion per patient was included in our reader study to preserve the independence of examinations for statistical analysis. Patients in our reader study ranged in age from 19 to 83 years (mean age, 49 years ± 17), which was not significantly different (P = .91) from the age range of the patients, with 303 masses, who were not included in the reader study: 13–91 years (mean age, 48.8 years ± 17.1).

Evaluation of B-Mode and Strain Images

Three interpreting radiologists (E.S.B., G.K.H., G.A.S.) working independently were included in our reader study, and all of them fulfilled the Mammography Quality Standards Act of 1992 requirements for volume of mammographic studies read per year and continuing medical education. All three radiologists (5–13 years of experience) are fellowship trained in breast imaging and spend at least 30% of their clinical time in breast imaging practice. Each of the three observers (readers A–C) completed a training module consisting of 56 instructional PowerPoint slides and 40 sample studies not included in our reader study. The introductory slides provided didactic instruction on (a) the physics of strain imaging; (b) the characteristic appearances of benign and malignant masses on strain images, (c) the importance of size ratio differences between B-mode and strain imaging, and (d) the methods used to evaluate the quality of a strain image (Appendix E2, http://radiology.rsna.org/cgi/content/full/245/2/401/DC2).

Once the training session was completed to the radiologist’s satisfaction, the selected studies for the testing phase of the experiment were presented in random order by a custom-made program that ensured that the radiologist was blinded to the lesion abnormality. The program first presented the B-mode images as a movieclip (Movies 1,2; http://radiology.rsna.org/cgi/content/full/245/2/401/DC3), which the radiologist assessed by using Breast Imaging Reporting and Data System descriptors and categories (27) and a probability of malignancy (0% = no chance of malignant abnormality, 100% = absolute confidence that malignant abnormality is present). To obtain measurements, the radiologist selected a frame from the B-mode cine loop on which to trace the lesion boundary. Strain images were then made available so that the radiologist could select a strain image frame (not necessarily the same as that used for B-mode measurements) on which to trace the lesion boundary. The radiologist then assessed the quality of the strain images by using a five-point scale (Appendix E2, http://radiology.rsna.org/cgi/content/full/245/2/401/DC2). Finally, the radiologist viewed the ratio of the lesion area on the strain image to the lesion area on the B-mode image before reassessing the probability of malignancy.
Data and Statistical Analyses

All statistical analyses were performed by using S-PLUS, version 5.3 (MathSoft, Cambridge, Mass), software. We used the two-sample Student t test to compare continuously measured data and the \( \chi^2 \) test to compare proportional data. Standard binormal (28) and standard empirical (29) receiver operating characteristic analyses were applied to the probability assessments made by the radiologist both without and with strain images. To combine information across the readers, we averaged the empirical areas under the receiver operating characteristic curves (AUCs) across readers, with 1000 bootstrap samples used to compute standard errors (25) and account for within- and across-reader correlations in the probability assessments. Point estimates and 95% confidence intervals for empirical AUCs were calculated, and differences were evaluated by using standard z scores for paired data. Receiver operating characteristic curves for individual readers and for all data across readers were constructed by using the LABMRMC computer program (http://www-radiology.uchicago.edu/kr1/roc_soft.htm). z-Score tests were used to assess differences in empirical AUC across readers, with bootstrapping accounting for within- and across-reader correlations.

The McNemar test was used to calculate the difference between the sensitivity and specificity achieved without strain imaging and those achieved with strain imaging (separately for each reader), with z-score testing used to compare the average sensitivity and specificity across readers. Sensitivity and specificity were defined at the level of a 2% probability of malignancy. Specifically, malignant studies estimated at greater than 2% probability were considered true-positive, and those estimated at less than 2% probability were considered false-negative. Benign studies estimated at greater than 2% probability were considered false-positive, and those estimated at less than 2% probability were considered true-negative. We also used the McNemar test to analyze interobserver differences in sensitivity and specificity. We chose to report average sensitivity, specificity, and AUC values instead of multireader and multicycle values because we preferred to avoid parametric assumptions. To confirm our results, we also calculated all of the statistical values involving multiple readers by using multireader and multicycle analyses, the results of which supported our initial conclusions (data not shown).

For image quality analysis, we computed coefficients for the correlations between the sequence DQM and the subjective quality assessment of each reader—first for all abnormalities and then for the malignant and benign lesions separately. To determine whether image quality influenced overall reader performance, we divided the studies into 55 higher-quality and 43 lower-quality images by using the median sequence DQM. Finally, we computed the average AUC, combining the information across readers separately for the higher-quality and the lower-quality strain images. \( P < .05 \) was considered to indicate significance.

Table 1

<table>
<thead>
<tr>
<th>Reader</th>
<th>B-Mode Imaging AUC*</th>
<th>B-Mode and Strain Imaging AUC*</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.781 (0.691, 0.870)</td>
<td>0.828 (0.748, 0.907)</td>
<td>.14</td>
</tr>
<tr>
<td>B</td>
<td>0.920 (0.862, 0.978)</td>
<td>0.931 (0.880, 0.982)</td>
<td>.60</td>
</tr>
<tr>
<td>C</td>
<td>0.928 (0.878, 0.978)</td>
<td>0.952 (0.915, 0.989)</td>
<td>.15</td>
</tr>
<tr>
<td>All readers (average)</td>
<td>0.876 (0.825, 0.927)</td>
<td>0.903 (0.859, 0.947)</td>
<td>.014</td>
</tr>
</tbody>
</table>

* Numbers in parentheses are 95% confidence intervals.

Results

The maximum linear dimensions of the lesions, determined from the B-mode boundary traced by each reader and averaged across the three readers, ranged from 4 to 31 mm (mean, 14.3 mm \( \pm 5.6 \) [standard deviation]).

AUC Values

Individual-reader AUCs ranged from 0.781 to 0.928 without strain imaging and from 0.828 to 0.952 with strain imaging (Table 1, Fig 4). Although each radiologist’s assessment of the risk of malignancy improved when strain imaging was available, only reader A had a significant improvement. When the AUCs of all readers were averaged, strain imaging provided a significant improvement \( (P < .014) \). To determine if the improvement of reader A was solely responsible for the total average improvement, we computed the average AUC for readers B and C (0.919 with B-mode imaging alone, 0.939 with strain imaging; \( P = .09 \)) and found the difference to be nearly significant.

Sensitivity and Specificity

At a 2% probability of malignancy, strain imaging allowed all readers to improve specificity while maintaining sensitivity (Table 2). If the decision to perform biopsy had been based on this threshold, each reader could have lowered the number of benign-result biopsies, without decreasing sensitivity. While the number of benign-result biopsies for reader A would have only decreased by one, reader B and reader C would have decreased their number of benign-result biopsies by six and 11, respectively, all without missing a cancer.

Assessment of Interobserver Variation

Differences in AUC between readers A and B \( (P = .002 \) for B mode, \( P = .01 \) for strain) and between readers A and C \( (P = .001 \) for B mode, \( P < .001 \) for strain) were significant with both B-mode and strain imaging. There was no significant difference in AUC between readers B and C. In terms of sensitivity at the 2% probability of malignancy threshold, all readers performed at a high level without a signif-
Differences in strain imaging specificity were significant for readers A and B ($P = .009$) and for readers A and C ($P < .001$) but not for readers B and C. Differences in B-mode specificity were marginally significant for readers A and B ($P = .07$) and for readers A and C ($P = .08$) but again not for readers B and C.

### Quality Measures

The mean sequence DQM was 19.9 (range, 6–52; median, 15; standard deviation, 10.6) for malignant lesions and 35.4 (range, 7–75; median, 35; standard deviation, 17.1) for benign lesions; the difference in values was significant ($P < .001$). We used the median sequence DQM (rounded to the nearest integer) to divide both malignant and benign lesions into higher-quality and lower-quality groups. For the malignant lesions, 30 strain image sequences were considered to be of higher quality and 20 were considered to be of lower quality. (The disparity in the split resulted from rounding median DQM values.) For the benign lesions, 25 sequences were considered to be of higher quality while 23 were considered to be of lower quality. To determine if image quality influenced reader performance, we assessed the correlations between sequence DQM and both radiologist subjective image quality assessment and radiologist performance. Overall, there was a significant correlation between sequence

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**Table 2**

<table>
<thead>
<tr>
<th>Reader</th>
<th>Sensitivity*</th>
<th>Specificity*</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B-Mode Imaging</td>
<td>Strain Imaging</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>1.000 (50/50)</td>
<td>1.000 (50/50)</td>
<td>&gt;.99</td>
</tr>
<tr>
<td></td>
<td>0.929, 1.000</td>
<td>0.929, 1.000</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>0.960 (48/50)</td>
<td>0.980 (49/50)</td>
<td>&gt;.99</td>
</tr>
<tr>
<td></td>
<td>0.862, 0.995</td>
<td>0.884, 0.999</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>1.000 (50/50)</td>
<td>1.000 (50/50)</td>
<td>&gt;.99</td>
</tr>
<tr>
<td></td>
<td>0.929, 1.000</td>
<td>0.929, 1.000</td>
<td></td>
</tr>
<tr>
<td>All readers</td>
<td>0.987 (148/150)</td>
<td>0.993 (149/150)</td>
<td>&gt;.99</td>
</tr>
<tr>
<td></td>
<td>0.968, 1.000</td>
<td>0.980, 1.000</td>
<td></td>
</tr>
</tbody>
</table>

* Sensitivity and specificity values were calculated at a threshold of 2% probability of malignancy. Values in parentheses are the numbers used to calculate the sensitivity or specificity. Numbers on the second line are 95% confidence intervals.
DQM and radiologist image quality assessment (Table 3). Compared with reader A, readers B and C appeared to have better correlations between their subjective quality scores and the sequence DQM; these results paralleled the AUC measurement performances. In addition, this correlation appeared to be stronger for benign abnormalities than for malignant ones.

Subset analysis of reader performance, in which the 55 best and 43 worst image sequences were compared on the basis of the sequence DQM, revealed that performance was worse for the lower-quality image sets (at both B-mode and strain imaging), but the differences were not significant (Table 4).

For four studies included in our reader analysis, the type of transducer used was not specified. For the remaining 94 studies, use of the VFX13-5 transducer resulted in a sequence DQM \((P < .001)\), average AUC for B-mode imaging \((P < .05)\), and average AUC for strain imaging \((P < .05)\) that were significantly higher than those achieved by using the 7.5L40 transducer (Table 5).

**Discussion**

Similar to prior results published in the literature (4–19,30), our study results show that the use of strain imaging can lead to improved discrimination of benign and malignant solid breast masses. We advanced this concept by determining that radiologists with experience in breast US who have not been involved in strain imaging system development and are blinded to the abnormality type can incorporate strain imaging results into a probability estimate of breast cancer risk and thereby improve the decision of whether to perform biopsy. Specifically, incorporating strain imaging findings into a radiologist’s determination that a solid breast mass is malignant can elevate the overall AUC and improve specificity without sacrificing sensitivity. In our study, we used a probability threshold as a surrogate for the decision to perform biopsy. The 2% threshold for the decision to perform biopsy has been well accepted in mammography practice (31,32). At this threshold, strain imaging may aid in minimizing the number of benign-result breast biopsies performed, which is an important goal that has not been achieved by using any one modality alone. We believe our investigation is a first step toward integrating strain imaging into decision making in clinical practice, but a larger prospective study is needed to further evaluate strain imaging in this context.

Interobserver variability, a commonly cited and important shortcoming of US imaging in general, was verified and extended to strain imaging in our study. Specifically, two readers had significantly greater AUC and specificity measures with B-mode and strain imaging compared with the third reader, despite similarities in their training, experience, and accreditation. Although the source of this interobserver vari-
ability could not be gleaned from our study owing to the small sample size, it is hoped that future studies will reveal whether it can be overcome with additional training and experience in strain imaging. It is important to remember that the radiologists in our study were virtual novices in applying strain imaging to risk assessment and decision making. Each reader had only a short introduction to the technique before interpreting images. A group of investigators with vast experience in strain imaging achieved better discrimination between benign and malignant masses—100% sensitivity and 75.4% specificity—in a series of 169 lesions (33).

By using the DQM we were able to objectively remove images that were degraded by extensive lateral, out-of-plane or shear motion and use the highest quality of images that best depicted axillary deformation. While objectively selecting data on the basis of image quality is important, this approach must be carefully analyzed. For example, there were more benign lesions depicted on the total number of studies collected (61.3%) than on our reader studies (50%). Therefore, there were more high-quality image sequences within the benign group to choose from, and this is why the sequence DQM for the benign masses was significantly better than that for the malignant lesions in our reader study. Furthermore, when suboptimal images were removed from the strain sequence, the corresponding B-mode images were also necessarily removed to keep the cine loops in sync. Specifically, as the overall sequence DQM decreased, more images were excluded from the B-mode and strain imaging cine loops, making the lesion “jump” owing to missing images. This process may explain why the performance in discriminating benign and malignant masses at B-mode imaging may have degraded in conjunction with the sequence DQM. However, strain imaging led to improved predictions at all levels of B-mode performance tested in our study.

There was a somewhat poor correlation between radiologist-assessed image quality and sequence DQM. Only the quality assessments of reader C correlated with the sequence DQM to a significant degree for all lesions. In addition, the correlations between radiologist quality assessment and sequence DQM were better for benign masses than for malignant ones. In fact, the quality assessments of readers B and C, the superior performers, showed a moderate and significant correlation with the sequence DQM for the studies depicting benign masses, while no radiologist’s quality assessment correlated significantly with the sequence DQM for studies depicting malignant masses.

It is possible that the radiologists judged the strain images that depicted benign masses more accurately because the size and/or morphology of benign lesions seen on strain images appears similar to that seen on B-mode images (6). Alternatively, the strain images depicting benign lesions were, on average, of higher quality than those depicting malignant lesions, and this difference probably influenced reader performance. Although these are only possible explanations, poor reader performance in assessing image quality is indirect evidence that the readers had a somewhat limited understanding of strain images. Other investigators have demonstrated that evaluations of strain imaging analysis in the “laboratory” setting may confer performance advantages compared with such evaluations performed in a busy clinical environment (18). We provided cine clips to the radiologists, did not provide the radiologists with two imaging planes for each lesion, and presented “jumpy” images as the strain image quality decreased. In short, the imaging protocol that we used was undoubtedly different from that used in clinical practice. While extra reading time may confer advantages in performance, some of our imaging procedures may confer disadvantages.

Overall, our results suggest that the ability of radiologists to recognize the quality of images influences their performance. The average AUC was larger for the higher-quality images than for the lower-quality images, but the improved risk assessment achieved with strain imaging, compared with that achieved at B-mode imaging alone, was almost the same for the 55 higher-quality and 43 lower-quality images. Therefore, although image quality may affect the overall AUC, poor image quality may not prevent strain imaging from improving performance.

Transducer type influenced the radiologists’ ability to discriminate between benign and malignant masses at strain imaging. This phenomenon may be related to the fact that the 7.5L40 transducer was used earlier in the data collection process when the individuals collecting the data were still learning how to acquire high-quality strain data. It is also possible that differences in spatial resolution, frequency-dependent acoustic scattering, and/or soft-tissue contrast (34) account for these differences. These theories warrant further study.

There were limitations to our study: First, the study design and image-processing algorithms made our study environment different from clinical practice. For example, we probably allowed the radiologists more time to assess findings both without and with strain imaging than would be available in actual clinical practice. Previous investigators have demonstrated that evaluations of strain imaging analysis in the “laboratory” setting may confer performance advantages compared with such evaluations performed in a busy clinical environment (18). We provided cine clips to the radiologists, did not provide the radiologists with two imaging planes for each lesion, and presented “jumpy” images as the strain image quality decreased. In short, the imaging protocol that we used was undoubtedly different from that used in clinical practice. While extra reading time may confer advantages in performance, some of our imaging procedures may confer disadvantages.

Second, interobserver variability between the inferior reader—reader A—who improved the most in strain imaging, and the superior readers—readers B and C—who improved to a lesser degree in strain imaging, was significant. Given our results, one
might wonder whether our single inferior reader might have accounted for the overall performance differences that we observed; however, we doubt this conclusion for several reasons: The combination of results for the two superior readers also indicated an improvement in AUC performance, which was nearly significant. Furthermore, the improvement differences make sense because reader A had greater room for improvement than did readers B and C, who performed better with B-mode imaging alone. Strain imaging might more profoundly aid radiologists who are less skilled at making breast cancer risk predictions on the basis of US results, but this theory requires further study.

Finally the case selection limits our ability to generalize our results to other practices with full ranges of image quality. In future studies, it will be important to determine the quality that must be achieved before using strain imaging data for clinical decisions. Although we believe our study results are valuable, one must hear in mind that these findings can, at best, be used to identify patterns that justify proceeding to larger prospective phase I and II clinical trials, the results of which can better prove the value of strain imaging.

In summary, we found that when radiologists integrate US strain imaging features with conventional US characteristics, the differentiation of malignant and benign solid breast masses improves. Therefore, we believe that strain imaging has the potential to improve the decision of whether to perform breast biopsy. Our study findings also demonstrate that interobserver variability and image quality can influence performance. Future research will be critical to understanding whether training and experience can ameliorate these effects. Larger prospective trials are necessary to determine whether strain imaging is a promising tool for the accurate diagnosis of breast cancer.

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