Application of Sound speed and Tissue Stiffness for Breast Characterization

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ABSTRACT

Mammography is not sufficiently effective for women with dense breast tissue. In North America and Europe, women with dense breasts are at much higher risk for developing breast cancer. Consequently, many breast cancers go undetected at their treatable stage. Improved cancer detection and characterization for women with dense breast tissue is urgently needed. Our clinical study has shown that ultrasound tomography (UST) is an emerging technique that moves beyond B-mode imaging by its transmission capabilities. Transmission ultrasound provides additional tissue parameters such as sound speed, attenuation, and tissue stiffness information. For women with dense breasts, these parameters can be used to assist in detecting malignant masses within glandular or fatty tissue and differentiating malignant and benign masses. This paper focuses on the use of waveform ultrasound sound speed imaging and tissue stiffness information generated using transmission data to characterize different breast tissues and breast masses. In-vivo examples will be given to assess its effectiveness.

Keywords: Sound speed, stiffness, spiculation, BIRADS category

1. INTRODUCTION

SomoInsight was a breast screening study that used whole breast ultrasound as a supplement to mammography. It demonstrated that whole breast ultrasound plus mammography outperformed mammography alone [1], leading to the first FDA approval for ultrasound screening for breast cancer. However, one drawback of ultrasound screening is that the call back rate increases significantly (up to a factor of 2 in case of the SomoInsight study) due to lack of efficient lesion characterization [2].

Whole breast ultrasound tomography (UST) offers the potential for multi-parametric evaluation of breast tissue beyond B-mode imaging by its transmission capabilities [3-19]. Complementary to B-mode imaging that uses pulse echo signals, transmission ultrasound takes advantage of transmitted signals to provides additional characterization by measuring tissue parameters such as sound speed, attenuation and stiffness which not only can potentially improve detection of subtle suspicious masses but also can help differentiate lesions.

The UST stiffness relates more to the bulk modulus than the previously discussed strain or shear wave elastogrpahy. SoftVue combines sound speed and attenuation images in a fusion format, which overlays upon an underlying reflection image [19, 20].

In this study, we are going to illustrate the adjunctive benefit of UST stiffness in conjunction with sound speed to render a variety of breast tissue and breast masses. We analyze in vivo breast sound speed and tissue stiffness images to demonstrate sound speed and stiffness features for different breast tissues and unique sound speed and stiffness signatures for a variety of breast masses. We present results from our analysis and discuss the implications of these results for clinical breast imaging.

The purpose of this study is to demonstrate the efficacy of SoftVue to characterize breast masses with sound speed and tissue stiffness color mapping, aiming at additional lesion characterization for possible reduction in call back rates.

2. METHOD

The SoftVue system utilizes a ring shaped ultrasound transducer that acquires both backscattered signals and transmitted signals [18]. Backscattered signals are used to produce SoftVue reflection images (B-mode), while transmission signals are used to reconstruct tissue sound speed, attenuation and stiffness distribution. The resulting tissue stiffness images are color coded and overlaid on the reflection images. All these parameters can be used to assist characterization of breast tissue and breast masses.

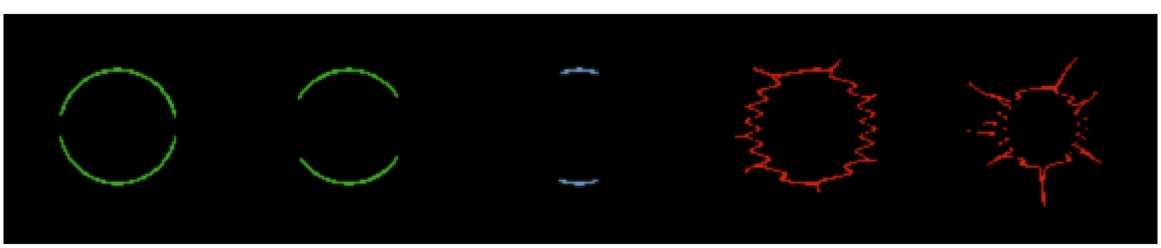
Validation of SoftVue tissue stiffness images to assist breast mass characterization was done in [2], where one anthropomorphic breast phantom was used for initial technique validation, and 11 in vivo breast masses' stiffness images were compared with the standard elastography measurements. In this study, we focused on using SoftVue's sound speed image and tissue stiffness image to help detection and characterization of breast tissue and breast masses. Our measuring metric for sound speed imaging are based on both the quantitative sound speed values and BI-RADS criteria (Table 1) [21]. Different mass boundary scores are sketched in Figure 1. We use stiffness imaging to addresses potential improved characterization of subtle suspicious masses. The method is illustrated in Table 2. A total of 16 in vivo breasts were imaged, representing a variety of breast lesions in patients whose breast density ranges from fatty to dense. Figures 2-4 demonstrate the potential for improved mass detection by a focal area of stiffness for both benigh an dmalignant masses, respectively.

Mass/Tissue Type			
Cyst	**Mass/Tissue Shape**	**Mass Margin**	**Sound Speed Value**
Fibroadenoma	Oval/round	Well circumscribed with distinct margin	Cyst: similar to water sound speed
Cancer	usually oval	Usually circumscribed	Fibroadenoma: similar or higher than water sound speed
Fatty Tissue	Irregular	Microlobulated, Indistinct, angular, spiculated	Varies, usually greater than water sound speed and dense parenchyma.
Dense Parenchyma	Any shape	n/a	Less than water sound speed

Table 1: Quantitative Sound Speed and BI-RADS Criteria for Different Masses

Mass/Tissue Type	**Possible measurements**
Cyst	<u>Soft</u> (bluer than background on average)
Fibroadenoma	Mixed (can be stiff or soft)
Cancer	<u>Stiff</u> (redder than background on average)
Fatty Tissue	Soft (blueish)
Dense Parenchyma	Stiff (generally not as stiff/red as cancer)

Table 2: SoftVue Stiffness Signatures for Different Masses



1 2 3 4 5

Figure 1. Mass boundary scores. Scores1-3: circumscribed; Score 4-5: spiculated.

SoftVue's sound speed and color stiffness images for the selected masses were analyzed and compared to the corresponding mammogram, standard ultrasound, and/or MRI, depending on their availability. A semi-transparent overlay of the SoftVue color stiffness images on the reflection image of the same coronal slice was used to ease the identification of the region of interest.

3. RESULTS

The above metrics were applied to 16 in vivo breast images reconstructed with the SoftVue system. Analysis results are summarized in Table 3. All 5 cancers were characterized as stiff or moderately stiff (red) with mean sound speed range from 1530-1571 m/s. Four fibroadenomas showed mixed stiffness (range of colors), one was stiff. Average sound speed for these 5 fibroadenomas spans from 1534 m/s to 1563 m/s, which is greatly overlapping with the above cancers' sound speed. All 4 cysts were found to be soft or moderately soft, with mean sound speed from 1520 to 1534, which is very close to water bath sound speed.

A few examples are presented below. A highly spiculated IDC is shown at 5 o'clock in figure 2 with an average sound speed of 1541 m/s and is stiffer than the surrounding dense breast tissue (Figure 2d). Spiculations of this IDC are better presented in the zoom-in view (figure 2c). In standard B-mode (figure 2a) this mass shows some shadowing, which indicates higher attenuation than surrounding tissue. Figure 3 shows a dense breast slice with a well circumscribed oval shaped fibroadenoma at 3:00 o'clock. In figure 3c we can clearly see the wall of the fibroadenoma. Figure 3d shows moderate stiffness compared to adjacent dense parenchyma and an average sound speed of 1538 m/s. Again, standard B-model image is presented in figure 3a for reference. An extremely dense breast slice is presented in figure 4, which has a multiple well circumscribed cysts with an average sound speed of 1530 m/s, and a complex cyst at 6:00 o'clock with an average sound speed of 1580 m/s. The stiffness image in figure 4d indicates that simple cysts are soft. The complex cyst at 6:00 o'clock show high focal stiffness and sound speed. In all three examples, fatty breast tissue has the lowest sound speed among normal breast tissue and breast masses, while breast parenchyma generally has higher sound speed than cyst.

Case #	Breast Density	Lesion Pathology	Average Lesion Size (cm)	Clock position	Mass Margin	Average Lesion Sound Speed compared to water sound speed	SoftVue stiffness assessment
1	Heterogeneous	Cancer (ILC)	0.93	5:00	5	greater	stiff
2	Scattered	Cancer (IDC)	3.0	11:00	4	greater	stiff
3	Dense	Cancer (IDC)	2	3:00	4	greater	moderately stiff
4	Heterogeneous	Cancer (IDC)	1.23	6:00	5	greater	stiff
5	fatty	Cancer (DCIS)		11:00	4	moderately greater	stiff
6	Scattered	Fibroadenomas	0.97, 1.38	4:00, 11:00	2, 1	greater, moderately greater	mixed, stiff
7	Dense	Fibroadenoma	1.89	10:00	1	greater	mixed
8	Heterogeneous	Scar		4:00	5	greater	stiff
9	Heterogeneous	Solid Benign Mass		12:00	2	greater	stiff
10	Dense	Fibroadenoma	2.19	3:00	2	moderately greater	mixed
11	Dense	Fibroadenoma		6:00	2	greater	mixed
12	Dense	Cyst		10:00	2	similar	soft
13	Extremely dense	Cyst		1:00	2	similar	Soft
14	Heterogeneous	Cyst	1.66, 1.53	6:00, 9:00	2, 3	similar, slightly greater	moderately soft
15	Heterogeneous	Cyst	3.7	8:00	2	similar	soft
16	Dense	Cysts, complex cyst		Multiple	2	similar, greater	soft, stiff

Table 3. Summary table for all 16 cases

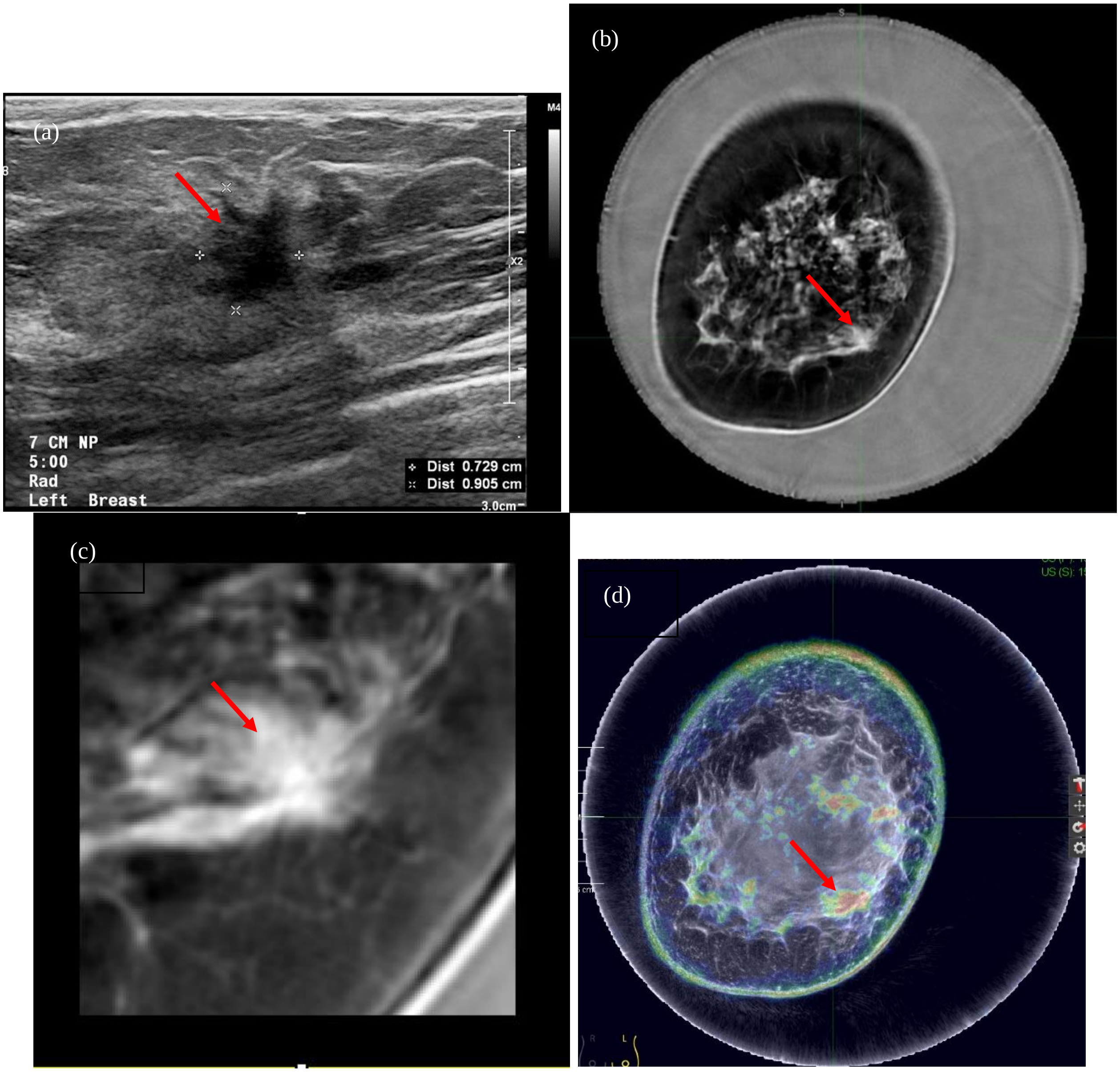


Figure 2. Coronal slice with an IDC at 5:00 o'clock. (a) Standard B-mode image for the IDC; (b) SoftVue sound speed image; (c) Zoomed-in view for the IDC; (d) Corresponding color-coded tissue stiffness information overlay on reflection image (from blue color to red color, tissue/mass get stiffer). Red arrow indicates where the IDC is.

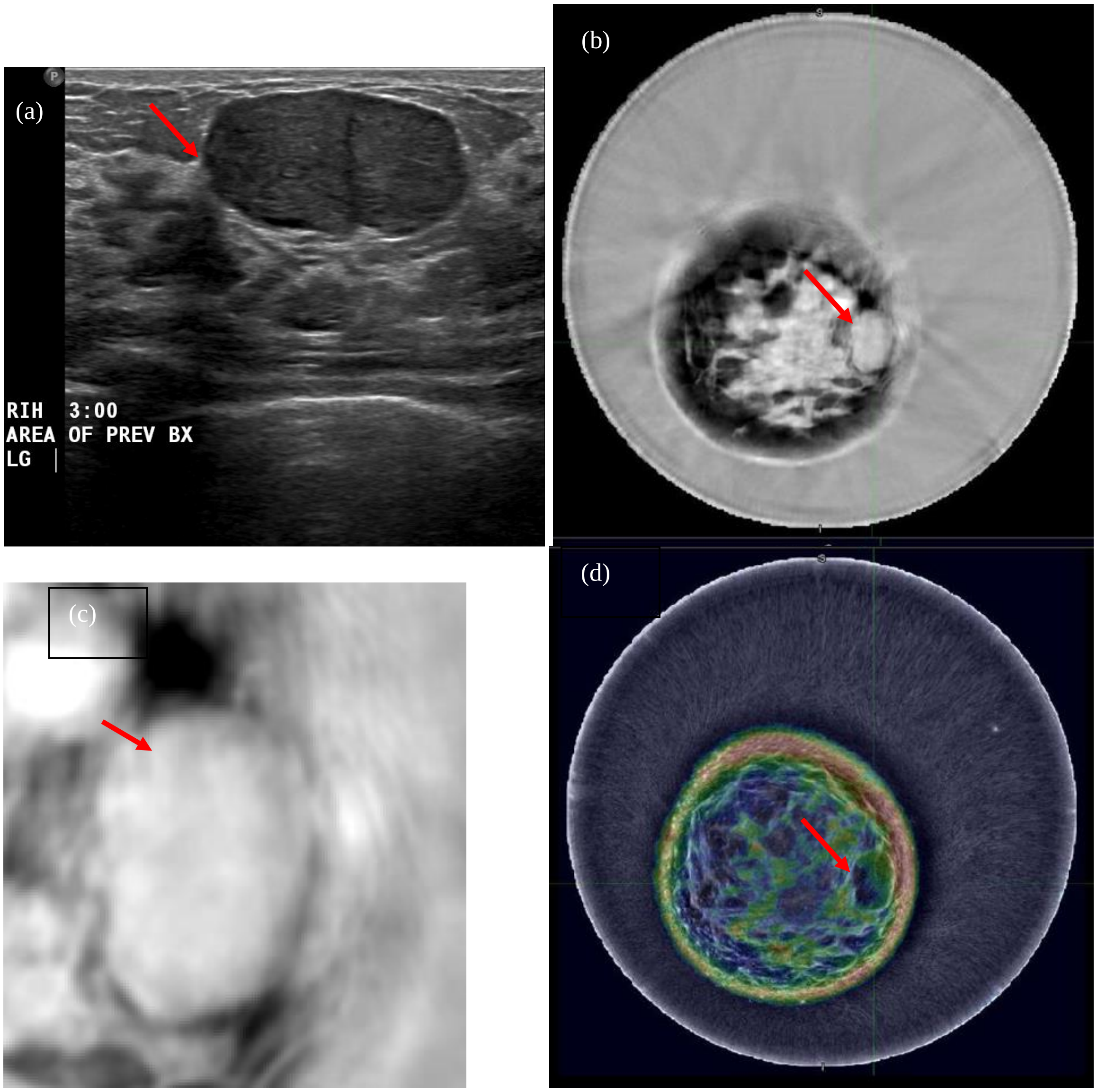


Figure 3. Coronal slice with a fibroadenoma at 3:00 o'clock. (a) Standard B-mode image for the Fibroadenoma; (b) SoftVue sound speed image; (c) Zoomed-in view for the fibroadenoma; (d) Corresponding color-coded tissue stiffness information overlay on reflection image (from blue color to red color, tissue/mass gets stiffer). Red arrow indicates where the fibroadenoma is.

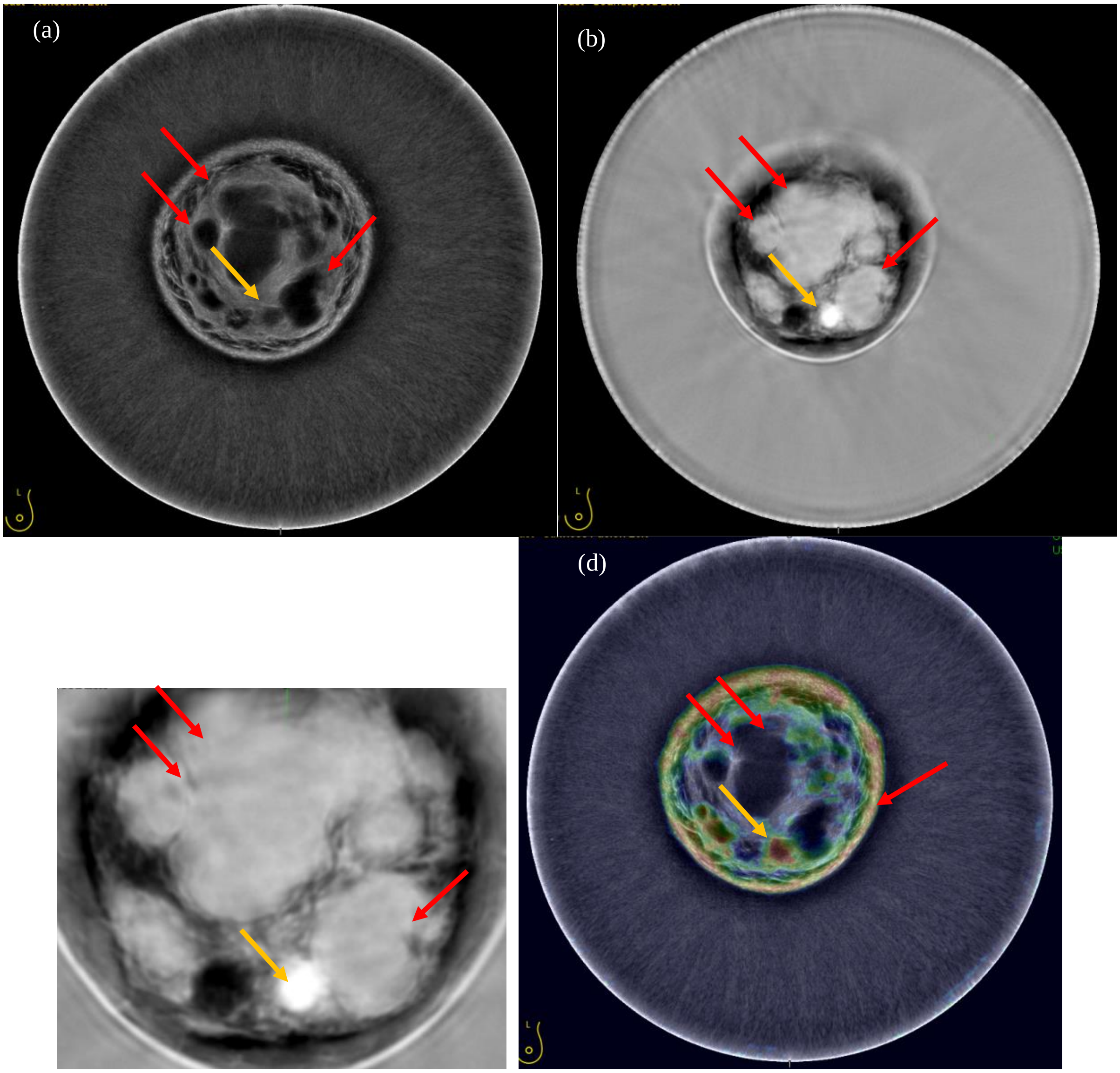
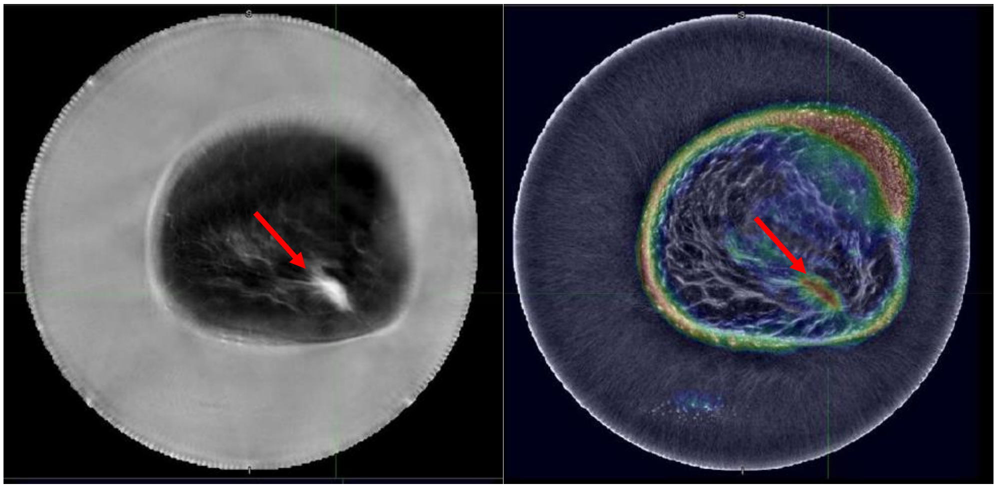


Figure 4. Coronal slice with multiple cysts. (a) UST reflection image; (b) SoftVue sound speed image; (c) Zoomed-in view for the cyst; (d) Corresponding color-coded tissue stiffness information overlay on reflection image (from blue color to red color, tissue/mass get stiffer). Red arrow indicates where simple cysts are and yellow arrow indicates where the complex cyst is.

4. DISCUSSION

The lesion stiffness distribution shows trends that cancers are in general stiffer compared to surrounding tissue, while cysts appear soft. Fibroadenomas can be either soft, stiff or mixed of both. This trend is consistent with properties shown in other modalities. Sound speed values for cancers and fibroadenomas are greatly overlapping, while, as expected, sound speeds of cysts are consistently similar to water sound speed. Combination of sound speed, stiffness and mass margin values demonstrates great potential to assist characterize benign from malignant breast lesions.

However, there are some outlier cases that that we might need to seek the pathology report in addition to the above analysis. The breast in figure 5 has scar tissue at 5:00 o'clock that demonstrates spiculated boundary with high sound speed (figure 5a) and stiffness (figure 5b).



(a) (b)

Figure 5. Scar tissue. Left: sound speed; Right: Stiffness. (Red arrows indicate the location of the mass).

5. CONCLUSIONS

Our in vivo analyses show that, in addition to standard reflection ultrasound, the combination of sound speed and tissue stiffness information provides unique metrics to assist detection and characterization of different breast tissue and breast masses.

We have established detection/diagnosis metrics for breast sound speed and through-transmission rendered tissue stiffness information. A few examples demonstrate that a combination of sound speed and tissue stiffness information has great potential to assist detection and characterization of different breast tissues and breast masses.

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