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An Overview on Shear Wave Elastography

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Abstract:

Shear Wave Elastography (SWE) is a cutting-edge ultrasound-based imaging modality that provides real-time, quantitative assessment of tissue stiffness. By utilizing acoustic radiation force to generate transverse shear waves, SWE measures the speed of wave propagation, which correlates directly with tissue elasticity. This technique has shown significant clinical value in differentiating benign from malignant lesions, particularly in the liver, breast, thyroid, and musculoskeletal tissues. Unlike strain elastography, SWE offers operator-independent, reproducible results with measurable stiffness values in kilopascals. The integration of SWE into routine diagnostic workflows enhances diagnostic accuracy, reduces the need for invasive procedures, and supports earlier disease detection. Despite some limitations, such as depth sensitivity and motion artifacts, SWE continues to gain prominence as a reliable tool in non-invasive tissue characterization.

Keywords: Shear Wave Elastography; Tissue Stiffness; Ultrasound Imaging; Elasticity Mapping; Acoustic Radiation Force; Quantitative Elastography; Breast Lesions; Liver Fibrosis; Thyroid Nodules; Non-invasive Diagnostics; Real-time Imaging; Elastogram; Medical Ultrasound.

Introduction:

Shear Wave Elastography (SWE) is a non-invasive imaging technique that has revolutionized the assessment of tissue elasticity in clinical practice. Based on the propagation of mechanically generated shear waves through tissues, SWE allows for real-time quantification of tissue stiffness, expressed in kilopascals (kPa), offering significant advantages over conventional imaging alone **(1).** Unlike strain elastography, SWE is less operator-dependent and provides objective, reproducible measurements, making it especially valuable in evaluating focal lesions and diffuse parenchymal diseases **(2)**.

The application of SWE spans multiple organ systems, including the liver for fibrosis staging, the breast for characterizing solid lesions, the thyroid for assessing nodule malignancy risk, and musculoskeletal tissues for evaluating tendinopathies and muscle pathology **(3).** In breast imaging, SWE enhances the diagnostic accuracy of B-mode ultrasound by helping differentiate between benign and malignant lesions through elasticity contrast **(4)**. Its role in liver disease management has been particularly impactful, reducing the need for invasive liver biopsies while improving patient monitoring and outcomes **(5).**

As technology advances and SWE becomes increasingly integrated into routine radiologic workflows, understanding its principles, clinical applications, and limitations is essential for radiologists and sonographers alike.

Ultrasound Shear Wave Elastography of The Breast

Principles of Real Time Tissue Elastography Imaging

In an effort to improve the sensitivity of palpation and provide quantitative measures of "palpable lesions" research groups around the world have been actively working toward imaging technologies that display quantitative maps of "tissue stiffness"**(6).**

Ultrasound Shear wave elastography (SWE) is a complementary, non-invasive, commercially available imaging technique that provides information about the mechanical properties of tissues in which stiffness or strain images are used to detect or classify anatomic areas with different elasticity patterns. This technique, based on tissue stiffness/elasticity, helps in the differential diagnosis of benign and malignant breast lesions that conventional ultrasound methods cannot detect **(7)** , thus improving the accuracy of diagnosis of breast cancer and reducing the number of unnecessary biopsies of BI-RADS 3 and 4 lesions **(8)**.

This technology has shown to be valuable in differentiating benign and malignant breast lesions on the basis of their stiffness . Shear-wave elastography (SWE) is advantageous over strain elastography because SWE is less operator dependent, requiring minimal uniform compression of the transducer, and because it provides quantitative measurements of tissue stiffness using a transducer-generated acoustic radiation force.

This method applies ultrasound push pulse to induce shear waves in tissue and uses their propagation to produce a color-coded overlay map representing tissue elasticity in real time . Elasticity can be measured from an ROI within the color overlay and can be displayed as the maximum (E-max), minimum (E-min), mean (E-mean) and SD (ESD) of Young modulus elasticity measurements.

Classification of SWE :

Two methods are available: Shear Wave Elastography (SWE) and ARFI mode (Acoustic Radiation Force Impulse). Shear wave elastography is less operator-dependent than free-hand elastography mode and provides a quantitative approach. A value equal to or more than 60 kPa or Vs of 4.5 m/s. are considered as suspicious. False negatives may occur in soft breast cancers (mucinous carcinoma, carcinoma with an inflammatory stroma, etc.) and false positives may be seen with poorly deformable benign lesions such as old fibrous adenomas.

In practical use, SWE is a useful complementary tool for undetermined breast lesions categorized as BI-RADS 4a or BI-RADS 3, or for cystic lesions but cannot avoid fine needle aspiration or core biopsy if ultrasound features are clearly suspicious. **(9).**

Technique :

The sensitivity of software to the movement is so high that breath alone is sufficient to create an image . Thus, technical procedure is easier to perform and less operator-dependent. B mode image must be located in the centre of the screen before activating the elastography mode and it is recommended to surround the lesion with adjacent tissue in order to obtain a high quality image. The image generated is an elastogram which is displayed as a colour image. in comparison with B mode image, or with an elasticity measurement in speed level (ARFI) or in elasticity in kPa (Aixplorer, SuperSonic Imagine) .Two different ultrasound probes are required, a very high frequency probe to obtain high resolution superficial ultrasound images and a lower frequency ultrasound probe used to obtain shear wave measurement. The velocity of the shear waves is proportional to the stiffness. The stiffness of a lesion can be displayed as the shear wave velocity (Vs) in m/s through the tissue, the shear modulus, or the Young modulus in kilopascals (kPa). Both systems allow you to obtain either measurement or convert from one to the other on the system .

Maintaining the same location of the lesion with no movement is important to obtain accurate results. After the ARFI pulse is applied data acquisition occurs for a short period of time. During the data acquisition period the movement of the shear wave is monitored by B-mode imaging. If there is tissue movement caused by movement of the transducer or the patient the system will interpret this non–shear wave movement in the calculation of Vs. For more accurate measurements, patients must hold still and hold their breath.

With shear wave imaging the color scale can be changed. Red always codes to the stiff tissues and blue to the soft tissues. However, the stiffness where the color changes occur can be changed. For breast tissues a scale with a maximum of 7.7 m/s (180 kPa) is usually the default. With this scale, lesions coded green, yellow, and red are stiff within the range of malignancies. When evaluating tissue with only benign tissue, decreasing the maximum value of the color scale (e.g. 3.7 m/s [40 kPa]) will allow for greater color differentiation of the stiffness of benign tissues. However, red will no longer code for a stiffness value suggestive of a malignancy.

Interpretation basis

In shear wave elastography mode (ARFI), three modes are available: a colour map can be obtained, or velocity measurements may be recorded in m/s or as a colour velocity map.

Velocities of over 4.5 m/s in the lesion are more often seen on malignant lesions (Fig.1) .With shear wave elastography technique, a relevant elasticity value cannot be measured in a pure cyst as shear waves are not induced when the ultrasound beam encounters a cyst. A such kind artifact induces a signal defect in a pure cyst, which can help for the diagnosis (Fig. 2).

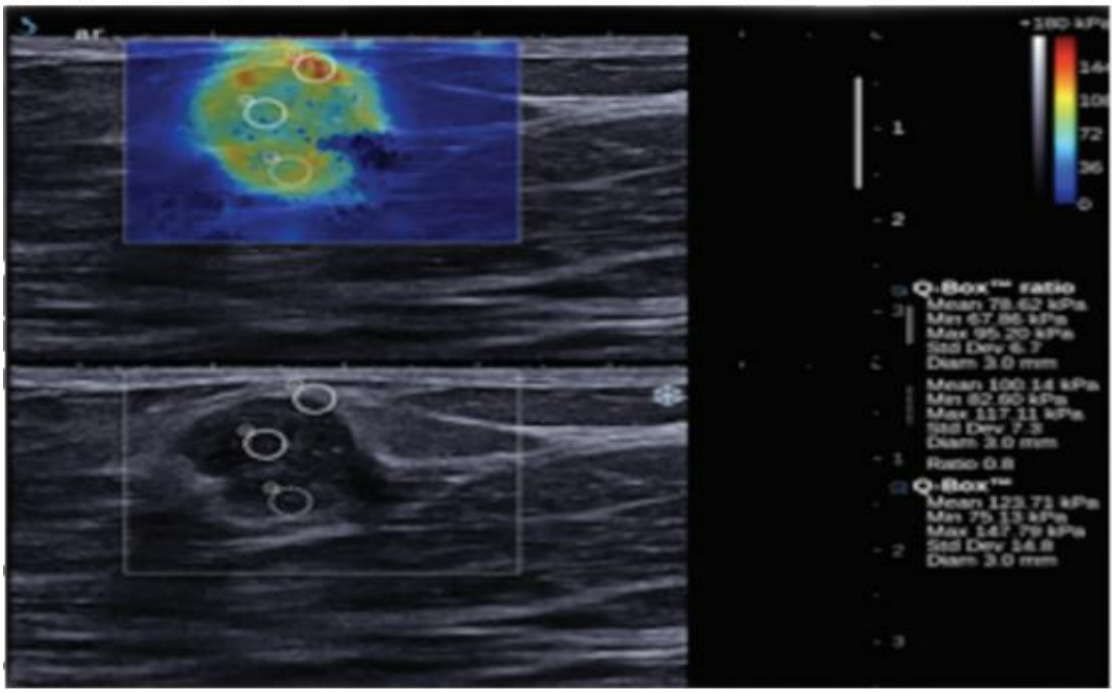

Figure 1: Shear wave elastography images use a color overlay on the B-mode image to provide the shear wave velocity (Vs) in m/s (or estimated Young modulus in kPa) for each pixel in the field of view. In this case the elastogram overlaid on B-mode image is the upper image, whereas the B-mode image is the lower image. The white square is the region of interest (ROI) where shear wave imaging was performed. Opposed to strain imaging, the color coding here corresponds to quantitative measurements that can be used to characterize a breast lesion. In this case of an invasive ductal carcinoma the Vs values are elevated in the malignancy to a maximum Vs of 6.3 m/s (118 kPa) and 2.2 m/s (15kPa) suggestive of a malignancy. When an ROI is placed over the area of interest the maximum, minimum, mean, and standard deviation of the pixels in the ROI is displayed

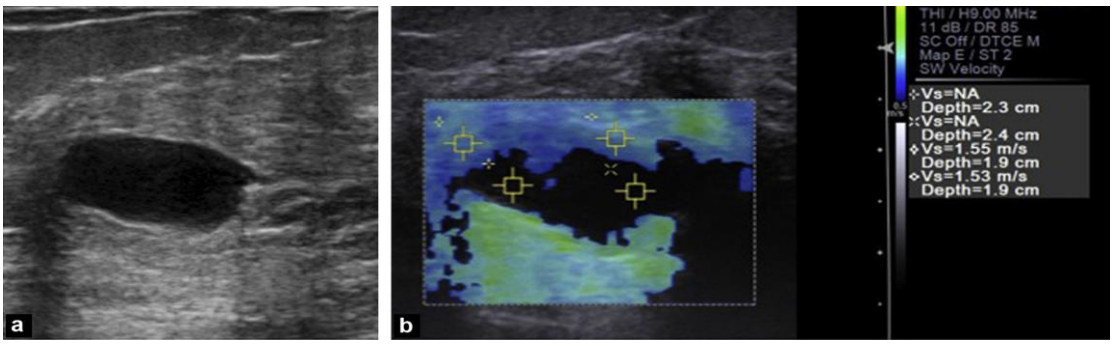

Figure 2. Cyst. Acoustic Radiation Force Impulse mode . The shear waves are not generated when the ultrasound beam encounters a pure cyst (a) as in this example. With this technique, the defect appears as an area of blank

signal (b) although this elastographic feature provides the diagnosis. Speed measurement or kPa measurements cannot be done in the blank signal areas of the cyst.

On Supersonic imagining ultrasound machines, elasticity is measured in kPa and images are displayed on a real time Color map with an adjustable elasticity scale shown in kPa configured by default for the breast at 180 kPa (Fig. 3). Once the acquisition has been performed (on a freeze image), the operator can measure elasticity and elasticity ratios on a region of interest. Several studies have shown variable elasticity threshold for benign or malignant lesions.

A recent study on a large cohort of patients has established that values under 60 kPa associated with an oval shape breast lesion were accurate parameters to assess a benign lesion . Using this cut-off, specificity was improved in comparison with B mode without loss of sensitivity . Malignant lesions usually have values over 120 kPa (Fig. 3 b).

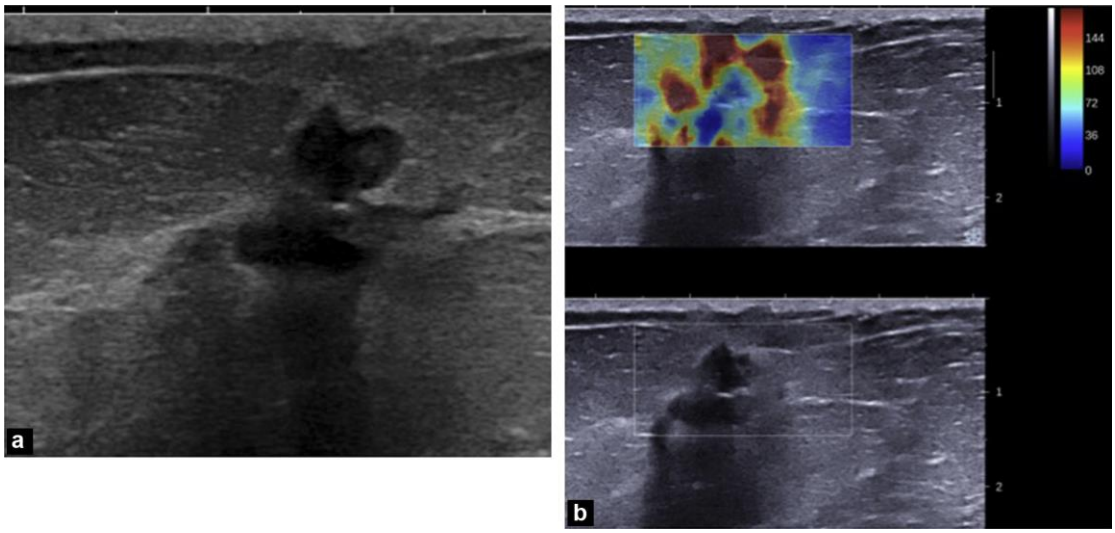

Figure 3. Grade 3 infiltrative ductal carcinoma. Shear wave elastography (SWE) The lesion appears morphologically malignant with spiculated contours and posterior attenuation in B mode (a). In SWE mode, periphery of the lesion is red. This is very common in poorly deformable malignant lesions with measured values of 140 kPa (b). Biopsy confirmed an infiltrative ductal carcinoma.

False positives and false Negatives

False positives :

Shear wave elastography measures elasticity and strain of a lesion. Breast cancers are usually poorly deformable in comparison with benign lesions. Nevertheless,some benign lesions can be poorly deformable: such as fibrous fibroadenoma or scars. Thus elastography is not an accurate tool to evaluate treated breasts. The presence of implants can also change strain of breast tissue around the implant; lesion characterization may be impossible.

False negatives :

Some breast cancers (such as mucinous cancers, cancer with an inflammatory stroma or lesions less than 5 mm in size) appear highly deformable with pseudo-benign features on elastography. However morphology of these lesions is usually highly suspicious on B mode; that may explain why both modes are then complementary.

Deep lesions (> 4—5 cm) are also not always easily analyzed with elastography . Inconsistent results can also be obtained if the density of the breast tissue is high, and lead to false negative results.

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Characterization of benign/malignant solid lesions :

The main interest of breast elastography is to improve the characterization of benign and malignant breast lesions . Many studies have shown that the use of elastography parameters in adjunct to ultrasound parameters can improve BI-RADS score . These results have been obtained with shear wave modes. While elastography may be useful to characterize a cystic content without fine needle aspiration, it is mandatory to avoid a false interpretation when a malignant lesion presents as highly deformable. On the other hand, it appears to be useful for malignant lesions presenting as benign lesions on B mode, which appear poorly deformable on elastography (Fig. 4). The best application seems to be applied to solid BI-RADS 3 or 4a lesions. Elastography can also increase the operator's confidence in his/her diagnosis before a biopsy.

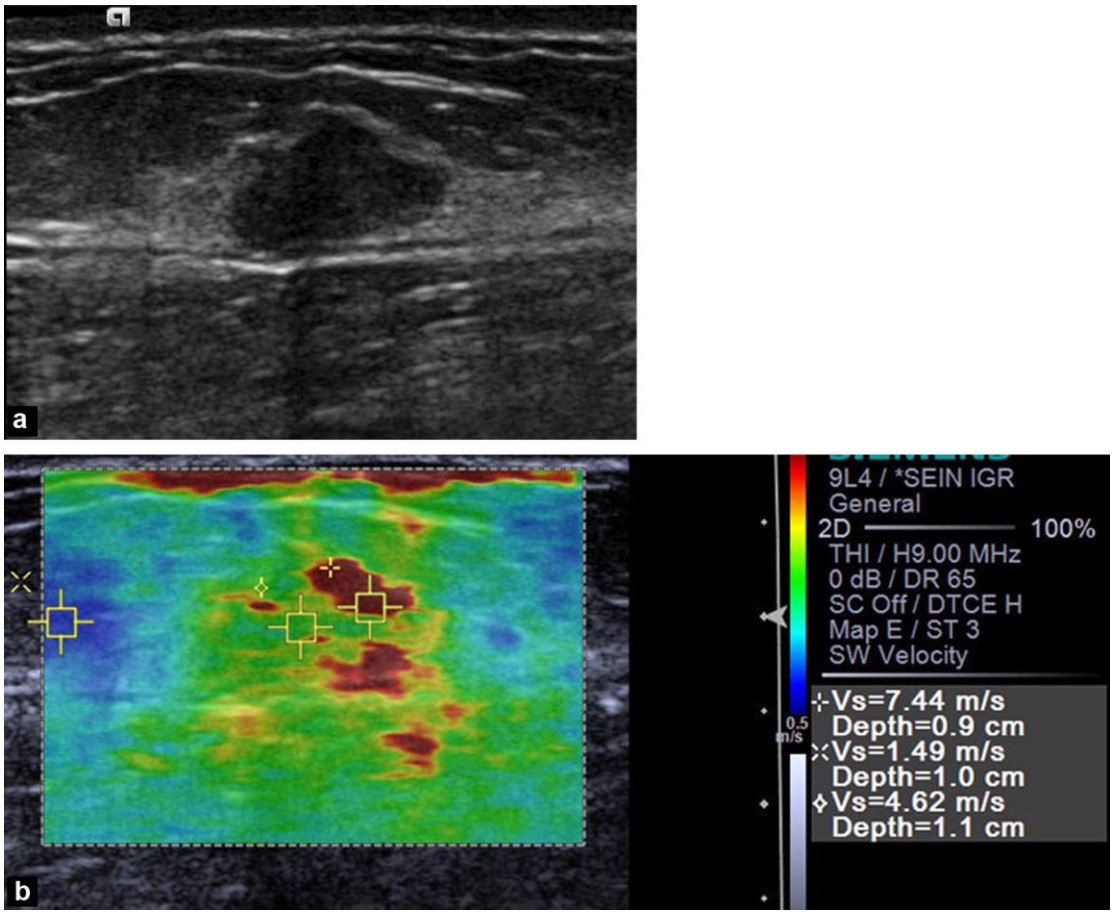

Figure 4. Grade 2 infiltrative ductal carcinoma. Acoustic Radiation Force Impulse mode . In B mode, this lesion appears non-suspicious with an oval shape, no posterior attenuation and regular margins excepted few microlobulations (a). It was categorized as BI-RADS 4a, as it was found in a 40-year-old woman. On the other hand, elastography is more suspicious with very high speed superior than 7 m/s (b). Histology confirmed a grade 2 infiltrative ductal carcinoma.

Shear wave elastography :

Like free-hand elastography, characterization of benign/malignant lesions is improved for solid breast lesions with shear wave elastography (SWE). Several studies have evaluated the input of SWE elastography to characterize breast lesions and have shown its ability to reclassify masses which were initially classified as BI-RADS 3 and 4a. In this study, SWE improved specificity of conventional ultrasound but elastography score must not be used alone independently of the BI-RADS score.

In practice, the discrimination cut-off between benign and malignant lesions is 4.5 m/s (60 kpa) depending on the studies where this technique was evaluated .

In both shear wave elastography techniques, SWE and ARFI, elasticity sometimes cannot be calculated when deformation of a tissue is too low. This may occur in large, very rigid infiltrative cancers . In this case, ultrasound beam cannot penetrate high attenuating areas such as the deepest part of scirrhous cancers. Colours are not seen on SWE mode (Fig. 5) or XXX value is displayed instead a register speed in m/s on ARFI mode. These features must not be misunderstood with low values seen on benign lesions. The systems cannot measure elasticity values in lesions where the tissue does not vibrate enough or because the amplitude of the shear wave is too low and thus lost in the background noise . Similarly, non-viscous cysts do not generate shear waves and can appear as black areas in the hypoechoic area on B mode ultrasound. When the cyst has a minimum level of viscosity, however, shear waves can be recorded with low values.

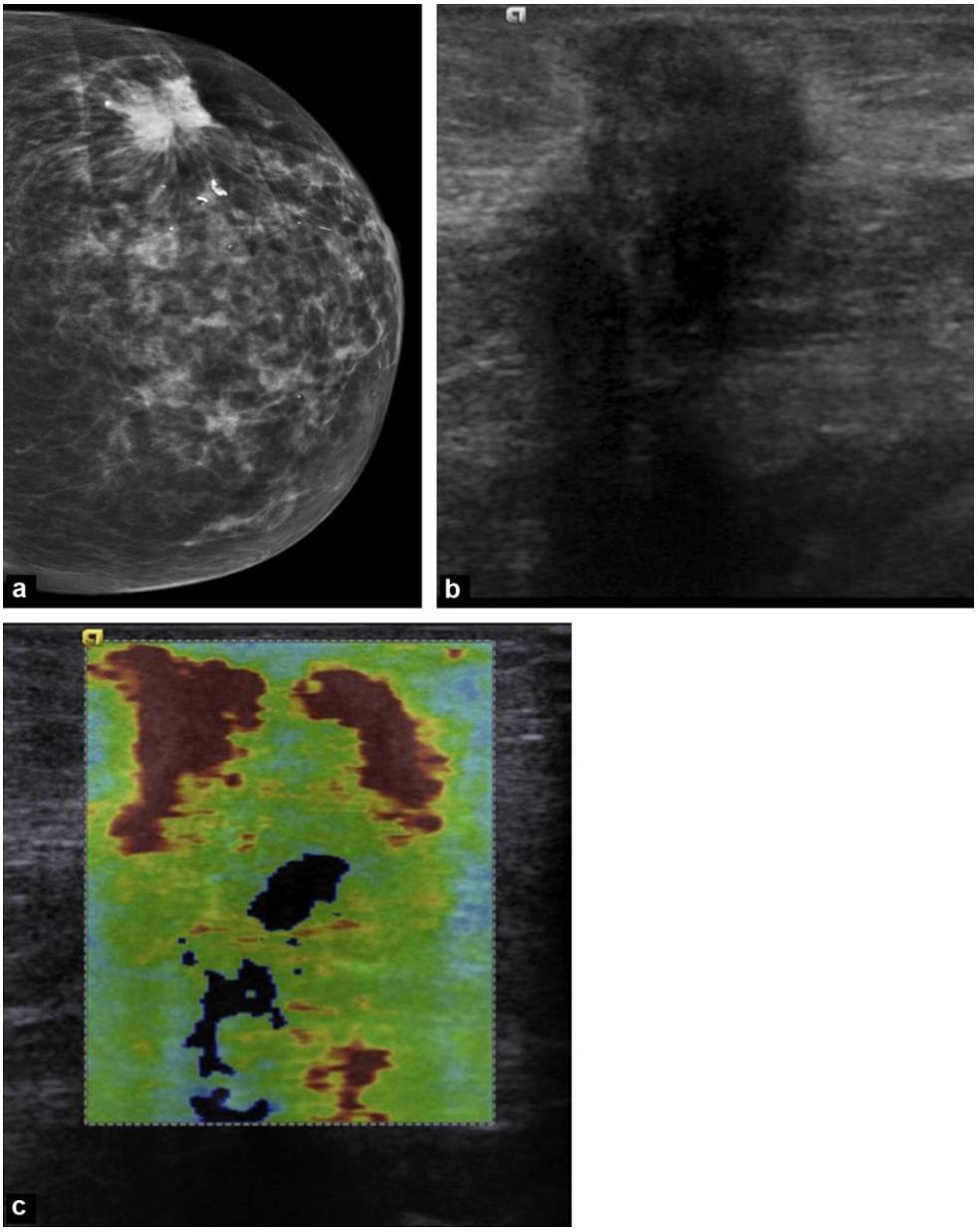

Figure 5 . Grade 3 infiltrative ductal carcinoma. Acoustic Radiation Force Impulse mode . In this spiculated malignant lesion (a), attenuation is very high (b), which is commonly seen in very rigid scirrhous lesions. In this type of lesion, shear waves are not generated, leading to signal defects in the center of the lesion (c).

Conclusion:

Shear wave elastography is a complementary technique to B mode ultrasound in the ultrasound assessment of breast lesions. If biopsy is still recommended, if ultrasound features are suspicious, elasticity imaging may be useful to increase the diagnostic confidence in an indeterminated BI-RADS 3 or 4a lesion. Elastography also appears to be particularly useful to assess the cystic content of a breast lesion with a pseudo-solid feature.

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