Breast Ultrasound Elastography

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After completing this article, readers should be able to:
- Understand the mechanics of compression to create elastic property results.
- Define the ultrasound Breast Imaging Reporting and Data System (BI-RADS) lexicon categories.
- Describe the ultrasounds timeline from its inception to its present-day application.
- Understand the different scoring systems used for elastography.
- Describe the results of studies on the efficacy of elastography.
- Explain how adding elastography imaging may affect imaging facilities’ patient throughput.
- Understand how elastography can improve conventional ultrasound specificity.
- Describe acoustic radiation force impulse and its application to elastography imaging.
- Understand what shear waves are and how, why and when they are measured on an elastogram.

Elastography is a newly emerging study of interest that can be especially helpful when used as an adjunct to conventional B-mode ultrasound in evaluating breast lesions. It is estimated that 80% of breast lesions currently biopsied prove to be benign. Reducing that percentage is advantageous to both patients and the imaging community. The specificity of conventional ultrasound when added to a mammography work-up needs improvement. Adding elastography may improve specificity.

This Directed Reading describes different acoustic techniques used to obtain an elastogram and evaluation of scoring procedures. Major technique differences exist in imaging the elastic properties of tissue.

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Mammography is the diagnostic standard for breast imaging screening. It has proved to reduce deaths by early detection. However, not all breast cancers are detected through use of mammography. Some are not visible or difficult to detect on a mammogram because of the patient’s breast density. Studies have shown that imaging using ultrasound or magnetic resonance (MR) imaging can find small cancers not visible on the mammogram.1

Breast MR imaging has a high sensitivity for carcinoma, especially in dense breasts. A major challenge for breast MR, however, is to improve the specificity to avoid patient anxiety caused by false-positive findings and unnecessary biopsy procedures.2 As with breast MR imaging, many abnormalities seen on breast ultrasound imaging may be false positive, thus limiting MR and ultrasound imaging as effective breast screening modalities.3 Even though generally not applicable for initial breast screening, both MR and ultrasound imaging are excellent resources for diagnosis when additional imaging is indicated. Still, these modalities may not offer definitive proof of malignancy.4

Ultrasound elastography may be the link to bridge the gap between suspicion of malignancy and more definitive differentiation. This modality is a noninvasive way to confirm lesions requiring biopsies and eliminate those that may not require invasive work-ups. When a patient presents with a noncalcified mass on a screening or diagnostic mammogram, an ultrasound is the most often recommended adjunct. B-mode sonography is performed in the region of interest (ROI), and the target mass is identified. Elastography may be performed along with ultrasound instead of biopsy to confirm suspected findings when there is low suspicion of malignancy, saving the patient an invasive procedure. Ultrasound may be the first imaging modality recommended for a
young patient with a palpable lump.\(^4\)

Some studies have shown elastography’s potential to drastically reduce unnecessary biopsies, but this finding has not yet been substantiated by the Agency for Healthcare Research and Quality (AHRQ). The last AHRQ executive summary in 2006 on this issue determined that use of MR, positron emission tomography (PET), scintimammography and ultrasound could reduce the number of false-positive biopsies in women. However, these additional studies still might miss some breast cancers in women. According to the AHRQ summary, the likelihood of missing breast cancers for MR is 3.8%, 7.6% for PET, 9.3% for scintimammography and 5% for ultrasound. Although the percentages are quite low, they still are above the < 2% considered acceptable.\(^5,6\)

Those people working in the field of breast imaging understand that reaching the goal of reducing the number of unnecessary biopsies would represent a huge step toward better patient care in breast imaging not only by saving the patient who has a lesion with low suspicion of malignancy from undergoing an invasive procedure but also as a cost savings. The patient benefits because the lesion can be evaluated in less than 2 hours and there is no need to undergo an invasive procedure or wait for its scheduling and results. Elastography certainly would be less expensive than any type of biopsy procedure. Because of the possibility of malignancy, these lesions need either short-term imaging follow-up or biopsy. Using the elasticity technique may offer a huge benefit in patient care by allowing physicians and patients earlier diagnosis through this noninvasive technique. Hopefully elastography can be useful in evaluating a benign classification and diagnosis but should be combined with conventional diagnostic ultrasound.

### History of Ultrasound Elastography

Ultrasound can be traced as far back as the 1790s when Lazzaro Spallanzani experimented with a bat’s ability to maneuver through the air by using its hearing rather than sight. The Swiss physicist and engineer Jean-Daniel Colladon discovered he could determine the speed of sound using an underwater bell in 1826.\(^7\) In 1880 a breakthrough occurred in Paris when Pierre Curie and his brother Jacques Curie discovered the piezoelectric effect in certain crystals. The following year Gabriel Lippman mathematically deduced voltage differences through use of thermodynamic principles and mechanical stress. The work of these early pioneers served as the foundation for the generation and reception of megahertz ultrasound and development of echo-sounding devices.\(^8\)

With the introduction of World War I submarines, Alexander Beltz of Vienna described an underwater echo-sounding device that allowed for the development of sonar detection systems for better underwater navigation of submarines. In the same year that the Titanic sank (1912), meteorologist Lewis Richardson filed for the first patent on an underwater echo-ranging sonar device.\(^9\) After the sinking of the Titanic, Paul Langevin and Constantin Chilowsky invented the powerful hydrophone to detect icebergs. This device proved to be the first transducer and a major advancement in the history of ultrasound. The hydrophone was able to send and receive low-frequency sound waves.\(^8,9\) The first working sonar system was developed in the United States by Canadian Reginald Fessenden in 1914.\(^9\)

### Ultrasound in Medicine

In the late 1930s the Austrian neurologist and psychiatrist Karl Theo Dussik was the first physician to use ultrasound for medical diagnoses. He attempted to diagnose brain tumors using hyperphonography with a heat-sensitive paper to record the echoes. This attempt is considered to be the start of ultrasonography.\(^9\) The first known diagnostic use of ultrasound in the United States was in the late 1940s when George Ludwig used A-mode industrial flow-detector equipment to locate foreign bodies in animal tissue.\(^9\) A-mode, or amplitude-mode, displays only the data collected from within a single line of sight from the ultrasound unit’s single transducer but provides no information about the echo or what the object generating the echo looks like. This simple early method of ultrasound is used primarily for measurement today.\(^10,11\)
Until the 1950s and 1960s, patients had to be submerged in water to produce images. Douglas Howry and Joseph Holmes improved the B-mode scanner by placing the transducer directly on the patient, which was the start of the way ultrasonography is conducted today. Also in the 1950s John Reid and John Julian Wild built a linear handheld B-mode instrument capable of demonstrating breast lumps by sweeping side to side. B-mode scanning uses a linear array of transducers that work simultaneously; it added a sense of direction to A-mode, giving it a 2-dimensional plane as well as recall of the different echoes.

Because of its heating and disruptive effects on animal tissue, one of the first medical applications of ultrasonics was therapy rather than diagnostics. Therapeutic application has been in use since the invention of the powerful high-frequency ultrasonic echo-sounding device called the hydrophone in the 1920s. High-intensity ultrasound was used as a neurosurgical tool for patients with Parkinson disease to destroy the basal ganglia. In 1953, Jerome Gersten of the University of Colorado reported using ultrasonic energy extensively for the treatment of rheumatic arthritis. Other researchers reported using ultrasonics for the treatment of Ménière disease. Then, because of excessive use for many ailments, ultrasound received criticism regarding its damaging tissue effects. This criticism slowed progress in the development of diagnostic ultrasonography.

The late 1960s and early 1970s could be referred to as the sonic boom period. That was the time when 2-D echocardiography was introduced by Klaus Bom and pulsed Doppler was developed by Don Baker, Dennis Watkins and John Reid. Echocardiography uses M mode to record measurements of the heart’s dimensions and provide details on the complex motions in the heart. It depends on how the sonographer angles the transducer. Another big advancement occurred in the 1980s with the development of real-time ultrasound. By the 1990s, 3-D and 4-D imaging had evolved.

During all of the years of ultrasound’s development, there was no organization or definition of a specific occupational category for the technologists who performed ultrasonography procedures. In 1973 the occupation of sonographer was created through the U.S. Office of Education. In 1979, once the educational requirements were defined in the Document of Essentials, the Joint Committee on Education in Diagnostic Medical Sonography was founded.

**History of Elastography**

In 1991 Jonathan Ophir, a professor and director of the Ultrasonics Laboratory at the University of Texas Medical School at Houston, invented today’s version of the elastography technique by using a modified ultrasound machine. Dr Ophir and his team of researchers discovered that it was possible to noninvasively image and measure the local elastic changes inside soft objects such as body tissue. The National Cancer Institute has supported their work at striving to perfect elastography techniques. Through their efforts they have gathered a large portfolio of patient study results over the past 20 years.

Although ultrasound elastography began in the United States in the 1990s, it also has incubated in research facilities around the world. A type of push and track manual static elastography first was described 30 years ago. Over the years this innovative technique has been referred to by many different names. In the early stages of research and development, Dr Ophir named it elastography. The procedure now is referred to as elasticity, elastogram, sonoeelasticity, sonoelastogram, sonoelastography, real-time elastography, shear wave imaging, color elasticity, strain imaging and ultrasound elastography, to name a few. Some names are more specific to how the elastogram is performed, whereas others refer to the general study itself.

The purpose of one of the early studies that Dr Ophir helped conduct in 1997 was to determine how various breast lesions appeared on elastograms and to explore elastography’s potential role in diagnosing those breast lesions. This groundbreaking elastography research included a total of 46 breast lesions that were examined using elastography. As a diagnostic reference, the patients underwent ultrasound-guided biopsies or aspirations of all the lesions. The pathology results of the individual biopsies or aspirations revealed 15 fibroadenomas, 12 carcinomas, 6 fibrocystic lesions and 13 other lesions. A 5-megahertz (MHz) linear-array transducer was used to generate and collect the elastogram data. Sonographers performed a corresponding conventional sonogram and a single observer evaluated both the sonogram and elastogram. The studies were evaluated for lesion visualization, relative brightness and margin definition and regularity. The sizes of the lesions at each imaging examination and at biopsy were recorded and compared.

The results showed that softer tissues such as fat were the brighter appearing areas on the elastograms and that firmer tissues appeared darker. The firmer
Definition of Elastography

Elastography is a relatively new technique that combines the concepts of ultrasound, physics and mathematical formulas with the tried-and-true clinical tool of tissue palpation. Ancient Greek physicians practiced palpation to find hard masses in organs. Today palpation is still practiced to obtain initial clinical examination information and to guide surgeons in removing diseased areas. During palpation, breast cancer lesions tend to feel harder than benign lesions. Because cancer usually is stiffer or firmer, and the breast is easily compressible, determining the elastic properties of lesions should be useful in differentiating breast masses. Some cancers may feel soft, however, and some benign lesions may feel hard. For instance, some fibroadenomas may be stiff, and mucinous carcinomas may be soft. The results can be very subjective.

B-mode — or conventional — ultrasonography looks at the backscatter of transmitted ultrasound waves through the tissue. Elastography uses the measurement of the tissue’s elastic properties and takes into account the mechanical properties of the tissue’s relative stiffness. The technique is based on the well-known principle that malignant tissue is harder than benign tissue. Also, when a malignant lesion is subjected to strain imaging, it tends to appear larger on the elastogram image than on the B-mode ultrasound image. Strain is the spatial rate of change in an object’s (breast tissue’s) displacement that occurs when an external force compresses it. Put simply, strain is deformation. Coupled together, conventional ultrasound and elastography have proved to be extremely effective in helping to diagnose breast cancers.

A low frequency vibration must be generated to stress — or compress — breast tissue when testing elasticity. This then generates an image with which to analyze tissue stiffness and produce a result within specific parameters. This is how elastograms have traditionally been performed and evaluated. Many studies have found that elastography imaging can help characterize the relative stiffness of tissue compared with its surrounding tissue. Hooke law, Poisson ratio, Young modulus and shear modulus all are referenced in the physics of elasticity. These physics principles of how tissue reacts to external force or stress form the basis of elastography. The Hooke law says that strain is directly proportional to stress. The Poisson ratio is one of the transverse strain to the axial strain.

A shear wave is one in which the disturbance in an elastic deformation is perpendicular to the direction of the wave’s motion. Shear modulus is the ratio of shear stress to shear strain and simply speaking, the Young modulus can put the stress strain ratio in a measurement value. Using these principles in comparing the radiofrequency signal captured before and after tissue compression creates the elastogram image. But using just direct compression and comparing it with the before-compression image is not feasible unless there are extreme differences in elasticity (see Figure 1).

There are 3 phases involved in elastography. In the first phase the breast is mechanically stressed either externally or internally; the second phase measures the tissue’s movement. The third phase estimates the elastic properties from the tissue displacement, which causes a deformation. Harder areas of tissue appear darker and softer areas appear bright. During the deformation part of the elastogram, malignant tissue is dark and has a high contrast next to normal breast tissue, whereas lighter areas of low contrast are typically benign. The elastogram technique is ideal for breast tissue application because the breast is easily assessible to compression using an ultrasound transducer.

Types of Elastography

Using the term elasticity imaging can refer to different techniques to acquire the elastic properties of tissue. These are referred to as strain imaging, shear wave or simply elastography. New techniques of shear wave and strain imaging are key factors in the ongoing...
The disturbance is a compression of the medium. Compression waves also are called longitudinal waves. The strain method is characterized as a static method. Real-time freehand sonoelastography is the most widely used technique. By compressing tissue with a linear-array transducer, the sonographer can impose a color elasticity image over a B-mode image.

**Acoustic Radiation Force Impulse**

Acoustic radiation force impulse (ARFI) imaging creates attenuating acoustic frequency waves that cause different types of elastic properties of tissue to respond differently. The force causes a displacement of tissue that allows the tissue’s mechanical properties to be assessed. ARFI can be assessed by determining the strain index or by determining the shear wave. An advantage to ARFI is that it is not dependent on operator manual compression or physiologic motion of the body. ARFI allows for a numeric measurement as well. Typically, the sonographer acquires a baseline B-mode sonogram. Next, a short acoustic push pulse is transmitted and as that pulse travels through the tissue, the tissue experiences a small displacing mechanical force before relaxing after the pulse. During this function, the sonographic tracking beams collect tissue response data that will be compared with the original B-mode image.

**Strain Imaging**

Strain has been used in elastography since the imaging technique first was developed. Early on, it was thought that the patient’s heartbeat and breathing cre-
ated sufficient strain to generate an elastogram. Strain from heartbeat and breathing, however, does not work for deeper lesions within tissue or for tissues farther from the straining source. Heartbeat and breathing also do not create adequate tissue compression for interpreting physicians to visualize strain.

Using freehand manual compression appears to create better tissue strain. When applying freehand manual compression, however, there is potential for operator error. Some observers have reported that manual compression is a less efficient means to evaluate tissue stiffness. Using the freehand strain method requires the physician or sonographer to manually compress the area of interest. The operator should acquire the initial raw frequency sonographic data, then apply light and consistent compression and capture raw frequency sonographic data again. The amount of compression should be from 0.5% to 2% of the total tissue thickness. Operator variability can present a disadvantage because different operators likely do not apply the exact same amount of compression. Therefore, strain measurements will differ if another operator repeats the study, rendering different results for the same lesion.

**Shear Wave Method**

The beating heart creates shear waves, which demonstrates that shear waves are a harmless natural occurrence in the human body. Tossing a pebble into a pond and watching the water ripple up and outward is a visual depiction of how shear waves might appear. Those ripples represent the shear wave. Until now, it has been difficult to use shear waves for ultrasound elasticity studies because of technologic constraints of ultrasound systems. It requires an extremely fast ultrasound system to track the shear waves and an external vibrator to create the shear waves. The external vibrators originally used were large and bulky and the technique required a 2-handed operation. It was found that by attaching an echographic device and remotely generating a supersonic shear wave, an operator could create supersonic imaging using a conventional ultrasound probe.

The supersonic imaging mode generates “pushing beams” when focused ultrasonic beams create a remote radiation force. The pushing beams only need to be applied once to generate a shear wave from the resulting vibration. Unlike conventional ultrasound, in which the beam is line by line, ultrafast echographic imaging forms the beam only in the receive mode and is slightly diffracting. Once the shear wave is generated, an ultrafast echograph records the acquired successive raw radiofrequency data.

A company called SuperSonic Imagine (Aix-en-Provence, France) developed a way to harness shear waves to evaluate tissue elasticity. The company’s ShearWave Elastography works by generating, capturing and computing shear waves. An ARFI induced by ultrasound beams displaces tissue to create shear waves. Pulses are successively focused at different depths in tissue at supersonic speed. By forming a Mach cone, the beam is enhanced, which increases the shear wave. The ARFI technique requires no transducer compression. Also, this particular technology does not require a change in workflow or a cool-down period for the transducer. The ShearWave Elastography method uses a color-coded tissue Doppler image on top of the conventional ultrasound image with a corresponding color-coded scale quantitatively expressed in values of kilopascals (kPa). In this software, red represents the stiff tissues, whereas blue represents softer tissues and shows the kPa associated value next to the color scale.

**Shear Wave vs Strain**

Supersonic shear wave imaging elastography has an ultrafast software platform. As shear waves move,
they propagate quickly through the body. An acquisition speed of 5000 Hz is necessary to detect them; this speed is 200 times greater than that of conventional systems.27 A line-by-line acquisition method is used in conventional ultrasound but the shear wave method uses flat insonification acquisition.26 The speed of the shear wave propagation is directly related to tissue elasticity values. It can be considered real-time imaging because each pixel in the shear wave ultrasound elastography image has a kPa value.26

The distinction between conventional, or strain, elastography and elastography with shear waves is that using shear waves is not as dependent on operator skill. Strain elastography may be more user dependent with certain equipment. The user applies mechanical compression with conventional strain elastography so the ultrasound scanner calculates and displays the induced deformation, not necessarily the true elasticity of the tissue being imaged. Because conventional strain elastography is not quantitative, it typically has poor reproducibility rates.28 Machine software generates the shear waves, which lowers risk of artifacts from the applied compression.26

**Elastography Strain Imaging Techniques**

The U.S. imaging community uses 3 different methods to exert tissue stimuli and create tissue deformation. These methods are static compression, dynamic vibration and pulsed excitation.27 Static compression uses a uniform compression on the surface of the body to cause deformation of tissue below. Dynamic vibration uses a continuous vibration and is well suited for MR imaging. The dynamic method may not be well suited for ultrasound because it requires an additional device manipulation by the operator. Pulsed excitation can be generated by the beating heart, external vibrators and the radiating force of ultrasound beams. When this acoustic pressure pushes tissue, the tissue reacts with a restoring force. This restoring force propagates shear waves that display transversely within the tissue. These waves are very weak, however, and dissipate quickly. There are limitations to ultrasound power and focus with use of pulsed excitation.26

Like most ultrasound studies, the success of the static method used for elastograms depends heavily on the operator’s technique. To prevent imaging error, the ultrasound operator should avoid nonperpendicular or angulated probe positions, lateral slippage of the transducer and probe compression and decompression that is too slow or too rapid when performing elastography imaging.27 Developing proper technique requires training and has a learning curve.

The sonographer should include adequate area around the lesion to demonstrate any difference between the lesion’s hardness compared with surrounding breast tissue and provide distribution of relative strain. The elasticity ROI should reach down to the subcutaneous layer of the pectoralis muscle vertically but should not include the ribs. The horizontal ROI should take up the entire width of the ultrasound unit’s screen.26 The lesion should not exceed 25% of the ROI’s width.22

**Manual Compression**

When using operator-induced, or manual, compression, the sonographer should compress with the probe only lightly to avoid distorting the breast tissue. False-negative results may be expected when too much compression is applied because overcompression changes the nonlinear properties of tissue elasticity.7 When color is added to this technique, adequate initial compression shows the pectoralis muscle as blue and the subcutaneous fat as a mosaic of green and red.6 The sonographer should acquire 2 series of images of at least 5 seconds each.6 Malignant lesions often appear larger with elastography than with conventional ultrasound because elastography can demonstrate desmoplastic reaction and the microscopically invaded tissue.7

When moving the probe, compression amplitude should be between 1 and 2 mm, and the correct speed for moving the probe vertically is 1 to 2 times per second. The images may have tracking errors and show distortion if the probe is moved too much and too quickly; this could cause a false-positive finding.6 The compression degree scale usually is displayed on the monitor and needs to be within the levels of 3 and 4. It is mandatory to avoid lateral slippage or rotation of the probe. A transducer stabilizer might be helpful to prevent slippage and rotation.6 When the sonographer finds that amplitude was too much, he or she can review all of the images and select for interpretation the still image with the lightest compression in which the lesion seems the firmest.7

**Automated Compression**

Using the word compression to describe elastography denotes a vision of mammography compression of approximately 40%. By comparison, elastography only requires 1% compression.26 Operators first acquired data and use of strain values and stiffness changes
using elastography technique by hand-held or freehand compression. The tissue elasticity is determined when the operator uses the conventional ultrasound transducer to apply pressure to an ROI and the difference in the stiffness of the lesion is compared with the healthy surrounding tissue. It requires a large collection of data and strain estimation algorithms. Operator motion may be prevalent when employing hand-induced compression and the operator also controls the amount of compression pressure, which ultimately influences the elastogram image and score. In 2001 a group of German researchers invented a step-motor controlled hand-held system in an effort to eliminate operator-dependent pressure. The system was purported to improve controlled compressions and synchronized data acquisition.

**Elastography Software**

Three different methods have been proposed to assess tissue elasticity. These methods are a spatial correlation method, a phase-shift tracking method and the combined autocorrelation method (CAM). Longitudinal and lateral displacement is better identified with the spatial correlation method, but the processing time is long. The phase-shift tracking color Doppler technique offers more rapid processing time and high precision, but this technique’s displacement domain measurability is narrow and its slip sensitivity is weak. The CAM method has a fast processing time with high precision and robust slip sensitivity, and unlike the other methods, can compensate for up to 4 mm of lateral displacement.

The principle that compression causes deformation can be expressed by the Young modulus of elasticity. This can be calculated with dedicated software, such as CAM. It produces a color-coded map of the degree of tissue elasticity; the image is referred to as an elastogram. In 2006 a study was done by Ito et al to evaluate the diagnostic performance of real-time freehand elastography by using an extended CAM to differentiate benign breast lesions from malignant ones applying pathologic diagnosis as a reference standard. The study’s researchers modified the CAM to an extended CAM to overcome the problems faced using the spatial correlation method, the phase-shift tracking method and the inevitable lateral and elevational tissue movements when using the original CAM method.

Conventional ultrasonography and then ultrasound elastography with this new CAM method were performed on 111 women who presented with breast lesions. Fifty-two of the lesions were malignant and 59 were benign. Elasticity images were assigned an elasticity score according to the degree of distribution of strain induced by light compression. To assess diagnostic performance, both the area under the curve and cutoff point were obtained by using receiver operator characteristic (ROC) curve analysis. The results showed elastography had 86.5% sensitivity, 89.8% specificity and 88.3% accuracy. Conventional ultrasound had 71.2% sensitivity, 96.6% specificity and 84.7% accuracy. Elastography had a higher sensitivity than conventional ultrasound and its specificity was not significantly inferior. Accuracy of elastography was equivalent to that of conventional ultrasound. The study concluded that when using elastography to assess breast lesions, elasticity scoring was simple compared with BI-RADS scoring and that elastography had almost the same diagnostic performance as conventional ultrasound.

In 2010, Chung et al published a study comparing computer-assisted quantification and visual assessment of lesion stiffness using ultrasound elastography as it pertains to the differentiation of benign and malignant lesions. They found nonpalpable breast lesions in 120 women using ultrasound elastography, which was subtracted from the color elasticity images to compute the mean strain lesion value. The lesions were assigned a color elasticity score between 1 and 5. Through biopsy and histology, 70 were found to be benign and 50 were malignant. When the studies were compared using a computer-assisted quantification method and visual assessment of the radiologists, the difference was not statistically significant. The authors concluded that there was no comparable difference between using computer-assisted image quantification vs a radiologist’s visual assessment.

Elasticity scoring assessment is more accurate in the horizontal plane because images change vertically with the vertical movement caused by compression. One study specifically designed to establish what factors would determine quality elastography found that elasticity scores can vary for the same lesion when it is imaged in the sagittal vs coronal projection. This study suggested that it was important to examine the lesion with both sections and to use the highest score if a score discrepancy occurred. The study also emphasized that compression influences the examination result and the need to include as much healthy tissue as possible vs limiting field of view to the lesion.

The elasticity score interpretation can differ depend-
ing on lesion shape and for mass vs nonmass lesions. When evaluating ductal carcinoma in situ, images may appear as partly mottled areas that are firmer than adjacent glandular tissue. Needle biopsy should still be considered for these types of lesions, no matter what the elasticity score is.7

### Ultrasound Scoring Systems

#### BI-RADS Ultrasound Scoring Criteria

Addition of elastography to breast imaging does not negate the importance of existing scoring available from the American College of Radiology’s Breast Imaging Reporting and Data System (BI-RADS) Atlas. The BI-RADS Atlas lexicon for ultrasound is basically the same in the final interpretation to that used for mammography. To help correlate the information to be more relevant to ultrasound results, the ACR created the BI-RADS-US. The ACR also provides an ultrasound BI-RADS classification lexicon form on its website.35 The Box on page 359 lists the ACR BI-RADS-US assessment categories.34

### Strain Scoring

Depending upon the type of equipment used, elastography with strain scoring superimposes an overlay of various colors or 256 gray shades on the 2-D image to represent a lesion strain score. This type of color elasticity scoring uses the strain of the tissue and adds the chromatic scale assigned to the different levels of elasticity.11 The stiffer areas usually are blue or dark gray and softer, and more elastic tissues are red and green or lighter shades of gray.6 The colors may vary by clinician preference.11 Clinicians should assess the horizontal rather than the vertical color patterns.4 As of this article’s writing, there were 2 strain elastography scoring systems. Tsukuba Elastography Score patterns were developed by Itoh and Ueno6 (see Figure 3). This system also has been referred to as Ueno-Itoh scores or just Ueno scores:

- **Score 1**: is predominantly green, which represents overall similar strain (see Figure 4).
- **Score 2**: lesions have an overall mosaic pattern of green and blue (see Figure 5).
- **Score 3**: these lesions have an elastic green periphery and a stiff blue core (see Figure 6).
- **Score 4**: represents rigid blue lesions, but it does not include an echoic halo (see Figure 7).
- **Score 5**: lesions are stiff blue and also have a blue echoic halo indicating their surrounding tissues have no displacement with compression12 (see Figure 8).

The Tsukuba scores are designed only for solid lesions that do not have the blue, green and red (BGR)


3-layered pattern typical of fluid-filled cystic lesions. The Italian research group of Locatelli et al developed and proposes the use of the Italian Elastography score. This scoring system is modified from the Tsukuba scoring system:

- Score 1 – represents the BGR 3-layered pattern of a cystic lesion.
- Score 2 – is a diffuse green and represents an elastic pattern.
- Score 3 – is predominantly green but with some areas of blue (no strain).
- Score 4 – is a predominantly rigid no-strain pattern of blue.
- Score 5 – is a stiff blue lesion with a rigid surrounding tissue as well.

The cancer probability increases the higher the numbered score for both the Italian and Tsukuba scores. A score of 1 to 3 suggests benign lesions and 4 and 5 indicates malignant lesions. In both scoring systems the 3-layered BGR appearance is indicative of a breast cyst. Blue is the superficial color, whereas red represents the deeper area. Elasticity has reportedly been helpful in diagnosing cysts. Complex cysts with impure content can be difficult to differentiate from solid lesions using conventional ultrasound only. With strain elastography, these complex cysts have the cystic BGR appearance and score. Their size also remains consistent with the B-mode ultrasound, unlike malignant lesions, which appear larger with elastography than on conventional ultrasound. Being able to differentiate complex cysts from solid lesions could help avoid an invasive procedure for women who have small benign-appearing but hypoechoic lesions.
The Italian group’s scoring criteria was derived from a 2006 large multicenter study. The researchers conducted high-resolution ultrasound and real-time elastography with the same technology and procedure at 8 different imaging centers. There were 874 breast lesions found in 784 women; definitive diagnosis was made with core biopsy or fine needle aspiration of 614 benign lesions and 260 malignant lesions. The ultrasound images were classified according to the BI-RADS criteria for ultrasound (see Box). An elastographic score of 1 to 5 was assigned to images according to the distribution and degree of strain of the lesion induced by light manual compression. They provided scores relating to both solid and cystic lesions by adding BGR as score 1 to this new scoring system. The Italian group justified their new classification by saying that it relates better to the BI-RADS assessment categories — the BI-RADS categories include cystic as well as solid lesions.

During the study’s elastography scanning process, many elasticity images were obtained by continuous compression and relaxation movements. The researchers observed that cysts always showed a consistent 3-layered artifact pattern, further justifying addition of the BGR score of 1. By applying the ROC curve, the researchers were able to demonstrate that elastography works better in lesions with a diameter ≤ 15 mm. This study also stated that the best results were obtained in imaging lesions of < 5 mm. An average of all lesions with elasticity scores 3 and 4 had a true negative predictive value (TNPV) of 98%. All BI-RADS 3 lesions in the study had a 96.3% TNPV, and lesions ≤ 5 mm had 100% TNPV.

The researchers maintained that the high specificity of elastography in this series confirmed the results they obtained with their scoring system. Their higher TNPV strictly correlated to the changes included in their new proposed scores and showed it clearly is insensitive to the thickness and the echogenicity of the breast and to the depth and size of the lesion. The researchers proved that their elastography scoring interpretation resulted in a high reproducibility level. They also found that operators could acquire diagnostic scores for nearly all patients in a few minutes, after a brief learning curve.

Strain Index

An important development to improve the strain method elastogram has been calculation of the strain index. Strain index is defined as the fat-to-lesion strain ratio determined by measuring the difference between the stiffness of the target lesion and that of the surrounding tissue once the predetermined amount of compression is exerted upon the ROI and surrounding tissue. The acquisition of the strain index calculation takes approximately 2 minutes. High-speed algorithms and software programs to measure strain index that are embedded in the ultrasound unit have become available. This software enables the system to automatically calculate the strain index, which reduces time and operator error. Performing strain index elastography also can be as simple as adding or activating a software program during ultrasound imaging. Recently, some researchers have set out to prove whether measuring the strain index ratio would be as good as or a better predictor of malignancy than the color elastography score by calculating the strain ratio (SR) value based on the average measurement of strain in the lesion compared with the average measurement of strain in the adjacent fattier breast tissue. The softer the tissue is, the more deformation it shows when compressed. Softer tissue strain is higher when compared with background tissue. Selecting an ROI in the lesion and an ROI in the adjacent breast tissue and applying a calculation formula can lead to determining the SR. The lesion SR increases as the lesion stiffness increases.

A 2009 Korean study concluded that the strain index based on the fat-to-mass strain ratio determined with elastography showed a diagnostic performance comparable to that of conventional ultrasound for differentiation of benign and malignant nonpalpable breast masses. This study suggested that the sonoelastic strain index can be used as a supplementary measure to differentiate benign breast masses from malignant ones.

In a 2008 Chinese study, researchers evaluated whether strain ratio measurement could semiquantitatively evaluate breast lesion stiffness. The study included 148 patients with 254 breast lesions. Of the 254 lesions, 183 proved to be benign and 71 proved to be malignant. The lesions were found using conventional ultrasound and the strain images were obtained using ultrasonic elastography. Each lesion strain index was calculated with the strain ratio measurement method on a conventional ultrasound system. This study found that by using the same depth compression of breast tissue as reference, the stiffness of breast lesions could be semiquantified. The authors also reported that the strain index of benign lesions in their study was in the range of 0.62 to 11.07 and malignant lesions were in the range of 3.12 to
Lesion Size Comparison

Some earlier studies were conducted to determine whether measuring the lesion size in B-mode and strain imaging might prove to be a predictor of malignancy. A scoring criteria may differ depending on specific software. Studies have suggested that a cutoff SR score ratio of 4.8 would be best for differentiating benign from malignant lesions, with an SR of < 4.8 indicating benign and ≥ 4.8 suggesting malignant properties. The scoring criteria may differ depending on specific software.

Box ACR BI-RADS Ultrasound Assessment Categories

- **Category 0** — Need Additional Imaging Evaluation: In many instances, the US examination completes the evaluation of the patient. If US is the initial study, other examinations may be indicated. An example would be the need for mammography if US were the initial study for a patient in her late 20s evaluated with US for a palpable mass that had suspicious sonographic features. Another example might be where mammography and US are nonspecific, such as differentiating between scarring and recurrence in a patient with breast cancer treated with lumpectomy and radiation therapy. Here, MRI might be the recommendation. A need for previous studies to determine appropriate management might also defer a final assessment.

- **Category 1** — Negative: This category is for sonograms with no abnormality, such as a mass, architectural distortion, thickening of the skin or microcalcifications. For greater confidence in rendering a negative interpretation, an attempt should be made to correlate the US and mammographic patterns of breast tissue in the area of concern.

- **Category 2** — Benign Finding(s): Essentially a report that is negative for malignancy. Simple cysts would be placed in this category, along with intramammary lymph nodes (also possible to include in Category 1), breast implants, stable postsurgical changes and probable fibroadenomas noted to be unchanged on successive US studies.

- **Category 3** — Probably Benign Finding-Short-interval Follow-Up Suggested: With accumulating clinical experience and by extension from mammography, a solid mass with circumscribed margins, oval shape and horizontal orientation, most likely a fibroadenoma, should have a less than 2 percent risk of malignancy. Although additional multicenter data may confirm safety of follow-up rather than biopsy based on US findings, short-interval follow-up is currently increasing as a management strategy. Nonpalpable complicated cysts and clustered microcysts might also be placed in this category for short-interval follow-up.

- **Category 4** — Suspicious Abnormality/Biopsy Should Be Considered: Lesions in this category would have an intermediate probability of cancer, ranging from 3 percent to 94 percent. An option would be to stratify these lesions, giving them a low, intermediate, or moderate likelihood of malignancy. In general, Category 4 lesions require tissue sampling. Needle biopsy can provide a cyto logically or histologic diagnosis. Included in this group are sonographic findings of a solid mass without all of the criteria for a fibroadenoma and other probably benign lesions.

- **Category 5** — Highly Suggestive of Malignancy/Appropriate Action Should Be Taken (Almost certainly malignant): The abnormality identified sonographically and placed in this category should have a 95 percent or higher risk of malignancy so that definitive treatment might be considered at the outset. With the increasing use of sentinel node imaging as a way of assessing nodal metastasis and also with the increasing use of neoadjuvant chemotherapy for large malignant masses or those that are poorly differentiated percutaneous sampling, most often with image-guided core needle biopsy, can provide the histopathologic diagnosis.

- **Category 6** — Known Biopsy-Proven Malignancy/Appropriate Action Should Be Taken: This category is reserved for lesions with biopsy proof of malignancy prior to institution of therapy, including neoadjuvant chemotherapy, surgical excision or mastectomy.
malignancy. A study in 2007 to determine the helpful diagnostic performance of sonographic elastography combined with conventional sonography concluded that the characterization of breast masses as benign or malignant did not improve radiologists’ performance. It did, however, determine that the area ratio of the lesion was of better diagnostic value than the 1-5 elasticity score. Another study in 2006 concluded that tracing and measuring the ratio differences was too time consuming in a busy imaging practice. The time might be lessened with observer training and automated processes. However, the study results did not show a high specificity. Calculating the lesion size would be best served with specific software designed to automatically do so for the operator.

Shear Elasticity Scoring

When assessing properties using shear elastography, mechanical waves are used to cause deformation on the lesion’s surface and interior. The order of magnitude of mechanical displacement is also an indication of elasticity. The most common way of measuring the physical quality of tissue stiffness is by the Young modulus and expressing the stiffness in kPa. According to the Young modulus, the ratio of stress to the corresponding strain equals its elasticity. Harder tissues have a higher Young modulus kPa value than softer tissues. A score > 100 kPa is considered a hard breast lesion. Normal breast tissue elasticity can vary between 1 and 70 kPa, but breast carcinomas can vary from 15 to > 500 kPa. A 2010 study found malignant lesions had a mean elasticity score of 146.6 kPa and benign lesions had an average elasticity score of 45.3. They also stated that complicated cysts could be distinguished from solid lesions because the cysts’ elasticity scores generally were 0 kPa; this was because no signal was retrieved from the liquid areas.

Clinical Application of Elastography Scoring

Although BI-RADS criteria don’t specifically mention the addition of elastography, they show the importance of further testing of suspicious lesions. If elastography can prove its intended role of biopsy reduction, clinical recommendations may eventually include different actions related to elasticity. At least 75% of patients have benign breast biopsy findings. Because elastography helps the radiologist better understand breast morphology, this modality would hopefully reduce unnecessary biopsies and focus on more definitive findings for biopsy. Reduction of unnecessary biopsies would be an overall improvement of patient care as well as a medical cost reduction.

The appropriate scoring system chosen is dictated by the type of elastography used. Scoring of an elastogram also depends on the type of software and ultrasound unit on which the examination in performed. Whether color is available dictates the resulting visual strain image. Researchers and clinicians continue to discuss which scoring system would be preferential to use as the best predictor of benign and malignant lesions — the strain ratio and the Tsukuba or Italian group scoring system when using transducer compression elasticity imaging — all of which are possibilities. Numeric kPa and color lesion elasticity scoring can be applied to ARFI shear imaging. BI-RADS scoring still will be the reported result of the study interpretation.

Evaluating the Efficacy of Elastography

Elastography has its limitations. Certain types of carcinomas along with larger carcinomas may not be evaluated with certainty using elastography. One study found that 79% of proven breast carcinomas had the higher 4 or 5 elasticity score, especially if they measured < 1.5 cm. Elastography can be helpful with diagnosing the atypical carcinomas that might be very small or are hyperechoic and have acoustic enhancement. Breast carcinomas that score a low 1 to 3 on one of the sonoelastogram scoring systems might be nondifferentiated or papillary carcinoma, inflammatory carcinoma, hypercellular, necrotic or pseudocystic malignant tumors, postbiopsy hemorrhagic lesions, small and deep neoplastic nodules, mucinous or medullary cancers. In addition, larger cancers > 2.5 cm also may score a benign 2 by displaying benign elastic features.

Improving Ultrasound Specificity

Adding elastography to conventional ultrasound imaging to measure the compressibility and mechanical properties of a lesion could improve ultrasound’s specificity. Specificity refers to the accuracy of a given test. The sum of true-negative results divided by the sum of true-negative and false-positive results is the ultimate specificity result. In other words, it is the probability that a test result shows a negative result that is indeed negative (in this case, free of breast cancer). Ideally, an examination should have a high specificity. Mammography, MR, ultrasound, PET and scintimammography have high sensitivity, but may lack specificity. This means the images from these modalities help radiologists identify questionable lesions but do
not help them distinguish the lesions as malignant or benign. The hope is that elastography combined with ultrasound imaging can fill this gap. In 2006 Thomas et al conducted a study to evaluate whether real-time elastography improves specificity; real-time elastography was performed on 108 patients.\textsuperscript{44} Cytologic or histologic results were used to confirm all 108 lesions, with 59 being benign and 49 proven malignant.

Using a 3-D finite element method, lesions were evaluated for elasticity measurement based on the correlation between tissue properties and elasticity moduli of the tumor and surrounding tissue. This method color-coded the information and superimposed it on the B-mode ultrasound image. To improve the objectivity of the method, a second observer evaluated the elastography images. The results of the conventional B-mode ultrasound and the real-time elastogram were compared with the results from histology and the previous sonogram findings. The conventional ultrasound had a sensitivity of 91.8% and specificity of 78% compared with 2 observers’ elastography evaluations at sensitivities of 77.6% and 79.6% and specificities of 91.5% and 84.7%.

The authors found that there was general agreement between elastography and conventional ultrasound. The study authors’ initial clinical results found that elastography is a promising approach for diagnosing breast cancer, and this study suggested that real-time elastography improves the specificity of breast lesion diagnosis. Additionally, the study reported that elastography might provide additional information for differentiating malignant BI-RADS category 4 lesions.\textsuperscript{44}

A 2008 study in China also evaluated whether real-time ultrasound elastography, when performed in conjunction with conventional ultrasound, can improve overall specificity. This study referenced 139 lesions found in 112 patients. All patients underwent both conventional ultrasound and real-time ultrasound elastography. According to the degree of strain distribution with mild manually induced compression, an elasticity score between 1 and 5 was assigned to each lesion. Those scores were compared with the lesion’s BI-RADS assessment category obtained from its conventional ultrasound finding. Surgical pathology results were used to assess the sensitivity, specificity and accuracy of each method. Pathology results revealed 70 benign and 69 malignant lesions. The mean elasticity score was significantly higher for malignant lesions and lower for benign lesions. With a cutoff score of 4, the results for ultrasound elastography were:

- Sensitivity — 85.5%
- Specificity — 88.6%
- Accuracy — 87%

Results for conventional ultrasound were:

- Sensitivity — 94.2%
- Specificity — 87.1%
- Accuracy — 90.6%

Of the 64 lesions assessed as BI-RADS category 2 or 3 (probably benign) on conventional ultrasound, 2 were scored 4 and 5 (probably and likely malignant) using ultrasound elastography and indeed proved to be malignant. Of the 75 lesions with BI-RADS category 5 (ie, likely malignant) from conventional ultrasound, 1 was scored as category 1 (benign) with ultrasound elastography and was determined to be benign by pathology. The results suggest that the addition of breast ultrasound elastography to conventional breast ultrasound imaging could be helpful in detecting and characterizing lesions.\textsuperscript{44}

Adding Assessment Information
A study by Tan et al was conducted to prove the efficacy of evaluating breast lesions using ultrasound elastography as an adjunct to B-mode conventional ultrasound. The authors of the study purport that using ultrasound elastography and the extended CAM combined with the BI-RADS scoring system allows for real-time strain image visualization at the same time conventional ultrasound is being performed using a freehand probe. The study’s 415 women had 550 breast lesions confirmed with conventional B-mode ultrasound. The lesions were assessed with ultrasound elastography using the elasticity 1-5 scoring system. There were 119 malignant and 431 benign lesions. The study results showed elastography sensitivity of 78%, specificity of 98.5% and overall accuracy of 93.8%.

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The authors reported that the median score for malignant lesions was 5, and the median score for benign lesions was 2. It found that 98.6% of the lesions with an elasticity score of 2 or below were confirmed as benign. The authors stated that BI-RADS category 3 lesions with an elasticity score of ≤ 2 may be reclassified as BI-RADS 2. There were 3 lesions with an elasticity score of 3 that were malignant. The conclusion of this study was that real-time ultrasound elastography is user friendly. It also concluded that it has a high accuracy rate, thereby improving B-mode ultrasound assessment.\textsuperscript{45}
Avoiding biopsy for women with BI-RADS category 4 lesions would be a substantial goal of elastography. One study’s objective was to compare the diagnostic performances of conventional ultrasound and ultrasound elastography for differentiation of nonpalpable breast masses and to evaluate whether elastography is helpful at reducing the number of benign biopsies by using histologic analysis as a reference standard. Conventional and real-time elastographic images were obtained for 100 women who had been scheduled for an ultrasound-guided core biopsy of 100 nonpalpable breast lesions. Histologic results revealed 83 benign lesions and 17 malignant lesions.

Two experienced radiologists who were unaware of the biopsies’ clinical findings analyzed conventional ultrasound and elastographic images by consensus and classified lesions based on the degree of suspicion regarding the probability of malignancy. Results were evaluated by ROC analysis; in addition, the authors investigated whether a subset of lesions was categorized as suspicious by conventional ultrasound but benign by elastography. The authors concluded that the subset of BI-RADS category 4a lesions with an elasticity score of 1 probably do not require biopsy. Category 4a is described by the ACR as a finding with low suspicion but needing biopsy.

Evaluating Suspicious Microcalcifications

A study conducted from 2006 to 2007 by Cho et al evaluated the efficacy of real-time ultrasound elastography in the differentiation of suspicious calcifications detected by mammography. The study involved 77 patients with 77 microcalcification areas found on mammograms. Histology results revealed 42 benign and 35 malignant lesions. Two experienced radiologists reviewed the images obtained by cine clips of elasticity and B-mode ultrasound. The radiologists assigned an elasticity score of 1 to 3 by consensus without prior knowledge of mammography or histology results. Elasticity scores of 1 and 2 showed 97% sensitivity and 62% specificity in differentiating benign from malignant microcalcifications. The researchers suggest that ultrasound elastography has the potential to differentiate benign from malignant lesions associated with microcalcifications that are detected by screening mammography.

U.S. Elastography Systems

The technique of elasticity has been approved by the U.S. Food and Drug Administration (FDA) since 2006. It is up to each manufacturer, however, to seek appropriate FDA approval for new equipment or software additions. Since the 1995 FDA approval regarding the use of ultrasound to diagnose solid mass lesions, several companies have shown interest in the further development of real-time elastography imaging hardware and software as demonstrated at the 2010 Environmental Collaboration and Conflict Resolution meeting. Hitachi Medical Systems (Twinsburg, Ohio) has been a pioneer in the clinical development of elastography. Philips Healthcare (Andover, Mass.) uses strain-based breast elastography; Siemens Medical Solutions (Malvern, Pa.) currently has eSie Touch strain imaging (approved by the FDA) as well as ARFI Virtual Touch, which — as of this writing — is not yet FDA approved; and Toshiba Medical Systems (Tustin, Calif.) uses the manual strain compression method to obtain breast elastograms on its machine.

GE Healthcare (Waukesha, Wis.) appears to be putting less stress on ultrasound elastography. This may be a result of the company’s emphasis on developing technology to combine elastography with MR imaging. However, they do offer the LOGIO E9 compression technique to acquire ultrasound elastography. Shear wave elastography has been approved by the FDA as of August 2009 for the SuperSonic Imagine’s Aixplorer using ShearWave technology.

Unlike digital breast tomosynthesis, which is potentially expected to revolutionize the breast imaging community, ultrasound breast elasticity can play a more supportive role in the diagnostic process. It is not facing the daunting FDA approval that digital breast tomosynthesis faced. Manufacturers are quickly implementing software and developing new machines to respond to the demand if or when elasticity studies become the standard adjunct to breast ultrasound. Much like full-field digital mammography, imaging institutions can add elastograms to their patients’ diagnostic armamentaria if this modality proves to be beneficial.

Conclusion

As more studies are conducted and more data gathered, along with improvement of software programs and operator techniques, elastography may prove to be beneficial when added to conventional ultrasound. Many studies have already proven that BI-RADS category 3 lesions can be confidently recategorized using elasticity imaging. Because approximately 75% of breast biopsies performed result in benign findings, reducing this number would result in less patient anxiety and...
discomfort and cost savings if these lesions can be categorized more definitively as benign. If incorporated into the diagnostic flow, elastography scores may minimize the number of biopsies for women with BI-RADS category 3 findings and may postpone the short-term follow-up time to yearly.

Elastography imaging is a helpful adjunct to conventional ultrasound by characterizing small breast lesions. Elastography scoring may suggest a more appropriate work-up for most of the cancers that present with indeterminate or even benign descriptors. Elastography scoring cannot work alone; it is such a new descriptor of margins, type of tumor and echo characteristics that scoring must always be integrated with other ultrasound and imaging findings.52

The challenge still lies with the many pathologic types of breast lesions and their size variations. Fibroadenomas may not clearly be a strain elasticity score of < 3, but a score of 4.52 Larger lesions of > 2 cm may contain liquefactive necrosis mixed with fibrosis and calcification that may lead to a deceptive elasticity score result.52 Also, superficial and deep lesions present a challenge for real-time accurate elasticity scoring.52

Where strain elastography falters, ARFI and shear elastography may prove to be more beneficial, especially for patients with denser breasts.

The future usefulness of this adjunct imaging technique lies with the gradual and collective confidence in its usefulness that those in the imaging community may gain. Manufacturer dedication and commitment to continue developing software programs and hardware upgrades also is essential. Implementation of the procedure throughout the ultrasound imaging community needs to progress and develop. Finally, professionals must agree upon a standardization and categorization scoring system.

References
18. Cho N, Moon WK, Kim HY, Chang JM, Lyou CY. Sonoclastic strain index for differentiation of


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