Sonoelastography

Jenna N Laquerre, BS, R.T.(R), RDMS, RVT

Sonoelastography was developed in the 1990s to image tissue stiffness. Current techniques allow for qualitative and quantitative evaluation of tissue stiffness.[1,2] This is useful for the assessment of physiologic and pathologic processes that change the stiffness and elasticity of tissues.[2,3] Sonoelastography can be used to diagnose and monitor liver disease (eg, fibrosis), breast lesions, thyroid disease (eg, nodules), prostate disease, renal fibrosis or focal renal lesions, lymph nodes, the appendix, and more.

Physics of Elastography

Sonoelastography assesses a medium's ability to withstand deformation as force is applied and regain initial shape as force is removed. Elasticity of a medium is described using Hooke's law, which can be expressed as:

$$\sigma = \Gamma \cdot \varepsilon$$

In this equation, σ represents force per unit area measured in newtons (N) per square meter. The elastic modulus (Γ) measures the resistance to elastic deformation under stress and is measured in kilopascals. The greater the elastic modulus, the stiffer the medium. Strain (ε) is a dimensionless extension per unit length.[2]

Elastic modulus (Γ) relates to the propagation speed of an acoustic wave traveling through a medium. This is expressed as:

$$c = \sqrt{\frac{\Gamma}{\rho}}$$

In this equation, c describes speed of the wave, and ρ describes the density of a medium. Waves have the propensity to propagate in a shear wave or longitudinal manner through a medium. Particle motion shear waves oscillate perpendicular to the direction acoustic waves propagate, which is expressed by the equation:

$$c_s = \sqrt{\frac{G}{\rho}}$$

Perpendicular particle oscillation is known as a *shear wave* (ie, transverse wave). Particle motion oscillating parallel to the direction of wave propagation is known as a *longitudinal wave* (see **Figure 1**). This is expressed with the equation:

$$c_L = \sqrt{\frac{K}{\rho}}$$

In this equation, c_L represents longitudinal wave speed.[2]

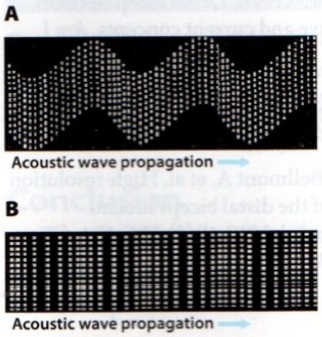

Figure 1. *Illustration comparing transverse particle motion of a shear wave (A) with longitudinal particle motion of a longitudinal wave (B). Images courtesy of the author.*

Types of elastic moduli that relate to specific methods of malformation include shear modulus (G), bulk modulus (K), and Young's modulus (E). Hooke's law describes shear modulus with σ_s representing shear stress, G representing shear modulus, and ε_s representing shear strain.[2] Shear modulus (μ) also can be expressed as:

$$\mu = \rho \cdot c^2$$

In this equation, ρ represents tissue density and c represents velocity of the shear wave.[4] Shear stress creates strain, with shear along a tangent to the surface. Bulk modulus is expressed as:

$$\sigma_b = K \cdot \varepsilon_b$$

In this equation, σ_b represents pressure, K represents bulk modulus, and ε_b representing strain. Normal inward pressure creates a change in volume, called *bulk strain*. Young's modulus (E) is defined as:

$$\sigma_n = E \cdot \varepsilon_n$$

In this equation, σ_n represents stress and ε_n represents strain.[2] Stress develops normal strain orthogonal to the surface.

Brightness mode (B-mode) ultrasound is produced with longitudinal waves, and the ultrasound system assumes the average speed of sound in soft tissues (ie, 1540 m/s [1.54 mm/μs]). A negligible difference in wave speed exists between soft tissues with B-mode application, which is insufficient for acquiring elastography measurements. Comparatively, shear-wave speed is minimized in soft tissues, producing a more expansive difference in shear modulus among tissues. This allows for adequate distinction among tissues for the acquisition of accurate elastography measurements.[2]

Evaluating Tissue Elasticity

Tissues throughout the body differ in stiffness and elasticity and thus deform differently after an application of mechanical force.[5] Some soft tissues are pliable whereas others are nonmalleable. Stiffness, or bulk modulus, is the ability of a structure to resist compression, an application of force. A medium's stiffness and density affect the propagation speed of sound. Compressible, nondense structures exhibit the greatest propagation speeds. A medium with a high elasticity, or compressibility, has a low stiffness.[5]

Sonoelastography technology collects quantitative and qualitative data related to the elasticity of a medium to estimate its stiffness.[2] Quantitative data refers to a measurable, numerical value generated relative to a biologic tissue's stiffness and elastic properties, while a qualitative assessment provides a generalized, and nonexact interpretation of tissue stiffness with use of a color scale. Sonoelastography is a complementary tool in scenarios where determining a medium's elasticity alters the course of the patient's care. For example, because benign and malignant lesions have specific tissue properties, sonoelastography can help clinicians differentiate between benign and malignant lesions based on tissue stiffness, with malignant lesions often demonstrating a greater stiffness and ability to compress surrounding structures compared with benign lesions. The use of sonoelastography could prevent a patient from undergoing an unnecessary biopsy or surgery.

Strain Elastography

Two ultrasound-based elastography techniques for calculating strain are strain elastography and acoustic radiation force impulse strain imaging. Strain elastography was the original form of sonoelastography implemented for diagnostic purposes.[2] Strain elastography uses external or internal compression stimuli.[2] The external strain elastography method relies on manual tissue compression by the sonographer depressing the ultrasound transducer on the medium and is used to evaluate superficial tissues such as thyroid and breast tissue.[2] For deeper structures, elasticity cannot be assessed using manual external compression. Internal strain elastography excitation relies on internal physiologic motion, such as motion produced by cardiac contraction or respiration, to estimate tissue elasticity in deeper structures.

With strain elastography, enforced stress and tissue displacement occur in the same direction.[2] Measurement methods vary by equipment manufacturer. A single method or a combination of Doppler processing and radiofrequency echo correlation-based tracking can be used. Manual and physiologic

applications of stress cannot be quantified but often are presented as a semitransparent color map superimposed over the anatomic grayscale image with pliable, high-strain tissue shown in red and noncompressible, low-strain tissue in blue.

Although strain elastography is nonquantifiable, a strain ratio can be calculated by dividing the mean strain of healthy, adjacent reference tissue by the mean strain of the targeted region of interest (ROI). When the strain ratio is greater than 1.0, it indicates the targeted region has a greater stiffness compared with surrounding tissue.[2] For example, in a retrospective breast lesion study in a group of 76 patients, the mean strain ratio of confirmed malignant masses was 5.5±1.4, indicating malignancy is associated with increased stiffness.[6,7]

Acoustic radiation force impulse is an alternative technique that involves high intensity, short duration acoustic pulses for internal displacement of tissues.[8] A focused acoustic beam is implemented in a temporal impulse acoustic radiation force with a pulse duration ranging between 0.1 and 0.5 ms.[1,2] The intensity of each pulse has a spatial peak pulse average of 1400 W/cm^2 and a spatial peak temporal average of 0.7 W/cm^2, which is relevant as this intensity can cause tissue heating.[2] The acoustic push pulse of the acoustic radiation force impulse technique is necessary for tissue displacement of 10 to 20 μm.[2]

Tissue displacement occurs orthogonally to the surface in a typical direction. Tissue displacement is displayed as a color map that overlays a grayscale image, like strain elastography.

Shear-Wave Elastography

A shear wave is a transverse elastic wave with motion produced orthogonal to particle direction.[1] Shear-wave elastography uses ultrasound-produced shear waves that propagate through a medium using acoustic radiation force impulse.[1,2] Comparative to strain elastography, shear-wave elastography calculates displacement of tissues parallel to the direction of applied typical stress. Dynamic stress produces shear waves parallel and orthogonally, allowing quantitative and qualitative measurements of tissue elasticity with shear-wave elastography. A color map demonstrates the stiffness metric as shear-wave speed or Young's modulus.[1] Technical production of shear-wave elastography is performed using point shear-wave elastography, 1-D transient elastography, or 2-D shear-wave elastography.

Point Shear-Wave Elastography

With point shear-wave elastography, a standard ultrasound unit and transducer are used. This allows direct visualization of tissue parenchyma with B-mode imaging to select a sampling location free of vasculature and other structures that would interfere with an accurate sample (eg, biliary ducts). An acoustic radiation force impulse technique focally displaces soft tissues in a typical direction. A segment of the longitudinal waves produced by the acoustic radiation force impulse is internally transformed to shear waves as acoustic energy is absorbed. Shear-wave speed, orthogonal to the excitation plane, is measured in the form of a quantitative stiffness metric.[1,2] These data can be reported immediately or reformed to produce a quantitative value of a tissue's elastic properties.[2] The minimum quantity of samples performed for production of reliable data is not well outlined. However, between 5 and 10 measurements for a point shear wave velocity and a minimum of 4 measurements with shear-wave speed imaging is recommended.[1] A standard deviation less than or equal to 30% of the mean value and a percentage of the net effective shear wave velocity at a minimum of 50% with point shear-wave elastography indicates a high-quality sample has been acquired.[9,10]

Transient Elastography

FibroScan (Echosens) was the first shear-wave elastography device on the market, approved by the U.S. Food and Drug Administration on April 5, 2013.[11] It used a 1-D-transient elastography approach for shear wave production.[2] 1-D-transient elastography excitation has been extensively studied and broadly accepted in the evaluation of liver fibrosis.[2] In transient elastography, a transducer containing a mechanical oscillation device produces dynamic stress via controlled oscillation at the transducer footprint-skin interface, which exerts an external push of acoustic energy into the body.[8] This push produces measurable shear waves that propagate through tissues parallel to the direction of excitation.[1,12] 1-D transient elastography approximates

elasticity along a nonadjustable acoustic amplitude-mode (A-mode) line using shear wave particle motion and Young's modulus for calculation,[2] which can be confusing because sonoelastography often is used with B-mode. 1-D transient elastography does not require imaging guidance for elastogram data production. The technique is based on time-motion ultrasound, using A-mode lines in time over various proximal locations (eg, superficial liver between 2.5 and 6.5 cm inferior to skin surface) (see **Figure 2**).[2]

A more developed version of the 1-D-transient elastography FibroScan device was released, the FibroScan 502 Touch, which uses controlled attenuation parameters to decrease acoustic amplitude and has the option for 3 transducer frequency selections for a variance in patient age, habitus, and ROI depth.[8]

2-D Shear-Wave Elastography

A modern form of shear-wave elastography that uses acoustic radiation force is 2-D shear-wave elastography. This is the only form of shear-wave elastography that allows for multiple focal zones during 2-D real-time shear-wave tissue evaluation while maintaining a superior temporal resolution. Two-dimensional shear-wave elastography produces a quantitative elastogram and Young's modulus or particle motion measurements. Several ultrasound systems with 2-D shear-wave elastography applications are currently available, including[2]:

- Acoustic Structure Quantification (Toshiba Medical Systems Corporation)
- ElastQ and ElastPQ (Philips)
- LOGIQ E10 (GE Healthcare)
- Real-time ShearWave Elastography (SuperSonic Imagine)
- Virtual Touch Imaging with acoustic radiation force impulse technology and Virtual Touch Quantification (Siemens Healthineers)

Other systems and elastography applications include[13-16]:

- eSie Touch Elasticity Imaging (Siemens Healthineers)
- Hitachi Realtime Tissue Elastography (HI-RTE; Hitachi)
- QElaXto (Easote)

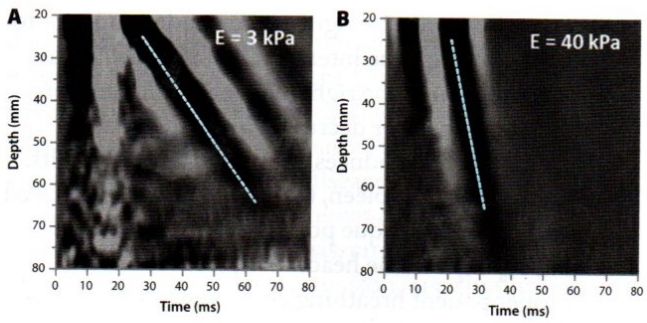

Figure 2. *Shear wave propagation maps created using transient elastography. A. Healthy liver. B. Cirrhotic liver. The cirrhotic liver demonstrates greater liver stiffness. Reprinted under the Creative Commons Attribution-ShareAlike 4.0 International license. creativecommons.org/licenses/by-sa/4.0*

- S-Shearwave (Samsung)
- SonixTouch (Redstone Healthcare)

Technique

Proper sonographic technique is essential during sonoelastography applications to produce accurate qualitative and quantitative results, and proper technique begins with patient positioning and preparation. Sonography is a user-dependent imaging modality where improper technique can substantially alter the diagnostic quality of the examination. Throughout the body, transducer pressure on the medium remains like that used during grayscale (B-mode) imaging. The American College of Radiology (ACR) outlines techniques and specifications based on the evaluation of organ or lesion stiffness. For evaluation of organ stiffness (eg, in the liver or spleen) operators should refrain from performing strain elastography because it does not provide quantitative stiffness data. Rather shear-wave elastography in the form of point shear-wave elastography or 2-D shear-wave elastography is recommended.

Organ Assessment

Image acquisition technique and patient positioning varies with application and the structure that is imaged. During a standard organ sonoelastography examination (eg, for the assessment of liver fibrosis), an adult patient should fast for a minimum of 4 hours, and the patient should be positioned supine or in a 30° left posterior

oblique position with the right arm extended superior to the head to optimize the intercostal acoustic scan window for evaluation of the right liver lobe.[9,17] Examining this segment of the liver decreases interference from cardiac motion and produces the most accurate results.[2] When evaluating the spleen, the patient should be placed in a right posterior oblique position with the left arm extended superior to the head.

Improper patient breathing cues can alter the accuracy of an elastography measurement. Deep exhalation or the Valsalva maneuver will generate a falsely elevated stiffness. For accurate results, patients should breathe normally and cease respiration after normal inspiration or at the end of neutral expiration.[2]

Shear-wave elastography is performed 1.5 to 2.0 cm deep to the organ capsule to reduce reverberation artifact interference. The optimal sampling location for the greatest generation of shear waves is between 4.0 and 5.0 cm below the transducer footprint-skin interface in a region of parenchyma without rib shadowing, vascular, or biliary structures.[2,9,17] Between 1.0 and 2.0 cm of parenchyma should surround the ROI. The interrogated region should extend 1.0 cm superior and inferior to the appropriated ROI. Ensuring that ample parenchyma surrounds the sampling location reduces pulse refraction and ensures the preciseness of obtained data.

A superior B-mode image will optimize shear-wave elastography because B-mode is employed to trace shear waves.[9] In addition, the direction of acoustic radiation force propagation should be directed orthogonal to the organ capsule.[2] With 2-D shear-wave elastography, 3 to 5 measurements should be acquired from individual images in the same sampling location. With point shear-wave elastography, 10 measurements should be acquired from individual images in the same sampling location; a median value should be calculated; and the interquartile range of stiffness to the median (IQR/M) should be calculated.[9] The IQR/M should be less than 0.15 m/s and less than 0.3 kPa for an accurate data set.[17]

Focal Lesion Assessment

For focal lesion assessment, 2-D shear-wave elastography or strain elastography should be used. Operators should refrain from using point shear-wave elastography because maximum stiffness cannot be determined in heterogeneous lesions.[17] When a lesion is identified, the operator should reduce scanning pressure, and transducer movement should be steadied. General sonographic technique is employed with shear-wave elastography, and patient positioning should be adjusted so the lesion is between 5 mm below the transducer footprint-skin interface and less than 4 cm deep to the transducer when allowable for optimal data acquisition.

Methods of interpreting strain elastography data include a 5-point color scale, strain ratio, or an elasticity to B-mode (E/B) ratio. The E/B ratio applies only to breast imaging. An adipose tissue component of breast tissue should be used as strain ratio reference tissue. For lesions being evaluated in tissue other than breast tissue, surrounding healthy tissue at an equivalent depth from the transducer footprint should be used as the reference. Acquiring a minimum of 3 strain elastography measurements is currently suggested. After implementation of strain elastography, the field of view should be large enough to include various tissues surrounding the ROI. A compression and release method with approximately 1 to 2 mm of compression is used, holding the transducer steady in a precise location for subsequent data acquisition.[17]

Elastography Applications

Sonography has many advantages including its portability, lack of ionizing radiation, low cost, wide availability, and relatively quick performance time. Elastography is an ultrasound-based application that provides a noninvasive method of assessing the mechanical properties of tissue (see **Figures 3** and **4**).[2] Elastography allows for the interpretation of pathological findings such as[2]:

- abnormal lymph nodes
- appendicitis
- breast lesions
- chronic kidney disease
- diffuse liver disease
- focal liver lesions
- focal renal lesions
- musculoskeletal
- prostate disease
- superficial soft tissue etiologies

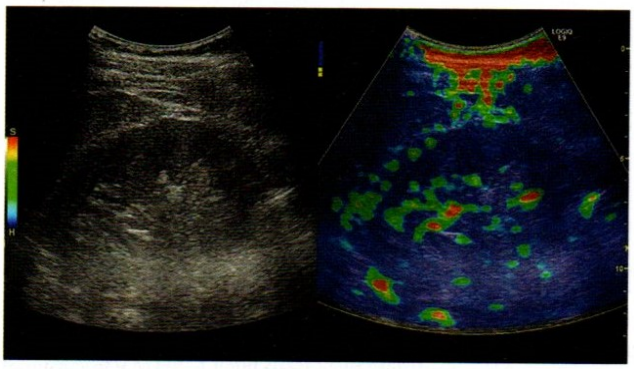

Figure 3. *Strain elastography of a healthy kidney. Reprinted under the Creative Commons Attribution 4.0 International license. creativecommons.org/licenses/by/4.0*

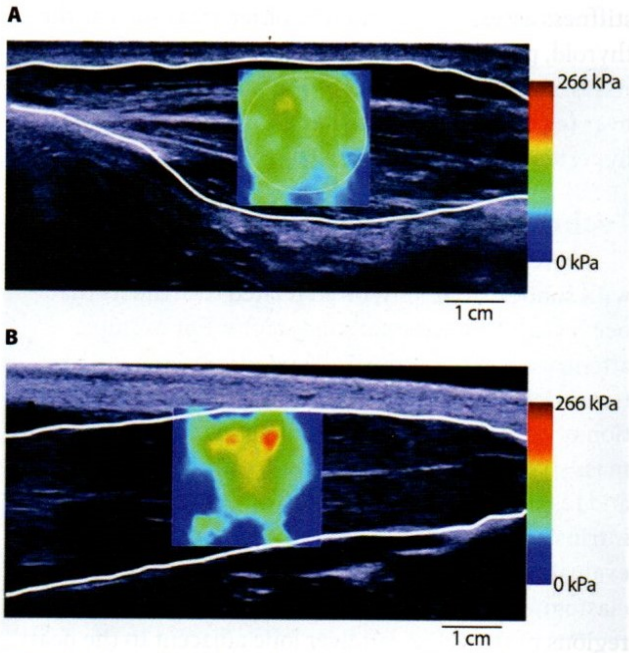

Figure 4. *Examples of shear elasticity maps and shear elastic modulus measurements (kPa) used to evaluate muscles in the hand. A. Abductor digitimi minimi. B. First dorsal interosseous. Reprinted under the Creative Commons Attribution-ShareAlike 3.0 Unported license. creativecommons.org/licenses/by-sa/3.0*

Assessment of liver disease is a common indication for sonoelastography. Although sonoelastography for evaluation and monitoring of nonliver-related disease is considered investigative by some medical coverage policies, many will reimburse providers for use of 1-D transient elastography (eg, FibroScan) related to the diagnosis and observation of liver fibrosis or cirrhosis. Roughly 1.4% of deaths in the United States transpire because of chronic liver disease, which encompasses nonalcoholic fatty liver disease, viral hepatitis (A, B, and C), autoimmune liver disease, and alcoholic liver disease. These disease processes can progress from inflammation to liver fibrosis, cirrhosis, insufficient liver function, portal hypertension, and finally hepatocellular carcinoma.[2]

If liver disease is identified in the fibrosis stage, the patient can be treated with antiviral, anti-inflammatory, adjunctive therapy (eg, antifibrotic agents such as angiotensin inhibitors and antioxidants), and immunosuppressant medications to reverse the onset of fibrosis. Sonoelastography for the assessment of elevated liver stiffness associated with an accumulation of liver scar tissue (fibrosis) can assist in early detection and management for an optimal patient outcome. As sonoelastography applications continue to develop, the number of liver biopsies is expected to decrease, and biopsies are expected to be reserved for cases that are indeterminate (eg, conflicting results between elastogram data and biologic methods) with sonoelastography and medical imaging investigation.[18]

Benign vs Malignant

Breast cancer is the most common malignancy in women in the United States and worldwide.[2,19] As early as 2006, the U.S. Food and Drug Administration granted approval for the use of sonoelastography for clinical research purposes in breast imaging for differentiation between benign and malignant lesions.[6] One of the most substantial clinical applications of sonoelastography is providing supplemental data, in addition to mammography and conventional B-mode ultrasound imaging, that can assist in differentiating benign from malignant lesion characteristics. Lesion characterization affects the outcome for the patient regarding their plan of care and treatment. Elastography data that suggests a mass is benign along with other benign findings might result in a recommendation for a short interval follow-up to ensure stability rather than an initial biopsy or surgery to examine or remove an abnormal finding. Use of sonoelastography can reduce morbidity and mortality rates associated with biopsy or surgical

evaluation methods, including risk of hematoma, pain, infection with progressive sepsis, hemothorax, pneumothorax, and death. A cutoff mean elastography value less than or equal to 72 kPa has a high sensitivity and specificity in the delineation of a benign breast lesion.[19] Studies that reported a high sensitivity and specificity with the use of sonoelastography for lesion differentiation noted that breast malignancies demonstrated an increased stiffness and greater dimension in size on strain elastography evaluation, compared with smaller, pliable benign breast lesions.[3,7]

In 2009, Real-Time ShearWave elastography application used in the Aixplorer ultrasound system was approved for shear-wave elastography evaluation of breast lesions. SuperSonic Imagine began its research in 2008 with 1800 patients who had breast findings.[3] Consistently reproducible qualitative and quantitative data were executed with the use of shear-wave elastography. Aixplorer is capable of strain and shear-wave elastography with the ability to render a color-coded map superimposed over a grayscale image, producing data related to the lesion's stiffness measured in kilopascals (see **Figure 5**).

Malignant lesions that have fewer elastic properties consistently demonstrate greater shear wave propagation speed. Use of shear-wave elastography can decrease the performance of invasive procedures and negative biopsies. A lesion that shows highly elastic properties is classified as Breast Imaging Reporting and Data System (BI-RADS) 3 (probably benign), whereas larger, stiffer lesions demonstrated on shear-wave elastography are more likely to be categorized as BI-RADS 4, with a greater likelihood of correlating to a positive biopsy.[3] The ACR BI-RADS Atlas described the characterization of a breast mass with sonoelastography in 2013, stating the technology's contribution for lesion analysis.[20] In 2019, the ACR and the Society of Radiologists in Ultrasound practice parameters for the performance of sonoelastography provided indications for determining lesion stiffness.

Shear-wave elastography and strain elastography are supplemental tools in breast characterization and should not be the sole gauge in determining breast cancer probability. Along with breast mass characterization, indications outlined by the ACR for lesion

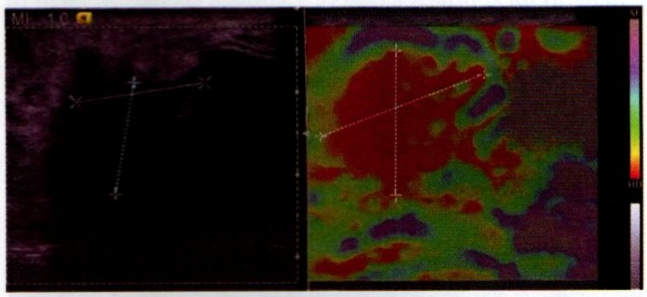

Figure 5. *Breast cancer is depicted on a color-coded shear-wave elastography map. Reprinted under the Creative Commons Attribution-ShareAlike 3.0 Unported license. creativecommons.org /licenses/by-sa/3.0*

stiffness assessment pertain to other areas such as the thyroid, prostate, and tendons (see **Figures 6** and **7**). Assessment of organ stiffness includes evaluation of the liver (eg, fibrosis, cirrhosis) and the spleen (eg, portal hypertension).[17]

Technical Limitations

There are inherent technical limitations affiliated with sonoelastography, often related to artifacts that occur with conventional sonography. For example, attenuation of the acoustic beam increases at greater tissue depths. This restricts sonoelastography evaluation of deeper anatomic structures such as a deep breast mass situated near the chest wall. Cardiac contractions and respiration (eg, diaphragmatic compression) are intrinsic sources of stress that affect sonoelastography evaluation. To minimize the effect of these stressors, elastography should be performed away from high regions of stress (eg, left liver lobe adjacent to the heart in the region near the xiphoid process). For example, if performing sonoelastography for evaluation of the liver parenchyma, tissue stiffness should be examined in the right lobe distant from the diaphragmatic interface to decrease internal stress on tissues that would produce inaccurate measurements. In addition, a change in the mechanical properties of soft tissue (eg, acute variations body mass index, steatosis, inflammatory changes [edema], venous congestion, viscosity) breach the set of assumptions which current sonoelastography technology on the market relies on for tissue analysis and measurement data.[1,2]

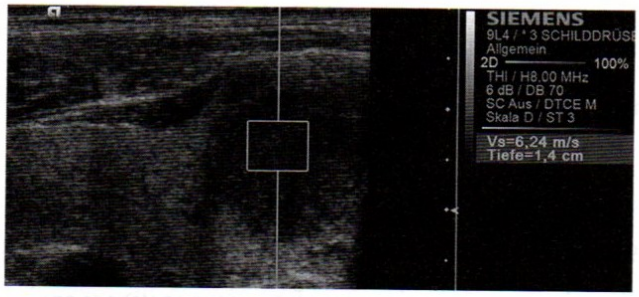

Figure 6. *Acoustic radiation force impulse performance on a hypoechoic nodule in the right thyroid lobe using a transducer at a frequency of 9 MHz. A point shear wave velocity (Vs) of 6.24 m/s is produced, and the histology report was consistent with papillary carcinoma. Reprinted under the Creative Commons Attribution-ShareAlike 3.0 Unported license. creativecommons.org/licenses /by-sa/3.0*

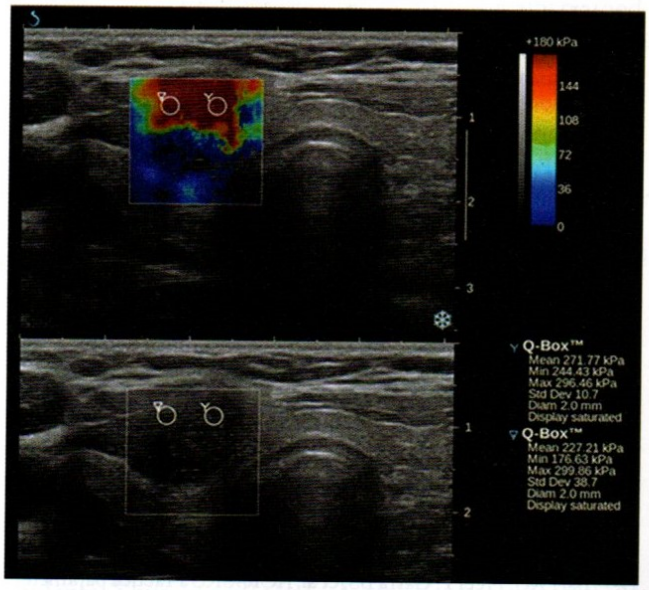

Figure 7. *Imaging from 2-D shear-wave elastography of a nodule in the right thyroid lobe that was confirmed on histology report as papillary carcinoma. Reprinted under the Creative Commons Attribution 3.0 Unported license. creativecommons.org/licenses /by/3.0*

Because sonography is a user-dependent modality, poor performance technique during a sonoelastography study can decrease the accuracy of measurements and diminish examination reproducibility. In addition, the measured value of organ or tissue stiffness is a capacity of shear wave frequency rather than a resolute physical property of the part being evaluated.[1] If the equipment used (eg, variance in manufacturer) or equipment settings (eg, transducer frequency) are inconsistent on follow-up studies performed on the same patient, this has the potential to inhibit examination reproducibility due to differences in data scoring and elastography color coding for lesion characterization among manufacturers.[2] With the strain elastography method, which relies on external stimuli and manual compression of tissues, measurement might vary with the extent of tissue compression dependent on the action of the user, and thus measured values can differ between users on the same patient.

Despite the technical limitations of sonoelastography, it is a highly beneficial tool in the realm of patient care and decisions regarding treatment methods. An understanding of the technical limitations is crucial in the ongoing research on sonoelastography to enhance technique among individual ultrasonographic units and reproducibility among various equipment manufacturers. In the scope of reproducibility, tissue-equivalent phantoms are being used in studies for standardization of quantitative measurements using various sonoelastography acquisition techniques.[2] Presently, to ensure reproducibility, strain is confined to the production of semiquantitative data related to tissue stiffness due to variance in results that are user dependent.[2]

In addition, benign and malignant nodules can result in thyroid fibrosis, limiting the ability to differentiate nodules based on their stiffness. Quantitative measurement data produced with shear-wave elastography shows promising results for the future of sonoelastography in thyroid and other small part applications.

Conclusion

The routine use of elastography in the clinical setting is becoming more commonplace, and rapid growth of this technology sets a benchmark for the future of sonography. Elastography applications presently on the market allow for qualitative and quantitative evaluation of tissue stiffness. This adjunctive data gathered in the assessment of physiologic and pathologic processes that change the stiffness and elasticity of tissues can aid clinicians in the differentiation between benign

and malignant masses based on tissue stiffness, as malignant lesions often demonstrate a greater stiffness compared to healthy, surrounding tissues. Furthermore, use of elastography is a complementary tool in scenarios where determining a medium's elasticity might alter the course of the patient's care and potentially prevent patients from undergoing unnecessary procedures.

Jenna N Laquerre, BS, R.T.(R), RDMS, RVT, is a professor of sonography and radiography at Palm Beach State College and a graduate student at the University of North Florida. She is American Registry for Diagnostic Medical Sonography–registered in abdomen, obstetrics and gynecology, breast, pediatric sonography, and vascular technology. She is a member of the Lambda Nu National Honor Society for Radiologic and Imaging Sciences, American Society of Radiologic Technologists, Society of Diagnostic Medical Sonography, and is a manuscript peer reviewer for the journal Radiologic Technology, *a published author, educational speaker, and has clinical experience from national institutions including Nemours Children's Hospital and AdventHealth. She recently wrote* Lange Review: The Fundamentals of Pediatric Sonography, A Registry Review and Protocol Guide.

References

1. Park SH, Kim SY, Suh CH, et al. What we need to know when performing and interpreting US elastography. *Clin Mol Hepatol.* 2016;22(3):406-414. doi:10.3350/cmh.2016.0106
2. Sigrist RMS, Liau J, Kaffas AE, Chammas MC, Willmann JK. Ultrasound elastography: review of techniques and clinical applications. *Theranostics.* 2017;7(5):1303-1329. doi:10.7150/thno.18650
3. Orenstein B. Hard decisions — ultrasound elastography seeks to help characterize breast lesions and, more recently, throughout the body. *Radiology Today.* April, 2011. Accessed January 12, 2024. https://www.radiologytoday.net/archive/rt0411p26.shtml
4. Zhu J, Miao Y, Qi L, et al. Longitudinal shear wave imaging for elasticity mapping using optical coherence elastography. *Appl Phys Lett.* 2017;110(20):201101. doi:10.1063/1.4983292
5. Edelman S. *Understanding Ultrasound Physics.* 4th ed. ESP; 2012.
6. Yaðtu M, Turan E, Turan ÇÖ. The role of ultrasonographic elastography in the differential diagnosis of breast masses and its contribution to classical ultrasonographic evaluation. *Meme Saglik Derg.* 2014;10(3):141-146. doi:10.5152/tjbh.2014.2024
7. Ozturk A, Grajo JR, Dhyani M, Anthony BW, Samir AE. Principles of ultrasound elastography. *Abdom Radiol (NY).* 2018;43(4):773-785. doi:10.1007/s00261-018-1475-6
8. Ferraioli G, Wong VW, Castera L, et al. Liver ultrasound elastography: an update to the world federation for ultrasound in medicine and biology guidelines and recommendations. *Ultrasound Med Biol.* 2018;44(12):2419-2440. doi:10.1016/j.ultrasmedbio.2018.07.008
9. Barr RG, Wilson SR, Rubens D, Garcia-Tsao G, Ferraioli G. Update to the society of radiologists in ultrasound liver elastography consensus statement. *Radiology.* 2020;296(2):263-274. doi:10.1148/radiol.2020192437
10. Jikuzono T, Ishibashi O, Kure S, Itoh C, Yamada T, Sugitani I. VsN, a reliability-index of shear-wave measurement in sonoelastography, is useful for the diagnosis of thyroid tumor malignancy. *In Vivo.* 2022;36(1):264-273. doi:10.21873/invivo.12700
11. GE receives FDA approval for shear wave elastography module. Imaging Technology. Published December 9, 2014. Accessed December 22, 2022. www.itnonline.com/content/ge-receives-fda-approval-shear-wave-elastography-module
12. Lee SM, Kim MJ, Yoon JH, et al. Comparison of point and 2-dimensional shear wave elastography for the evaluation of liver fibrosis. *Ultrasonography.* 2020;39(3):288-297. doi:10.14366/usg.19090
13. U.S. Food and Drug Administration. Acuson 510(k) Summary, K142876. Accessed December 20, 2022. https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfPMN/pmn.cfm?ID=K142876
14. U.S. Food and Drug Administration. Philips MRE 510(k) Summary, K140666. Accessed December 20, 2022. https://www.accessdata.fda.gov/cdrh_docs/pdf14/K140666.pdf
15. U.S. Food and Drug Administration. SonixTouch 510(k) Summary, K083095. Accessed December 20, 2022. https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfPMN/pmn.cfm?ID=K083095
16. U.S. Food and Drug Administration. SuperSonic Imagine 510(k) Summary, K203645. Accessed December 12, 2022. https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfPMN/pmn.cfm?ID=K203645
17. Barr RG, Freer P, Garra BS, et al. ACR–SRU Practice parameter for the performance of ultrasound elastography. American College of Radiology. Published 2019. Accessed December 22, 2022. www.acr.org/-/media/ACR/Files/Practice-Parameters/US-Elastography.pdf
18. Sporea I. The future of liver elastography in the field of hepatology. *Ultrasound Int Open.* 2017;3(2):E50-E51. doi:10.1055/s-0043-106178
19. Farooq F, Mubarak S, Shaukat S, et al. Value of elastography in differentiating benign from malignant breast lesions keeping histopathology as gold standard. *Cureus.* 2019;11(10):e5861. doi:10.7759/cureus.5861
20. Mendelson EB, Böhm-Vélez M, Berg WA, et al. ACR BI-RADS ultrasound. In: *ACR BI-RADS Atlas, Breast Imaging Reporting and Data System.* American College of Radiology; 2013.