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ULTRASOUND ELASTOGRAPHY SUCH AS MAIN METHOD FOR DIAGNOSIS BREAST PROBLEMS

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Abstract
On the other hand, SE is a qualitative or semi-quantitative imaging technique that assesses and compares relative stiffness between tissues when an external force is present. Because it uses external stimuli, it is considered one of the most challenging elastography techniques. Strain elastography is divided into two methods: excitation or manual (compression). Manual compression can be helpful in assessing superficial organs and their pathology. In this method, the operator applies manual compression and pressure to the region of interest, which works best in identifying a superficial pathology in the thyroid or breast tissue. Meanwhile, the second method uses information from tissue displacement resulting from internal physiologic motion and is not dependent on superficially applied compression, unlike the first method, which makes it beneficial in the assessment of deeper organs such as the cardiovascular and respiratory systems.

Keywords: Breast, elastography, ultrasound.

Hooke's law, an elasticity principle formulated by the English scientist Robert Hooke in 1660, asserts that the displacement or size of the deformation of an item is precisely proportionate to the applied force or load, as long as the deformations are relatively modest. Under these circumstances, the object reverts to its initial shape and dimensions once the load is removed. The elastic behavior of solids, as described by Hooke's law, can be attributed to the proportionate relationship between the force applied to the solid and the resulting displacement of its constituent molecules, atoms, or ions from their normal positions.

One can exert various types of deforming forces on a solid, such as stretching, compressing, squeezing, bending, or twisting. Therefore, when

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subjected to a doubled force, a metal wire exhibits elastic behavior in accordance with Hooke's law, as its length increases proportionally. Hooke's law can be expressed mathematically as F = kx, where F is the applied force, k is a constant, and x is the displacement or change in length. The value of k is contingent upon not just the type of elastic material being examined, but also its dimensions and shape.

The significance of elastography physics lies in its ability to employ several methodologies to measure tissue stiffness, a physical attribute known as Young's modulus (E). Young's modulus, a constant, establishes the relationship between the force per unit area, known as stress, and the resulting change in tissue dimensions, known as strain. As mentioned before, the principle of elastography depends heavily on the assessment of tissue elasticity, which is defined as the tendency of the tissue to return to its original shape and resist disfiguration following the application of force. Deformations of tissue elasticity can be characterized by strain, stress, and elastic moduli, according to Hooke's law. Based on their static deformation and the speed of wave propagation, we can classify multiple types of elastic moduli. Young's modulus, shear modulus, and bulk modulus provide an indication of the difficulty of soft tissue deformation following compression and shear. These three types of elastic moduli vary in their method of deformation due to the different production of strain. Young's modulus, for example, produces a normal perpendicular strain on the tissue, whereas shear modulus produces a shear strain tangentially, and bulk modulus involves a normal inward pressure that results in a volume change, also known as bulk strain.

Shear waves and longitudinal waves define the types of wave propagation in ultrasound. Shear waves, which are also sometimes called transverse waves, cause particles to move in a way that is perpendicular to the direction of the wave. This motion is directly correlated with the shear modulus G and exhibits a rapid and subtle weakening effect (reduced amplitude). Compared to longitudinal waves, which show particle movement in the same direction as the wave's propagation and are directly affected by the bulk modulus, K employs longitudinal waves. However, these waves do not offer sufficient tissue contrast due to the relatively minor variations in wave speed and bulk modulus. It is important to note that the conjunction of both longitudinal and

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shear (transverse) waves is needed in order to provide a functional ultrasound.

Acoustic radiation force impulse (ARFI) is an alternative tactic used to measure strain in situations where no excitation or external stimulation is applicable. This technique involves the use of a high-intensity acoustic "pushing pulse" with a short duration of 0.1–0.5 ms. The spatial peak pulse average is 1400 W/cm^2, and the spatial peak temporal average is 0.7 W/cm^2. This pulse is used to displace tissue in the normal direction, which is perpendicular to the surface. The displacement of the tissue is approximately 10–20 μm. The displacement within a specified ROI is subsequently measured by the same methods as in strain elastography. Also, similar to strain elastography, the displacements may be displayed as an elastogram overlaid on the B-mode image. The authors did not focus on this technique due to the underwhelming extent of research conducted around it and its recent development. However, it is important to note that ARFI imaging does not rely on transducer compression as other quasi-static elastography methods do, which can help in the assessment and imaging of deeper organs. On the other hand, SE is a qualitative or semi-quantitative imaging technique that assesses and compares relative stiffness between tissues when an external force is present. Because it uses external stimuli, it is considered one of the most challenging elastography techniques. Strain elastography is divided into two methods: excitation or manual (compression). Manual compression can be helpful in assessing superficial organs and their pathology. In this method, the operator applies manual compression and pressure to the region of interest, which works best in identifying a superficial pathology in the thyroid or breast tissue. Meanwhile, the second method uses information from tissue displacement resulting from internal physiologic motion and is not dependent on superficially applied compression, unlike the first method, which makes it beneficial in the assessment of deeper organs such as the cardiovascular and respiratory systems.

Shear wave imaging is an elastography technique that results in the generation of shear waves in perpendicular or parallel dimensions. After applying dynamic stress, researchers estimate tissue elasticity by measuring the shear wave speed qualitatively and quantitatively. Shear wave imaging

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is currently approached using three various techniques: one-dimensional transient elastography (1D-TE), two-dimensional shear wave elastography (2D-SWE), and point shear wave elastography (pSWE).

One-dimensional transient elastography (1D-TE) is the first shear wave imaging technique developed, and it is also the most widely available and used scheme of the three. The main use of 1D-TE is for assessing liver fibrosis, which later led to the development of Fibroscan® (Echosens, Paris, France), a diagnostic non-invasive ultrasound-based imaging technique that measures fibrosis and other liver pathologies. The Fibroscan® probe includes a mechanical vibrating device and an ultrasound transducer that generate shear waves through external vibration, propagating through the tissue. Although one-dimensional transient elastography is US-based, it is functional without direct B-mode usage and instead uses A-mode ultrasound that measures the shear wave speed and therefore calculates Young's modulus.

Aside from the diverse advantages provided by the usage of ultrasound as the imaging modality associated with elastography, we have to expect that at some point we will be disrupted by some of the technical difficulties that the modality may possess in light of the sensitivity of the ultrasound image and its susceptibility to change depending on many factors ranging from machine-based artifacts to errors on behalf of the operator.

Multiple factors contribute to error generation during the USE scan. Sonography limitations can come in the form of clutter, shadowing, or even reverberation artifacts. Because of strain, elastography proved to be the most challenging form of USE due to the limited quantification and application of external stress and stimuli. The probe-based ultrasound system requires a highly skilled sonographer who is adept and knowledgeable of the right imaging technique in order to provide an accurate diagnosis and assess the patient properly. It is important not to over-compress or under-compress and to select the right probe frequency. Given the multiple possibilities, it is not unlikely that the operator might err in some way during image acquisition, especially in the selection of the ROI, which is crucial for the image and may vary considerably.

Our tissues are of heterogenous nature and vary in shapes and sizes due to being acclimated to our bodies. Tissue attenuation is inversely related to

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patient size, making it harder to image obese patients and make out coherent images that provide an accurate diagnosis. The patient's variable body habitus is a major factor in determining how clear the image comes out to be, because internal organs have their own involuntary motion that results in internal stress that is easily sensed by the USE, as well as the external stress and stimuli provided by the sonographer, which can easily be the main cause of artifact generation in the image. It is important to mention that USE artifacts are easily fixable with slight changes in the imaging circumstances, such as the chosen angle or pressure applied, as well as the proper selection of the ROI.

The most common type of breast pathology that includes a variety of stages and lesions is breast cancer. It begins with the abnormal growth of a lesion within the breast tissue, mainly in the upper outer (lateral) quadrant of the breast with an extension towards the armpits. It is the second most common cancer in the United States after skin cancer, having a nearly 12.3% lifetime diagnosis rate, and affecting approximately 1 in 8 women. However, this does not mean that men are completely immune to the disease, as men can still develop breast cancer even if there is less of a likelihood of that happening; about 1 in 100 men develop breast cancer in the United States, the most common kinds being invasive ductal carcinoma and ductal carcinoma in situ.

Symptoms of breast cancer often include a change in the size or appearance of the breast, peeling or flaking in the areola area or breast skin, and a lump that feels thicker or stiffer than the surrounding breast tissue. The early screening and detection of breast cancer reduces the morbidity risk and results in better and quicker treatment of the pathology. Breast cancer is a primarily hereditary disease, as the risk increases if the patient has any direct family members diagnosed with the illness at any point in their lifetime, thereby augmenting the need for a family history study. However, that does not take away from the external causes that might affect the patient in the long run, as most of the breast cancer cases that are not hereditary derive from the healthiest of lifestyles; indulging in smoking and alcohol consumption, along with obesity, are some of the risk factors that can be controlled. While some risk factors can be controlled by the patients themselves, some others are not in our power, such as increasing age, being

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a female, beginning menopause at an older age (later than 65 years of age) or having your period at a younger age (prior to 12 years of age), and avoiding pregnancies or having children at an older age (later than 30 years old), as well as the usage of contraceptives, which exposes the patient to a higher risk of developing breast cancer.

Elastography Techniques in Breast Disease Diagnosis

Breast cancer screening is usually performed using mammography and ultrasound scans (specifically B-mode US), but both have shown some faulty limitations in the image, such as poor specificity in B-mode and false-negative results in the mammography of dense breasts. However, since the development of USE, it has served as an additional complementary tool to improve the assessment of breast lesions in a non-invasive manner by evaluating the stiffness levels of the mass. Comparative studies have demonstrated that USE exhibits superior accuracy in detecting and determining the extent of breast lesions, regardless of whether they are cancerous or non-cancerous, with a specificity of 95.1% compared to mammography.

Radiologists found that the additional usage of USE alongside B-mode US and mammography aids in the diagnostic improvement of the scans, helping with the decision of the appropriate category of the BI-RADS (Breast Imaging Reporting and Data System) categories, which range from category 1 (not cancer) to category 6 (high likelihood of cancer). Category 0 means more tests are needed. Mammogram reports also include four categories for breast density, utilizing both shear wave imaging and strain elastography as their primary USE techniques, but also depending on three main parameters: the Tsukuba score, the EI/B-mode ratio (also called the width or length ratio), and the strain ratio (the fat-to-lesion ratio, FLR).

The Tsukuba score is a five-point scale that visually grades the stiffness of a mass or lesion and possesses high detection accuracy. This makes it easy to distinguish between benign and malignant tissues. The system computes the score based on lesion stiffness relative to the surrounding tissue stiffness. The tissue score is directly proportional to the degree of malignancy; therefore, the higher the score, the more malignant the lesion is.

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Score 1 shows a lesion with less or equal stiffness to the background tissue; score 2 depicts that the lesion has mixed areas of stiffness; in score 3, the lesion is stiffer than the background tissue and smaller on the elastogram than in B-mode; score 4 shows that the lesion is stiffer than the background tissue and is of equal size on the elastogram compared to B-mode; in score 5, the lesion is stiffer than the background tissue and is of larger size on the elastogram than in B-mode.

The EI/B ratio describes a ratio where the size of the lesion is measured on the elastogram image and the B-mode image and then divided by each other. Given that benign lesions appear smaller on the elastogram than in B-mode and malignant lesions are depicted larger on the elastogram than on the B-mode scan, this ratio incorporates findings from both B-mode and the elastogram. The EI/B-mode ratio shows great promise in the differentiation between malignant and benign masses, given its outstanding sensitivity and specificity of 100% and 95%, respectively.

Since fat has a constant elastic modulus over a plethora of compressions, the strain ratio ends up being a semi-quantitative measurement that reflects the ratio of the strain in mass to the strain in subcutaneous fat to reflect the relative stiffness of the lesion rather than the absolute tissue stiffness. Researchers have conducted multiple studies of breast lesions using the EI/B-mode ratio and the strain ratio. Radiologists found that pooled sensitivity and specificity were acceptable for the EI/B-mode ratio (98% and 72%, respectively) and strain ratio studies (88% and 83%, respectively).

A quantitative measurement of the shear wave velocity (also known as Young's modulus) in a mass is obtained in shear wave imaging. To obtain a high-quality SWE image, gaining an adequate gray-scale image is necessary before switching to the SWE mode in order to characterize breast lesions correctly. The most commonly used parameters included a variety of quantitative elasticity values, such as mean and maximum stiffness. Maximum stiffness had a sensitivity of 93% and a specificity of 81%, while mean stiffness had a similar sensitivity of 94% and a specificity of 71% in these studies. SWI can improve the performance of the B-mode ultrasound and its function in assessing breast lesions, as it improves the specificity of the B-mode ultrasound (from 61.1% to 78.5%), reducing the need for unnecessary invasive biopsies and improving patient management.

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Technical Limitations in Breast Elastography

The main problem with breast elastography is that it can be hard to tell the difference between different types of tissues and if they are cancerous or not. This is because cancerous lesions can sometimes look soft on SWI, and cystic (benign) tissues can look stiff if they are described as breast fibrosis or fat necrosis. This is due to the fact that breast elastography has a difficult time determining whether heterogenous tissues are malignant or benign. Elastogram color coding in shear wave elastography is exhibited as blue for a soft, lean tissue and red for a solid, higher stiffness tissue; however, elastography color coding and scoring suffer from a lack of consistency, and this could cause a problem for the operator. If the mass was located toward the posterior aspect of the breast, then it would be more difficult to scan and assess. Deep tissues may not always be displaced by applying pressure to the breast surface, which increases the requirement for mammography. Another challenge depends on the position of the lesion. It is important to note that there are not many comparative studies to determine which of the USE techniques is preferred over the other, although a compound usage of strain imaging and shear wave imaging USE would increase the accuracy and ameliorate the detection of breast lesions, as well as their staging].

Elastography Techniques in Breast Disease Diagnosis

A high-resolution B-mode US can detect thyroid nodules in up to 67% of adults and in ~50% of autopsy exams. Malignant thyroid nodules are critical to recognize because thyroid cancer morbidity and mortality rise with disease stage. Despite the prevalence of thyroid nodules, only 4–8% of FNA-sampled nodules are malignant. First, B-mode US reveals select thyroid nodules for FNA. Malignancy is indicated by spiculated edges, a taller-than-wide form, hypoechogenicity, and microcalcifications. Usually, FNA confirms malignancy. The gold standard for diagnosis, FNA, is unsatisfactory because 15–30% of samples are non-diagnostic or inconclusive. Repeated FNA yields clear results in most nodules, although 9.9–50% of non-diagnostic nodules and 38.5–43% of indeterminate nodules yield inconclusive results. Technical issues including insufficient sample can cause inconclusive FNA results, although follicular neoplasms can cause 6.7% of total FNA results or 22% of inconclusive outcomes.

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CONCLUSIONS

Clinical settings frequently employ ultrasound elastography for two primary purposes: monitoring the progress of pathology treatment and assessing the severity of the disease. Through an assessment of the three primary clinical uses of ultrasound elastography, it becomes evident that liver pathology, particularly liver fibrosis and diffuse liver disease, is most prominently recognized due to its accurate utilization and assessment. Although biopsies are now necessary for certain renal studies due to existing restrictions, the use of ultrasound elastography (USE) can still be considered for localized renal mass studies to avoid unneeded invasive procedures. Furthermore, ultrasound elastography has been found to be useful in ruling out renal pathologies, including renal fibrosis. On the other hand, with the development of USE, it has served as an additional complementary tool to improve the assessment of breast lesions in a non-invasive manner by evaluating the stiffness levels. The technology of USE still has a long way to go and needs to be investigated more along with other non-invasive medical imaging modalities in order to solely depend on it in the near future, but until then, its contributions are carefully taken into consideration.

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