**Review**

**Ultrasound Elastography: Methods, Clinical Applications, and Limitations: A Review Article**

**Ammar A. Oglat** * and **Tala Abukhalil**

Department of Medical Imaging, Faculty of Applied Medical Sciences, The Hashemite University, Zarqa 13133, Jordan; talaabukhalil11@gmail.com
* Correspondence: ammara@hu.edu.jo; Tel.: +962-796311835

**Abstract:** Ultrasound is a highly adaptable medical imaging modality that offers several applications and a wide range of uses, both for diagnostic and therapeutic purposes. The principles of sound wave propagation and reflection enable ultrasound imaging to function as a highly secure modality. This technique facilitates the production of real-time visual representations, thereby assisting in the evaluation of various medical conditions such as cardiac, gynecologic, and abdominal diseases, among others. The ultrasound modality encompasses a diverse range of modes and mechanisms that serve to enhance the methodology of pathology and physiology assessment. Doppler imaging and US elastography, in particular, are two such techniques that contribute to this expansion. Elastography-based imaging methods have attracted significant interest in recent years for the non-invasive evaluation of tissue mechanical characteristics. These techniques utilize the changes in soft tissue elasticity in various diseases to generate both qualitative and quantitative data for diagnostic purposes. Specialized imaging techniques collect data by identifying tissue stiffness under mechanical forces such as compression or shear waves. However, in this review paper, we provide a comprehensive examination of the fundamental concepts, underlying physics, and limitations associated with ultrasound elastography. Additionally, we present a concise overview of its present-day clinical utilization and ongoing advancements across many clinical domains.

**Keywords:** ultrasound; elastography; medical imaging modalities; sound waves

**1. Introduction**

Ultrasound is a form of imaging that utilizes sound waves at high frequencies. The primary purpose of this function, like other imaging techniques, is to generate visual representations of internal organs and structures within the body [1–3]. Typically, clinicians employ it to observe the heart, blood vessels, kidneys, liver, and other organs. In addition, ultrasonography is employed to visualize the fetus during the course of the pregnancy. Images can offer useful insights for identifying and treating a diverse range of diseases and conditions. Typically, ultrasound tests are conducted using an external sonar instrument. Nevertheless, certain ultrasound tests necessitate the insertion of a device into your body [4,5].

In the beginning of the 1990s, the idea of transient tissue elasticity and stiffness aiding in the detection of diseases originated, denoted as ultrasound elastography (USE) [6–9]. The scope of uses for elasticity imaging (EI) in medical diagnosis and therapy monitoring is continuously expanding. Recent publications have provided extensive data indicating that the shear elasticity modulus of tissue is a highly variable physical property. It is also extremely responsive to alterations in tissue structure that occur during normal and abnormal biological processes. It is remarkable that this comprehension emerged only approximately two decades ago. The fact that the qualitative assessment of tissue elasticity through manual palpation has been extensively used since ancient times and continues to be employed today makes it particularly astonishing. Elastic moduli are regarded as...
fundamental parameters when describing non-biological materials. An engineer cannot conceive of designing a machine or any other construction without conducting a quantitative evaluation of the mechanical properties of the components and materials employed. Given the fact that different pathologies vary in tissue structure, a change in stiffness can lead to various diseases, such as liver-cirrhosis-associated fibrosis, cancerous pathology, and arteriosclerosis-associated calcification [10–13].

CT and MRI are commonly utilized for disease detection; however, ultrasound elastography is still the best technique to observe changes in tissue elasticity and stiffness. Moreover, ultrasound elastography is used to image tissue stiffness, using the acquired information to enhance disease diagnosis accuracy, aid in early disease detection, and monitor the response to treatments like chemotherapy. Although it may reflect qualitative changes even when morphological changes are not visible, tissue stiffness measurement has the following clinical applications: (a) early detection and differential diagnosis of diseases; (b) improvement in accuracy for diagnosing diseases involving fibrosis, such as cancer, chronic hepatitis, and atherosclerosis; (c) evaluation of the response to treatments, such as rituximab [10,14–17]. Medical practitioners throughout history have acquired knowledge about tissue biology by using diagnostic palpation, a physical examination technique that identifies alterations in mechanical tissue properties. Alterations in tissue mechanics often accompany common disease processes such as fibrosis, inflammation, and neovascularization. However, using diagnostic palpation to assess the stiffness of tissue can be an effective method of detecting tumors, but it is restricted to parts of the body that are accessible to the physician’s hand. Therefore, the physician can assess these changes using innovative ultrasonic elastography techniques.

Conventional ultrasound (US), which also applies to USE, offers the advantage of being an inexpensive, adaptable, and widely available modality that can be used at the bedside. In recent years, USE has been researched for a number of clinical applications, and it has even been included in clinical practice for certain applications. Some examples of these applications include the evaluation of liver fibrosis and the characterization of breast lesions. Elasticity imaging by USE adds complementary information to typical US imaging techniques by incorporating stiffness as an extra quantifiable parameter into existing US imaging procedures [18–21].

The main goal of this study is to investigate USE clinical applications in the liver, breast, and kidney, present an overview of USE principles and concepts, and define many different USE approaches.

2. Elastography Physics

Elastography is a technique used to evaluate the elasticity of tissue. Elasticity refers to the ability of tissue to resist deformation when a force is applied and to return to its original shape once the force is removed. If a material is completely elastic and its deformation does not depend on time (i.e., it is not viscous), then its elasticity can be explained by Hooke’s Law:

\[ \sigma = \Gamma \cdot \varepsilon \quad (1) \]

where stress (\(\sigma\)) is the force per unit area with units of kilopascals (i.e., N/m\(^2\)), strain (\(\varepsilon\)) is the expansion per unit length, which is dimensionless, and the elastic modulus (\(\Gamma\)) relates stress to strain with units of kilopascals.

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 [22,23]. 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. See Figure 1.
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 [6,8,10,14,18,24–28].

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 shear (transverse) waves is needed in order to provide a functional ultrasound [8,29–31].
3. Elastography Techniques

These principles categorize the various USE techniques currently available based on the specific physical quantity under measurement. (SWI) Additional clarifications of strain imaging and shear wave imaging are provided below.

3.1. A: Strain Imaging

There are two main types of ultrasound elastography techniques: strain imaging and shear wave imaging. Each of these techniques is further segmented into its own variable schemes. Strain imaging is classified as a technique that provides a qualitative evaluation of Young’s modulus by applying normal stress and subsequently measuring the normal strain. Furthermore, strain imaging can be divided into two mechanisms: strain elastography (SE) and acoustic radiation force impulse (ARFI).

3.1.1. Acoustic Radiation Force Impulse (ARFI)

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/cm², and the spatial peak temporal average is 0.7 W/cm². 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 [32]. 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 [33]. 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 [6,10,34–37].

3.1.2. Strain Elastography

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 [38]. 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 [39].

3.2. B: Shear Wave Imaging

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 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) [39–42].

3.2.1. One-Dimensional Transient Elastography (1D-TE)

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 [43–45].

3.2.2. Two-Dimensional Shear Wave Elastography (2D-SWE)

Two-dimensional shear wave elastography (2D-SWE) is the newest shear wave imaging method developed, which uses dynamic stress by ARFI as the excitation method. In 2D-SWE, the shear waves measured are perpendicular to the ARFI application and use multiple focal zones that are interrogated quickly, rather than one single location. The evolution of this method has given us the ability to visualize a color quantitative elastogram superimposed on a B-mode image and can easily produce tissue stiffness information [46–51].

3.2.3. Point Shear Wave Elastography (pSWE)

Point shear wave elastography (pSWE), developed in 2008, is similarly dependent on the dynamic stress ARFI but instead focuses on a single focal location, unlike 2D-SWE, which uses multiple focal locations. While 1D-TE primarily serves liver applications, pSWE offers numerous advantages that could potentially displace 1D-TE in shear wave imaging. Unlike 1D-TE, pSWE utilizes B-mode ultrasound to directly visualize and select the region of interest, whereas 1D-TE is heavily dependent on A-mode ultrasound. pSWE can easily be performed on a conventional ultrasound machine as well, with no need for any special probe or machinery, but it does not have the ability to showcase images of tissue stiffness [52–58]. See Figure 2.

Figure 2. Methods for ultrasound elastography. By the physical quantity that was measured, the following USE methods can be divided into two groups: shear wave imaging (right) and strain imaging (left). A “thumping” transducer at the tissue’s surface causes dynamic mechanically induced compression to produce shear waves, quasi-static mechanically induced displacement via active external compression or passively induced physiologic motion, and dynamic ultrasound-induced tissue displacement and shear waves via acoustic radiation force impulse excitation.
Furthermore, we can estimate tissue stiffness using ultrasound and MR elastography techniques, which measure shear wave speed. The documentation of different stiffness metrics may vary depending on the employed methodology. The frequently reported parameters and their respective units are shear wave velocity in meters per second, the magnitude of the complex shear modulus in kilopascals (referred to as “shear stiffness” in literature), and Young’s elastic modulus in kilopascals (referred to as “elasticity” in medical literature). The absence of consistency in the documented parameters hinders the ability to make comparisons between different procedures. These elastography techniques offer the capability to assess factors beyond stiffness, such as shear wave attenuation and tissue viscosity. However, it is important to note that these additional parameters are still being investigated and have not been reported in clinical settings [40,59].

4. Technical Limitations and Difficulties

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 [60,61].

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 [14,62–66].

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 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 [66–69].

5. Clinical Applications of Ultrasound Elastography

5.1. Liver

Chronic liver diseases involve a long-term and progressive condition where the liver sustains ongoing inflammation and damage, particularly months or years of damage, resulting in significant liver deterioration that is considered one of the most prominent causes of death in the United States, accounting for 1.4% of deaths and being the 12th most common cause of death. It primarily affects patients with high alcohol consumption as well as those with a metabolic syndrome of some sort, such as obesity or diabetes mellitus. Chronic liver disease (CLD) is primarily caused by various illnesses, including alcoholic liver disease, which affects 35% of Americans in the US, hepatitis viral disease (both hepatitis B and hepatitis C), which affects nearly 5 million Americans, and non-alcoholic fatty liver disease, which affects 20–30% of Americans, among others [70,71].

CLD can aggravate and eventually lead to liver fibrosis, cirrhosis, or portal hypertension, which are all considered life-threatening for the patient. The medical term for any type of scarring is fibrosis, whereas cirrhosis denotes late and extensively severe fibrosis.
Increased blood pressure within the portal system, known as portal hypertension, causes varices, as we will discuss later in this section. Ultrasound elastography widely assesses CLD patients, ensuring an accurate diagnosis without the need for invasive intervention. Imaging the patient in a slight (30°) left lateral decubitus fashion showcases the right liver lobe and avoids cardiac motion artifacts, as well as vascular, biliary and rib shadowing, and superimposition. This position, combined with shear wave elastography techniques, has proven to show the most accurate results in CLD diagnosis [14,72,73].

5.1.1. Elastography Techniques in Liver Disease Diagnosis

Shear wave imaging has proven to be the most accurate type of imaging for chronic liver diseases, primarily relying on 1D-TE, but can be detected with pSWE and 2D-SWE. However, due to the fact that pSWE and 2D-SWE are both newer techniques in contrast to 1D-TE, the latter method is predominantly used following its extensive research and diagnostic accuracy in the detection of fibrosis. The use of 1D-TE in liver pathology detection is mostly referred to as Fibroscan. The device measures the propagation speed of the shear waves generated by the vibration, and this information is used to estimate liver stiffness. Throughout the use of 1D-TE, research has shown that histopathologic fibrosis stages correspond with liver stiffness. In multiple studies conducted on liver fibrosis, using liver biopsy as the reference, they found that 1D-TE was the most authentic way to diagnose F4 fibrosis rather than F2 or F3. These results are indicative of how poorly the 1D-TE technique can differentiate between the various stages of fibrosis, but it still has the gift of being the most useful method to detect cirrhosis, unlike the pSWE technique that can detect F4 cirrhosis but is slightly less exact than 1D-TE. Some physicians encourage the use of pSWE to gather stiffness information from both the liver and the spleen, given the fact that pSWE may help cover a larger area than 1D-TE [74–76].

Many other studies compared 1D-TE and 2D-SWE and found that 2D-SWE was better at detecting significant (F2) and severe (F3) fibrosis than 1D-TE and pSWE. 2D-SWE uses ARFI, which aids in the inducement of shear waves in the organ of interest at more than one point. We conducted a comparison study among all three modalities to determine the accuracy of each individual method. A total of 349 patients participated in this study, and we used a liver biopsy as the reference [76]. Following studies conducted across all patients and modalities, 2D-SWE (also referred to as supersonic imaging) has shown the highest authenticity when it comes to detecting significant (F2) and severe fibrosis (F3) compared to both pSWE and 1D-TE, making it the only modality with the ability to fully differentiate between the four stages of fibrosis. Even though 2D-SWE has more benefits than 1D-TE, the latter is still being used primarily due to the recent development and new nature of 2D-SWE [77].

5.1.2. Technical Limitations in Liver Elastography

As mentioned before, the live imaging nature of ultrasound and US elastography calls for an easily influenced image, whether it be from the surroundings of the organ of interest, including involuntary motions and normal physiologic processes, or from nearby pathologic structures, and such findings can result in limitations and artifacts in the image, thereby causing a potential false diagnosis. Breathing, inflammation, right heart failure, and fasting are all examples of what can easily affect liver stiffness. Right heart failure, for example, can result in hepatic venous congestion, which causes an increase in liver stiffness following the increased venous pressure. Performing the Valsalva maneuver, or inspiration and expiration at an augmented rate, also affects liver stiffness by increasing it in the image. Breathing techniques should be given to the patient beforehand in order to avoid any unwanted blunders while collecting liver measurements [62,66,78].

One of the most common types of limitations when it comes to liver elastography imaging is patient obesity, especially when imaging with the Fibroscan or 1D-TE technique, because it depends heavily on the excitations applied to the skin surface. The technique of 1D-TE, as mentioned previously, does not allow for the acquisition of B-mode images,
which limits the sampling area of interest and results in a poor acoustic window and poor penetration. In the 2D-SWE imaging method, the most commonly observed limitations included spotted reverberations and involuntary motion due to cardiac, respiratory, and vascular pulsation. Scan protocols have been optimized to minimize the influence of these errors on liver elasticity quantification [66,79].

5.2. Kidneys

Chronic kidney disease (CKD) is a long-term and progressive disease that results in kidneys losing their ability to function properly, causing major renal damage and an inability to clean and filter the blood as well as healthy kidneys do, resulting in toxic waste and fluid accumulation that leads to potential heart disease and might eventually cause strokes and early death. CKD is primarily common among adults over 65 years old in the United States and the United Kingdom, with an estimation of 14% of patients diagnosed with CKD in the US and 10% in the UK [80–82]. CKD can run in families with African or Asian backgrounds and affect anyone from children to elders. Some CKD patients develop it as they grow older, while others might be born with it. Symptoms can range from mild itching and headaches to more advanced breathing difficulty due to the buildup of fluids inside the lungs. Muscle cramps and weakness, insomnia, and frequent nighttime urinating can count as CKD symptoms as well. Anybody can develop CKD, and the risk factors are influenced by many causes, such as hypertension, diabetes, the overuse of various medications, including Ibuprofen and Diclofenac, glomerulonephritis (which is an inflammation within the kidneys), and possible family history [83–87]. See Figure 3.

![Figure 3.](image)

**Figure 3.** The stages of chronic kidney disease (CKD) from 1 to 4 were determined by analyzing data obtained from the National Health and Nutrition Examination Survey conducted between 2017 and March 2020. The analysis utilized the CKD Epidemiology Collaboration GFR estimation equation for the year 2021, which incorporated variables such as serum creatinine levels, age, and sex. For a more comprehensive understanding of the methodologies employed, please refer to the section titled “Calculation of Estimates”.

5.2.1. Elastography Techniques in Renal Disease Diagnosis

The primary function of the kidneys is to filter waste products and excess fluids from the blood, help regulate blood pressure, and maintain electrolyte balance, but developing CKD can interfere and cause the kidneys to function improperly.

There are five stages of CKD, as measured by glomerular filtration rate (GFR), that can range from mild kidney damage in stage one to possible kidney failure in stage five. CKD can lead to multiple complications throughout the patient’s life and can affect a variety of organs in the body. It can lead to cardiovascular diseases, anemia, electrolyte imbalance, and renal fibrosis, but it is important to note that the detection of the disease in its early stages can aid in a quicker treatment and recovery, refraining from adverse treatments such
as dialysis and renal transplant. Later stages of CKD can result in renal fibrotic pathologies (native and allograft) [87,88].

Currently, renal biopsy is the only surefire way to stage renal fibrosis. However, new studies have shown that shear wave imaging (USE) may be able to find and monitor the disease without surgery, so there is less need for an invasive biopsy. SE has an accuracy of about 95% in predicting moderate (F2) and severe (F3) fibrosis in renal transplant patients. Allograft kidneys have the advantage of a superficial location, which makes assessment easier than that of the retroperitoneally located native kidneys; therefore, applying external pressure to native kidneys during SE makes for a somewhat false diagnosis of pathology. In addition to the fact that SE cannot distinguish between different stages of CKD, this calls for the use of shear wave imaging [87,88].

Shear imaging does not depend on external compression, showing advantages in evaluating both native and allograft kidney fibrosis and CKD as well, depicting a significant correlation between the presence of fibrosis found in elastography and biopsy and between the urinary creatinine levels and transverse elastography measures, unlike liver fibrosis. It has been shown by SWI studies of kidney fibrosis that CKD progression and shear wave velocity are inversely proportional, observing a decline in shear wave velocity as the CKD stages develop in comparison to normal kidneys [88–90].

USE can also aid in the detection of renal lesions using SI and susceptibility-weighted imaging (SWI is an MRI sequence that is particularly sensitive to compounds that distort the local magnetic field and, as such, makes it useful in detecting blood products, calcium, etc.), reducing the need for rather time-consuming CT and MRI imaging and eliminating any intravenous contrast media usage. Beneficial masses appear hyperechoic on the scan, but malignant masses tend to appear hypoechoic in approximately 10% of studied cases and hyperechoic in another 10%, although they could be somewhat confused together. The fact that malignant masses have the tendency to be 2.8 times stiffer than benign cells and that shear wave velocity has the ability to differentiate between them can assist in the assessment of the pathology at hand. Most radiologists prefer to use renal USE as an exclusion test rather than a test for diagnosis [91–96].

5.2.2. Technical Limitations in Renal Elastography

The presence of an outer fibrous coating in the kidneys, resembling Glisson’s capsule in the liver, introduces challenges in obtaining consistent data using ultrasound elastography. This is mostly due to the influence of blood, vascular movement, and urine pressure on kidney elasticity measurements. The aforementioned are the principal constraints of ultrasonic elastography. The potential exists for the recorded scans to exhibit inadequate precision due to the involuntary motion of the internal organs and vasculature, which may readily introduce distortions into the images. The native kidneys are constrained by their anatomical placement within the retroperitoneal space. Therefore, results show that USE can provide promising results in the ruling out of some pathologies and the detection of fibrosis since it is a non-invasive, affordable, and time-conserving alternative to renal biopsy, but it does not do a good job in differentiating between fibrosis stages or grading them; therefore, further research needs to be conducted regarding renal elastography to say that we can fully depend on it in the future [97,98].

5.3. Breast

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 [99,100].

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 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 [101–103].

5.3.1. 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 [99].

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) [100].

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.

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 [14]. See Figure 4.
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 [33,99]. 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

**Figure 4.** Visual representation illustrating the Tsukuba score. The lesion is depicted in an oval shape, with varying colors denoting differences in lesion stiffness in relation to the surrounding tissue. Specifically, the color blue represents increasing stiffness, while the color red represents decreased stiffness. As the Tsukuba score (ranging from 1 to 5) increases, there is an elevated likelihood of malignancy in lesions. The presence of blue, green, and red (BGR) bands exhibiting a tri-laminar pattern, as shown in the far right image, can serve as a diagnostic indicator for the presence of a cyst when visualized by various ultrasound equipment manufacturers, such as Hitachi and Toshiba [14].

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 [104,105].

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) [106].

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 [16,99]. 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 [107,108].

### 5.3.2. 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 [33,99]. 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 [33].

5.3.3. 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, hypoechochogenicity, 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 [109–111].

5.3.4. Technical Limitations in Thyroid Elastography

The primary problem with thyroid elastography is that external artificial compression in strain scanning causes operator-dependent variability. Moreover, the unpredictable nature of the stiffness of a tissue causes higher stiffness measurements. Furthermore, ultrasound is ineffective for nodules with cystic components, as fluid movement does not indicate solid component stiffness [112,113].

6. 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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