Zagazig University Medical Journal
www.zumj.journals.ekb.eg

https://doi.org/10.21608/zumj.2024.277715.3260 Volume 30, Issue 9.1, December. 2024, Supplement Issue

Manuscript ID ZUMJ-2403-3260
DOI 10.21608/ZUMJ.2024.277715.3260

Review Article

Possible Role of Shear Wave Elastography in Diagnosis of Malignant Pleural Effusion

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Submit Date 18-03-2024
Revise Date 21-03-2024
Accept Date 23-03-2024

ABSTRACT

Background: A malignant pleural effusion (MPE) occurs when there is a buildup of exudate in the pleural space together with the presence of tumor tissue or malignant cells. The clinical context and the elimination of other potential causes are crucial in making a diagnosis of the source of many pleural effusions. Shear wave Elastography is ultrasound technique which is capable of creating color maps of stiffness or elasticity without compression as strain elastography requires. Shear waves generated by mechanical stimulation of solids, with particle motion perpendicular to the propagation direction, are the primary subject of this theory. The purpose of this article was to offer a synopsis of the importance of shear wave elastography in the detection of malignant pleural effusions.

Conclusion: One new ultrasound technique, shear wave elastography (SWE), measures the amount of distortion caused by an applied force and can thus quantitatively evaluate tissue stiffness (shear waves). It is possible that ultrasound elastography has evolved as a complementary technique to thoracic ultrasound for the purpose of differentiating pleural effusions. As a radiological technique, it offers a noninvasive, simple, and inexpensive tool to differentiate and interpret pleural effusion.

Keywords: Shear wave elastography, Thoracic ultrasonography, Malignant pleural effusion

INTRODUCTION

A malignant pleural effusion (MPE) occurs when there is a buildup of exudate in the pleural space together with the presence of tumor tissue or malignant cells. Breathlessness, discomfort, cachexia, and decreased physical activity are symptoms of it. As the world's cancer rate rises and systemic medication becomes more effective, extending the lives of many patients, the healthcare expenses and occurrence of MPE are projected to expand [1].

While malignant pleural mesothelioma (MPM) is a possible cause of malignant pleural effusions (MPE), metastatic malignancies involving the pleura are the most common cause. This condition manifests in 15% of cancer patients and is common in those with metastatic disease [2].

Diagnostic approach of MPE:

Conducting a thorough history and physical examination is the initial stage in diagnosing a pleural effusion. A large number of pleural effusions do not show clear diagnostic characteristics on pleural fluid analysis or pleural biopsy, which highlights the significance of the patient's medical history and physical examination. The clinical context and the elimination of other potential causes are crucial in making a diagnosis of the source of many pleural effusions. After

collecting a sample of the pleural fluid, it must be classified as either an exudate or a transudate [3].

Ultrasound is becoming more popular among physicians due to its low cost, lack of invasiveness, and ease of use [4].

Despite being a well-established and validated imaging technique, respiratory physicians still do not fully employ transthoracic ultrasonography. It enables a quick and portable evaluation that may supplement the traditional chest x-ray [5].

Twenty years ago, transthoracic ultrasonography was only used by radiologists. Now, it is an essential tool for diagnosing and managing chest disorders, especially pleural diseases so it is used by non-radiologists e.g., pulmonologists. Research has shown that using point-of-care ultrasound for procedural guidance can greatly decrease the rate of consequences [6].

Originally, it was developed to identify a viable location for a pleural intervention; transthoracic ultrasound has now expanded its usage to evaluate pleural anomalies and subpleural pulmonary consolidations, among other pleural illnesses. [6]. the pleura, diaphragm, and lungs are all can be examined with thoracic ultrasound. When evaluating patients at the point of care, this gives a wealth of clinical information [7].

Various thoracic conditions, including pleural disease, pneumonia, interstitial lung disease, tumors, evaluation of diaphragmatic excursion, and tumours of the chest wall and mediastinum, can be effectively diagnosed and managed with this approach. In the evaluation of certain entities, it outperforms other radiological procedures (traditional x- ray, CT), and in most circumstances, the information given by the different techniques complements each other [8].

Whenever lesions come into contact with the parietal pleura thoracic ultrasound (TUS) has shown to be an incredibly helpful tool for diagnosis and interventional procedures in the pleural space and lung parenchyma. Compared to computed tomography (CT), thoracic ultrasound is more cost-effective, takes less time to execute, and produces less radiation when used to guide operations in certain lesions [8].

It is the gold standard for guiding thoracentesis since it increases the success rate and decreases the likelihood of complications, the most common of which is pneumothorax. To rule out pneumothorax, it checks normal lung sliding before and after the procedure, finds complex sonographic signs such septations, and approximatively estimates the volume of pleural fluid [9].

One of the steps in detecting pleural effusion in cases where cancer or tuberculosis is suspected is to do an ultrasound-guided pleural biopsy [10], not only does it take less time and doesn't expose the patient to radiation compared to CT-guided biopsy, but the operator can also adjust for the patient's breathing patterns in real-time, eliminating the need for apnea maneuvers [11].

Regarding pleural diseases, TUS has truly been a game-changer. In cases when pleural biopsies are required, it aids in their differentiation into various types, guides their performance (which is more cost-effective in these cases), and helps with the decision to remove thoracic drainage following talc pleurodesis [8].

About 5 millimeters below the cortical level of the ribs is where you can find the pleural line [12]. To check for motion, one looks for the pleural line, a shimmering echogenic linear structure. A "sparkling" effect (also known as "lung sliding") and the possibility of synchronization with heart pulsation are both produced when the pleural line glides parallel to the chest wall during respiration in healthy persons. The characteristic "seashore" symbol is produced by M-mode, which can be used to confirm lung sliding [13].

Pleural effusion:

The best way to find and measure pleural effusions is with a transthoracic ultrasound. On top of being more sensitive, it can detect even small pleural effusions as little as less than 5 ml. This is in contrast to traditional CXR, which has limited sensitivity even under ideal settings (such as standing or deep inhalation), since the fluid detection threshold is more than 150 ml. When the patient is in a supine position or if there are additional parenchymal pulmonary diseases, such as infiltrations or atelectasis, the results are significantly worse (500 ml) [14].

It is the most important tool for respiratory physicians to use when evaluating patients who have pleural effusions. In addition to being more sensitive than chest radiography for diagnosing effusions, thoracic ultrasound offers significant additional information regarding the size, depth, pleural thickening, septations, diaphragmatic movement, and complexity of the effusion. It can also shed light on potential underlying causes of pleural effusions in the lung tissue, such as cancer, pneumonia, pulmonary embolism, or pulmonary edema [6].

In order to ascertain the cause of the pleural disease, make informed treatment decisions, and direct any further invasive procedures, pleural effusion evaluation with TUS is crucial [6].

The parietal and visceral pleurae create a homogeneous, anechoic area when a pleural effusion occurs. Respiration often causes the area to alter form, but if the pleural surfaces become adhered to each other, lung movements above the effusion may be impossible. The presence of a tongue-like atelectatic lung within a bigger effusion is not uncommon [15].

Ultrasound elastography

Diseases include malignant tumors, fibrosis in liver cirrhosis, and atheroma and calcification in arteriosclerosis are known to involve alterations in tissue stiffness. Despite the widespread use of imaging modalities like CT, MRI, and PET for morphology and function diagnostics, ultrasonic elastography is the first method for quantitatively evaluating tissue stiffness. Clinical applications of tissue stiffness assessment include, but are not limited to:

1) It can help with differential diagnosis and early disease detection by picking up on qualitative alterations even in the absence of obvious morphological ones.

2) By assessing the size of lesions and the rate of advancement, the accuracy of identifying fibrosis-related disorders such cancer, chronic hepatitis, and atherosclerosis is enhanced.

3) We look at how well therapies like chemotherapy and radiofrequency ablation worked [16].

Radiologically, ultrasound elastography (UE) has been around since the 1990s and is a great tool for predicting the elasticity and stiffness of tissues. While UE gives both quantitative and qualitative data on tissue elasticity, B-mode ultrasonography shows the organs' morphological features and volume values [17].

Physical Principles of Ultrasound Elastography Imaging:

Elastography is a collection of methods for measuring the Young's modulus, a physical characteristic that describes the stiffness of tissues (E) As a proportionality constant, Young's modulus (E= stress/strain) links the relative change in tissue dimension (strain) to the applied force per unit area (stress) [18]. The deformability of the target lesion relative to the surrounding tissue is the fundamental determinant of elastography imaging. Because compressing softer tissues causes them to deform more than their harder counterparts, they will exhibit higher strain than the background tissue. On the other hand, compared to the background tissue, hard tissue deforms less during compression and exhibits less strain. By utilizing the strain differences, a visual elastogram can be generated, drawing attention to the target lesion's relative stiffness relative to the surrounding tissue [19].

There are two main types of ultrasound elastography techniques, based on the mechanism of applying the external mechanical excitation: quasi-static (also known as strain elastography) and dynamic (also known as shear wave elastography) [19].

Quasi-Static or Strain Elastography:

Using strain elastography, the first commercially available scanners in the US integrated tissue stiffness evaluation [18]. By pressing on tissues, strain elastography determines how stiff they are. The deformation of tissue dimensions caused by applied pressure is known as strain. As a result of reduced deformation, lower strain, and a greater Young's modulus, stronger lesions are desirable [20].

One way to calculate the strain ratio is to compare the strain in one area of tissue to that in another reference area. The applied force is not necessary to compute the strain ratio. This is why the strain ratio—which is mathematically equal to the

Young's Modulus ratio—is so popular in clinical practice [21].

In most cases, a strain ratio greater than 1 signifies reduced strain and increased stiffness, as the target lesion compresses less than the normal reference tissue (or lower elasticity). When assessing nodular lesions, for instance, when the likelihood of malignancy rises with increasing deformation ratios, the utility of this index becomes apparent [22]. Different types of tissue excitation (external manual stimulation and excitation with internal physiological movement) further categorize strain elastography into two subsets:[19].

a) Evaluating the elasticity of deeper-lying organs like the liver is difficult when using excitation with manual pressure, but it gets the job done for more superficial organs like the thyroid and breast.

B) Another way to create tissue stress is by stimulating normal physiological motions like breathing and heart pulse. This technique allows for the evaluation of deep organs.

The biggest problem with strain elastography is that the operator has no control over how much tissue is compressed by the ultrasonic transducer [14].

Here is a step-by-step description of strain elastography (Figure 1) [23] that should help:

Step 1: By comparing the structure when at rest and while under compression, the displacement (δ) caused by the operator's compression on the tissue may be determined.

Step 2: The strain, denoted as ε, is the ratio of the displacement difference between two points to their distance before compression (L).

Step 3: An elastogram, a colour map, is superimposed on top of the B-mode image to show the strain readings. Normally, blue is used to represent low strain (hard tissue) and red for high strain (soft tissue).

Dynamic or Shear Wave Elastography (SWE):

Dynamic shear unlike strain elastography, which requires compression, elastography uses ultrasound to produce colour maps of elasticity or stiffness. In this case, the particles travel perpendicular to the propagation direction, and the shear waves generated by mechanical excitation in solids are the main subject. Traditional B mode picture creation makes use of compressive acoustic waves, which propagate rapidly through soft tissues, at velocities ranging from 1450 to 1550 m/s. On the other hand, shear wave elastography makes use of mechanical shear waves, which move at a snail's pace of 1–10 m/s. The speed of shear waves is proportional to their elasticity in the tissue [22].

Rather than using physical compression, SWE relies on the transducer to generate shear waves, which are then monitored for their propagation speed. Propagation velocity of shear waves is directly related to tissue elasticity squared. Ultrasound systems capable of acquiring images at a rate higher than 1000 images per second are required to track the propagation speed of shear waves, which is between 1 and 2 m/s [24]. You can evaluate the results of shear wave elastography in two ways:

a) First, a colour elastogram, which shows a uniform blue pattern for benign lesions and a spectrum of yellow to red for malignant lesions' rigid areas. (Figure 2) [25].

b) Secondly, we have the Young Modulus value, which typically falls within the range of 20–80 Kpa for benign lesions and above 100 Kpa for malignant ones. [25].

Here are three easy steps to help comprehend SWE (Figure 3) [26].

In the first step, a linear ultrasound array is employed to produce focused acoustic radiation force, which causes localized displacement in the tissue and stresses it out. Next, the primary wave that generates the acoustic radiation force travels at a considerably slower speed through the transverse plane, which is perpendicular to the tissues adjacent to it. This causes the shear displacements in the tissues.

In the second step, the velocities of the shear waves and the displacement of the tissues are monitored by using fast plane wave excitation. A speckle tracking method is used to determine the displacement of the tissue.

Step three involves using tissue displacement maps to determine the shear-wave velocity, which is usually given in metres per second. A simple mathematical calculation gives the shear modulus, which expresses the stiffness and elasticity of the tissue in terms of pressure (often kilopascals), and

this in turn determines the distribution of shear-wave velocities at each pixel. The colour bar represents the relationship between shear velocity and shear modulus, where the density is assumed to be 1 g/cm3. Density estimations can be found in published literature or by experimenting with various forms of soft tissue.

In colour elastograms, soft consistency is represented by blue, hard consistency by red, and intermediate stiffness by green and yellow. A familiarity with the fundamentals of shear-wave physics in ultrasonography is necessary for comprehending and making sense of colour electrograms and velocities [26].

Sub types of Shear Wave Elastography include:

1) **1D Transient Elastography (TE)**:

One of the earliest SWI systems, the "FibroScan TM" 1D-TE system for liver evaluation, was commercially available. In the office, doctors frequently employ this method since it is the most popular and well-established way to evaluate liver fibrosis [22]. A mechanical vibrating mechanism and an ultrasonic transducer are housed in a single device known as the FibroscanTM probe. After that, the mechanical vibrating device applies a regulated external "punch" to the skin, creating shear waves that travel through the body's tissues. To determine Young's modulus E, the identical probe measures the shear wave speed using A-mode US [22].

Compared to liver biopsies, transient elastography (also known as FibroScan) assesses tissue stiffness across a 100-fold wider area, measuring 1 cm in diameter and 4 cm in length [27].

2) **Point Shear Wave Elastography (PSWE):**

The method of Acoustic Radiation Force Impulse (ARFI) imaging occurs when focused ultrasound causes focal tissue displacement. By following the ensuing shear waves, one may estimate their speed, which is a function of tissue stiffness in an algebraic form [28]. The "point" SWE is an abbreviation for "acoustic radiation force impulse," which is utilized to cause normal-direction tissue displacement at a single site [22]. Unlike 1D-TE, PSWE doesn't require specialized equipment; in fact, a regular ultrasound probe can do both the shear wave generation and detection, allowing for B-mode picture guidance throughout the experiment. [22].

3) **2D Shear Wave Elastography**:

Recent technical developments have led to the development of 2D-SWE, a method for evaluating tissue elasticity using acoustic radiation force [22]. This method involves the displacement of tissue at various sites using sonic radiation force. By tracking the shear waves' movement in real time at various locations in the image, high frame rate imagery makes the resulting wave easier to spot. An elastogram, a quantitative picture of elasticity, is shown as a coloured display map. The numerical findings can be found as the algebraically calculated Young's modulus in kPa or as the shear wave propagation speed in m/sec. One of the benefits of this method is that it allows the operator to be led by both anatomical and tissue stiffness information, as a colour quantitative elastogram may be superimposed on a B-mode image in real-time [22].

Shear-Wave Elastography in Pleural Effusion

Using the amount of distortion measured when an external force is applied, shear wave elastography (SWE) may objectively evaluate tissue stiffness. SWE is a newly created, innovative ultrasonic technique (shear waves). Breast[29], thyroid[30], and liver diseases[31] are only a few examples of the many conditions that can benefit from SWE's ability to distinguish between benign and malignant conditions by measuring tissue stiffness. The expanding list of SWE uses now includes the pleura [32]. Based on evaluation of pleural physical features, it can diagnose MPE quickly, cheaply, and without radiation [33].

Although pleural thickening and nodules are pleural morphological criteria used to diagnose MPE by transthoracic ultrasound, these symptoms are not always present in patients. This limitation is circumvented by pleural SWE, which is employed to diagnose MPE by measuring pleural stiffness. (Figure 4) [32]**.** A number of regulations must be followed in order to get reliable values for pleural stiffness: [31]**,** Place the traditional linear transducer parallel to the intercostal window and keep it in place while applying minimum pressure to the chest wall to prevent rib shadowing, take readings while holding your breath halfway through your breath, but not while you're deeply inhaling, optimal B-mode images are required, Measurements should

only be taken on tissue sections with sufficient shear wave propagation, as shown by an imaging confidence map in conjunction with the stiffness map (electrogram).

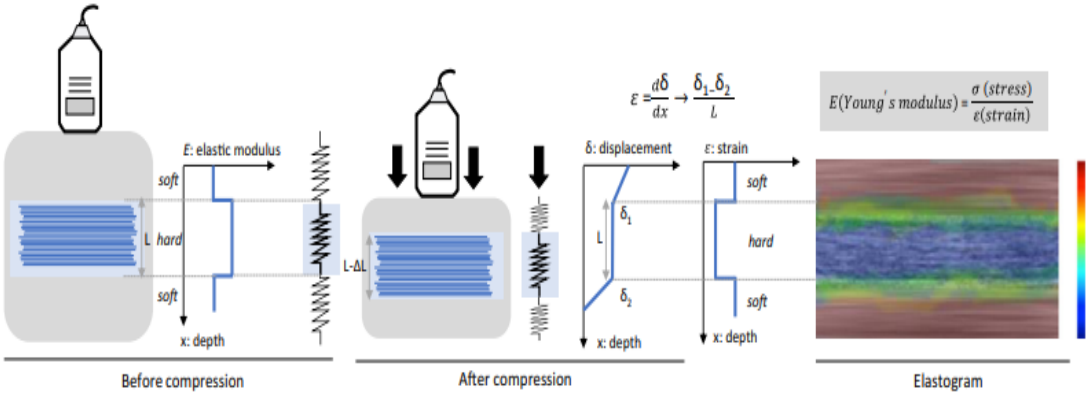


Figure 1: Basic physical principle of compression elastography (CE) **[23]**

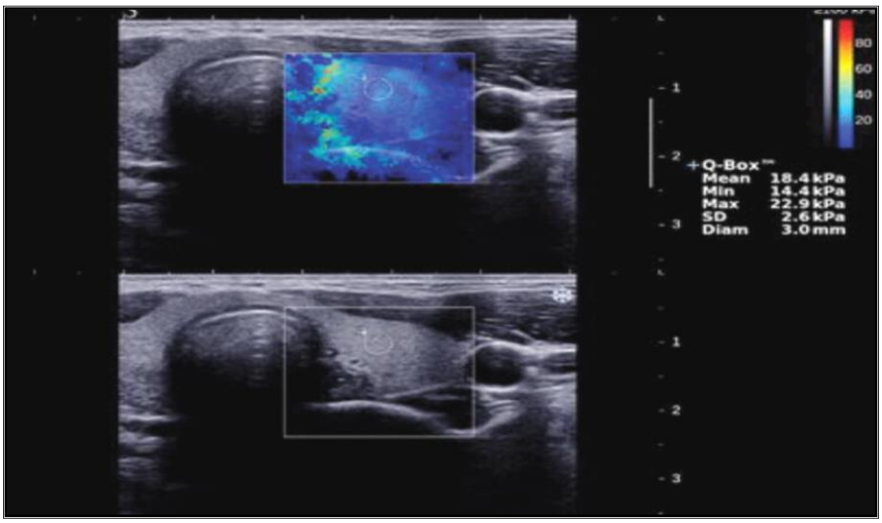


Figure 2: SWE image of thyroid [25].

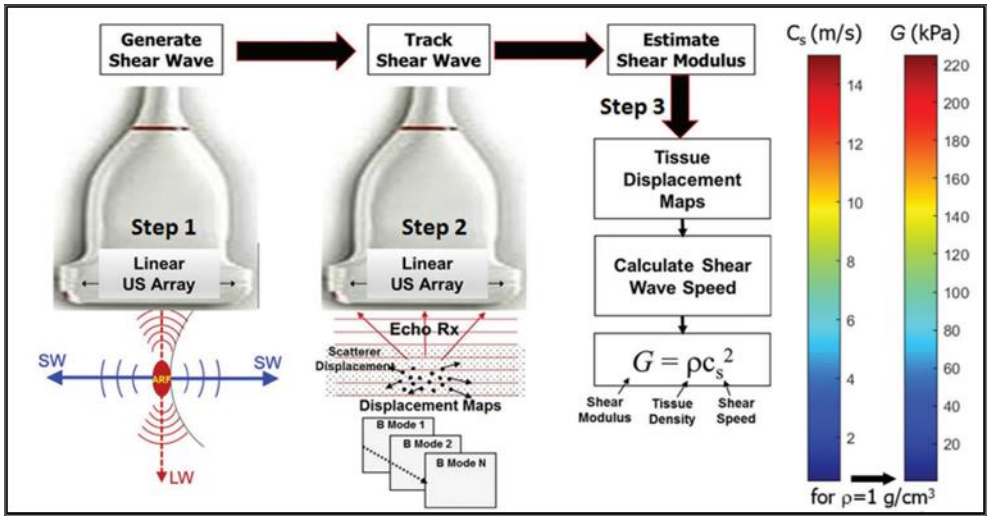


Figure 3: (a) Basic physics of SWE. In step 1, shear waves are generated using acoustic radiation force; they propagate perpendicularly to the primary US wave at a lower velocity. In step 2, fast plane wave excitation is used to track displacement and velocity as shear waves propagate, and tissue displacement is calculated using a speckle tracking algorithm. In step 3, tissue displacements are used to calculate shear-wave velocity (c_s) and shear modulus *(G)*. **(b)** Relationship between shear velocity and shear modulus expressed as a color bar, which assumes, in this case, a density equal to that of water (1 g/cm^3). Actual density estimates will vary for different types of soft tissue and can also be found using values [26].

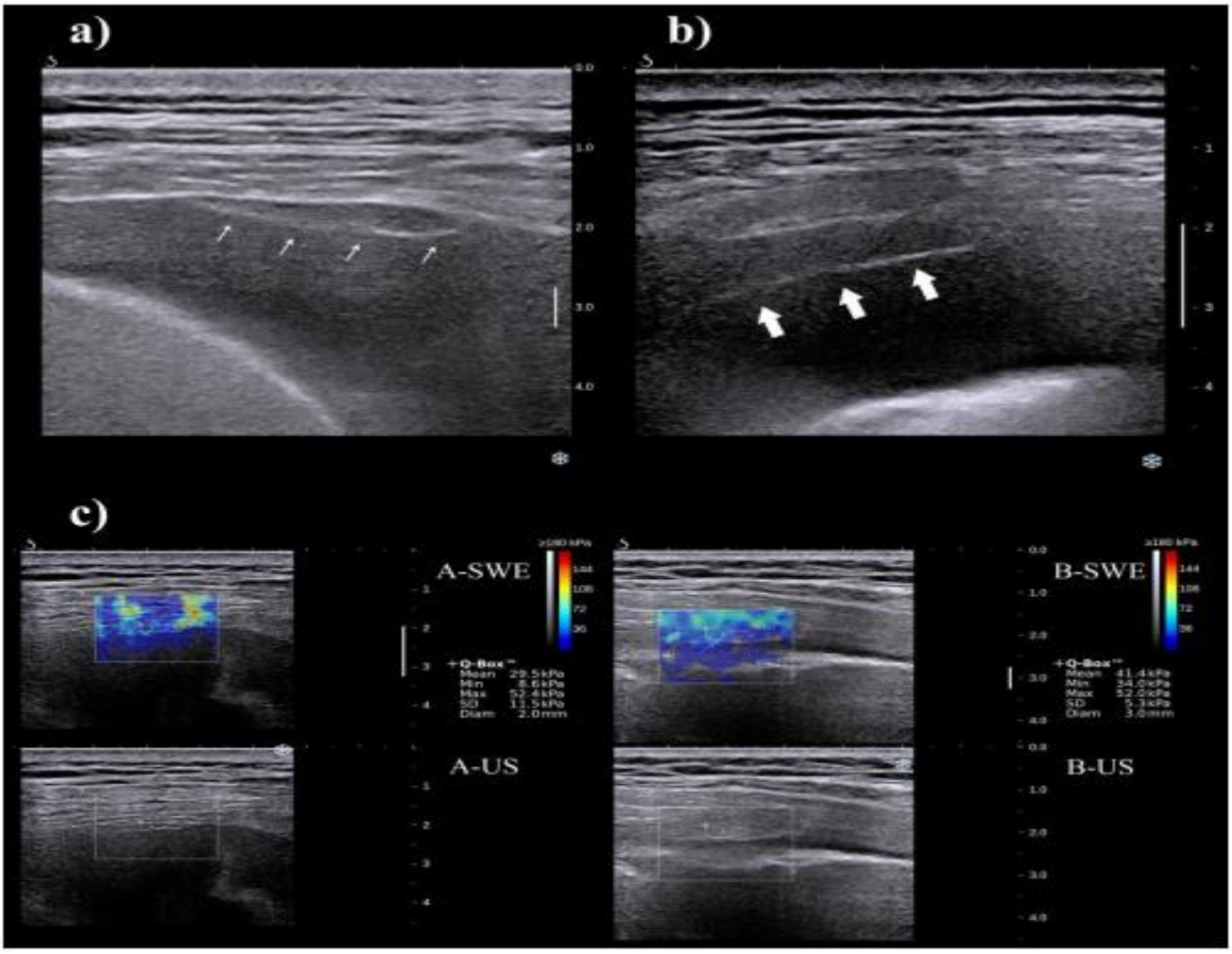
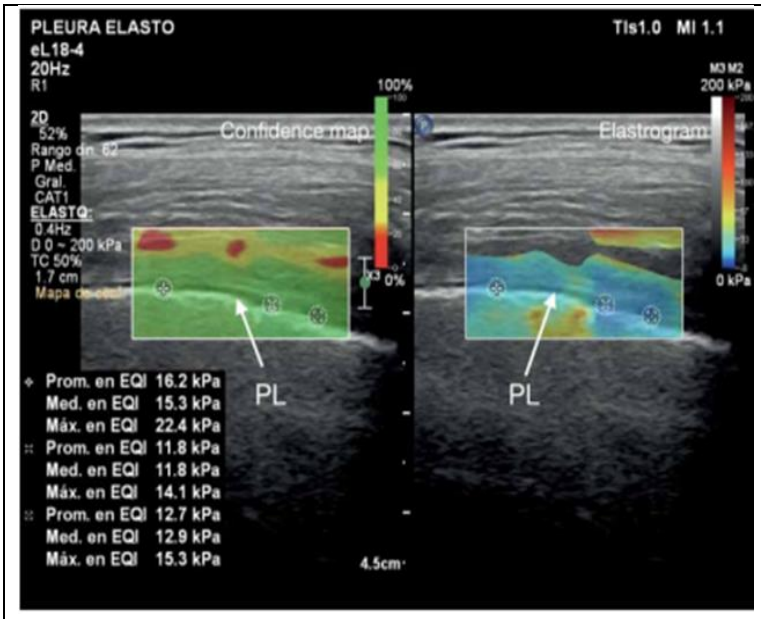
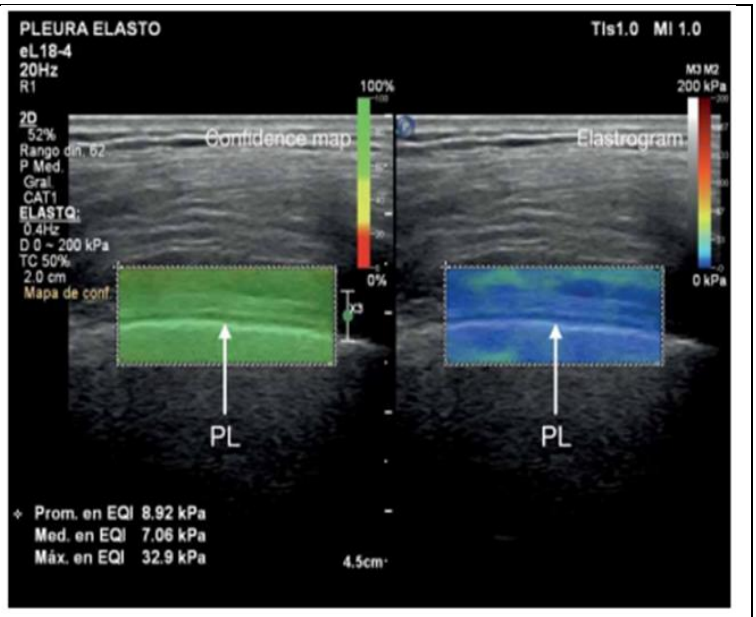


Figure 4: Ultrasound features of pleural nodules and focal pleural thickening and measurements of pleural stiffness by shear wave elastography. Pleural nodules appeared as hypoechoic nodular lesions with defined margins located in the parietal or visceral pleura (a), while focal pleural thickening was identified as an echogenic area of increased thickness in the parietal pleura with poorly defined margins (b). Images of pleural thickening or nodules are displayed together with the grayscale ultrasound images. After placing a box (frame) over the pleura, a colored image appeared, revealing blue and red areas on an elastogram. Dark blue areas correspond to soft tissues, whereas red areas correspond to stiff tissues (c) [32]**.**



(A)



(B)

Figure 5: Pleural shear wave elastrography in a patient with a cardiac effusion. Stiffness values (kPa) can be obtained from a) specific regions of interest (circles) or b) selected areas (boxes). A confidence map (left hand panel in a and b) indicates trusted values (green colour), which are visually displayed according to a colour map or elastogram scale (right hand panel in a and b) and numerically quantified (bottom left in a and b). PL: pleural line [32]

CONCLUSION

A new ultrasound technique -new regarding its use in pleural diseases- called shear wave elastography (SWE) measures the amount of distortion caused by an external force and may thus quantitatively evaluate tissue stiffness (shear waves). It is possible that ultrasound elastography has evolved as a complementary technique to thoracic ultrasound for the purpose of differentiating pleural effusions. As a radiological technique, it offers a noninvasive, simple, and inexpensive way to differentiate and interpret pleural effusion in everyday practice.

No potential conflict of interest was reported by the authors.

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Citation

Ibrahim, D., Amer, W., Elhawary, A., Gamal Nada, M., Kabeel, Y. Possible Role of Shear Wave Elastography in Diagnosis of Malignant Pleural Effusion. *Zagazig University Medical Journal*, 2024; (5192-5201): -. doi: 10.21608/zumj.2024.277715.3260