Types and applications of elastography technique: An overview

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Abstract— **One of the most accurate methods for identifying cancerous tumors such as breast, liver, prostate, and thyroid is elastography. This non-invasive technique replaces sampling and is now used in many countries to identify tumors and tissue damage. Elastography is a method of imaging in which healthy tissue can be identified from the surrounding cancerous tissue by measuring the mechanical properties of the tissues. With this method, many benign and malignant tumors in some tissues of the body can be separated from each other without the need for biopsy. According to the studies that show the lack of a comprehensive study in this field and the importance of the elastography method, in the present work for the first time, various types of elastography methods and their applications are evaluated. The purpose of this study is to help develop this method and get acquainted with the use of this method to diagnose various diseases. The authors of the present work hope that the present study will help researchers in the development and advancement of the elastography method.**

Keywords- Elastography; Tissue; Stiffness; Elastisity; Biopsy; Sampling.

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1. Introduction

Nowadays, non-invasive simulations and methods have attracted a large part of researchers' attention [1-5]. Because they cost less, have fewer side effects, and are also a better diagnostic way [6-10].

Elastography is a method for imaging tissue stiffness using shear waves, which can be used to compare the mechanical properties of tissue at different points and be used to identify and determine the progression of diseases. This non-invasive technique replaces sampling and is now used in many countries to identify tumors and tissue damage [11]. Elastography is a medical imaging technique that determines the elastic properties (elasticity) and hardness of soft tissue. The reason for measuring the softness and hardness of the tissue is that it can be used to detect the presence or progression of some diseases. For example, cancerous tumors are usually harder than the surrounding tissue, or, for example, diseased livers are harder than healthy livers [12].

Palpation is the estimation of the hardness of a patient's tissue using specialist hands. Touch examination dates back to at least 1500 BC. In ancient Greece, Hippocrates provided guidelines for various types of diagnosis by palpation, including tactile examination of the skin, wounds, intestines, breasts, tumors, gastric and uterine ulcers. In today's world, in the 1930s, this method was considered an accepted method. The first clinically useful elastography system was registered in 2003, and since then extensive research has been conducted on various diseases and their diagnostic importance [13].

However, palpation examination has two major drawbacks: first, it can only be used for tissues that are accessible to a specialist, as it may be distorted by a barrier tissue, and second, it only shows quality. Detection does not quantify, for example, it can’t say anything about the severity of the tumor tissue or the severity of its progression. For example, to check for liver disease, when fibrosis is diffuse, if a biopsy is used, the fibrous part of the patient's tissue may easily remain intact, resulting in misdiagnosis and negative and false to be received. As a result, measuring the hardness of the tissue, which is called elastography, can meet these limitations [14].

2. Definition of Elastography

Elasticity is a very important physical property of solids. In the field of clinical application, the elastic property of tissue is used in physical tests. The elastic properties of soft tissues depend on the molecular blocks and macroscopic and microscopic structural structures of the tissues. For example, tissue damage is generally associated with changes in stiffness. Tissue changes in many cancers, such as breast cancer, appear as very hard areas in the soft tissue. Therefore, differences in elasticity can facilitate the diagnosis of tumors and the extent of their progression. The touch technique, for example, is a common diagnostic tool based on differences in the elasticity of a tissue lesion and the surrounding environment [15]. Determining the elasticity of a medium during elastography is done through the following steps:

- Apply a static or cyclic mechanical pressure to the tissue;
- Measuring the amount of deformation created in the environment in response to the pressure applied to it;
- Calculation of the elastic coefficients of the environment from the values obtained by measuring its deformation [15].

3. Types of Elastography

Considering the different ways of recognizing the macroscopic properties of tissue, the elastography method can be divided into the following three categories [16]:

- Ultrasonic elastography
- Magnetic resonance elastography
- Optical elastography

Elastography methods are divided into four different types based on how mechanical stimulation is created in the tissue: static, dynamic, passive, and shear wave-based. In these methods, the static method has disadvantages such as low reproducibility, operator dependence, and inefficiency for deeper textures, and the dynamic method with problems such as high cost, low access, and non-real-time imaging. The passive elastography method has no active source of external radiation and the firmness of the tissue is measured by the reciprocal correlation of noise in the contracted muscles, which are recorded by sensors placed on the surface of the skin. Due to the lack of external stimuli, this method is cheap, non-invasive, and available. Finally, an important advantage of the shear wave-based method is that it does not depend on the skill of the experimenter, and the stiffness of deeper tissues can also be measured [17].

There are generally two ways to create a shear wave in tissue. One is the elastography method of Acoustic Radiation Force Induced (ARFI) and the other is the transient method. In the ARFI method, an acoustic pulse with a period of fewer than 100 microseconds and high intensity with a frequency of 2.67 MHz is used to create displacement in the tissue at the micron scale. The advantage of this method is its availability and the need for

no additional equipment, so that in many cases only by adding a piece of software to the ultrasound device, these devices can be used to assess tissue elasticity. In the transient method, a vibrator is applied to the tissue as a mechanical exciter, a vibration with a gentle amplitude and low frequency, and a probe containing an ultrasonic transducer is connected to the vibrator axis. One of the advantages of transient elastography is the reduction of processing volume by using instantaneous and transient stimuli. Because these stimuli are applied very quickly, they do not interfere with the feedback signal and involve only the return signal from the tissue [17].
It is worth noting that diagnosis by elastography alone is not practical. Elastography is needed as an aid to complete the diagnosis in a conventional way. Interpretation of elasticity as a diagnostic aid may vary depending on the shape of the lesion. One of the advantages of elastography is that when the doctor is familiar with the appropriate technique, accuracy of over 80% is achieved [15].

3.1. Ultrasonic elastography

Many tumors can be detected using sonography or other common imaging systems, but they cannot be diagnosed as benign or malignant without tissue biopsy, which is an invasive technique. It is also not possible to examine the tumor using this method in the extracorporeal environment, which has been solved by elastography [18]. Ultrasonic elastography is a new imaging technique with the ability to determine small amounts of some mechanical properties, such as the elastic properties of biological tissues. This technique was proposed by Ophir et al. in 1991 with the aim of determining the benign and malignant lesions of breast tissue without the need for biopsy [12]. Figure 1 shows an example of this method.

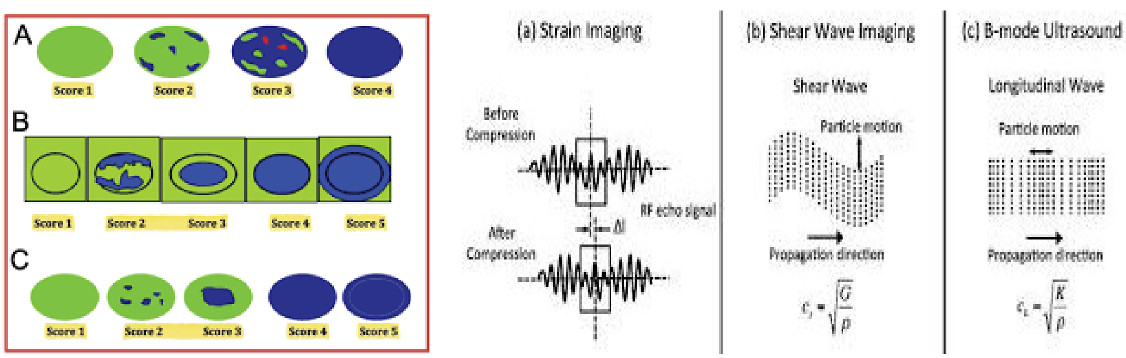

Figure 1: Ultrasonic elastography [12]

3.2. Quasi-static elastography (stretching imaging)

Quasi-static elastography, sometimes referred to as elastography (alone), is one of the oldest elastography methods. In this method, external pressure is applied to the tissue, and the tissue is imaged with an ultrasound device before and after applying pressure, and then the two are compared. Areas of tissue that are less deformed are harder areas and areas that are more deformed are softer. In general, what is shown to the specialist is an image of the distortion (stretching) of different areas of tissue relative to each other, which is usually used for clinical use [15]. Figure 2 shows an example of this method.

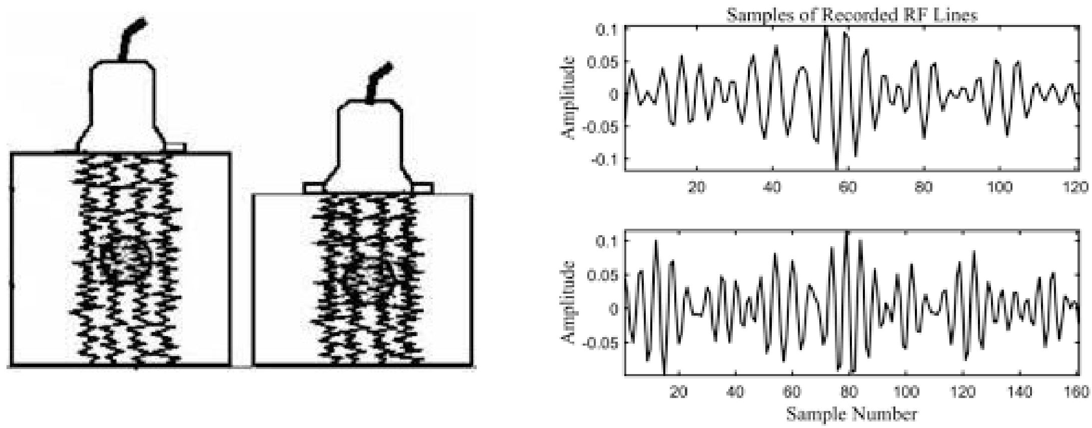

Figure 2: Stretching imaging [19]

3.3. Imaging with acoustic impact radiation

This type of imaging uses sonography to create a two-dimensional image that qualitatively shows the hardness of different parts of the tissue. This is achieved by applying pressure inside the tissue, using acoustic radiation generated by a focused beam of ultrasound. The extent to which tissue exposed to radiation is compressed indicates the degree of hardness of the tissue. Softer textures are easier to compress than harder textures. If pressure is applied to large areas of tissue, a general map of tissue stiffness is obtained [15]. Figure 3 shows how this method works.

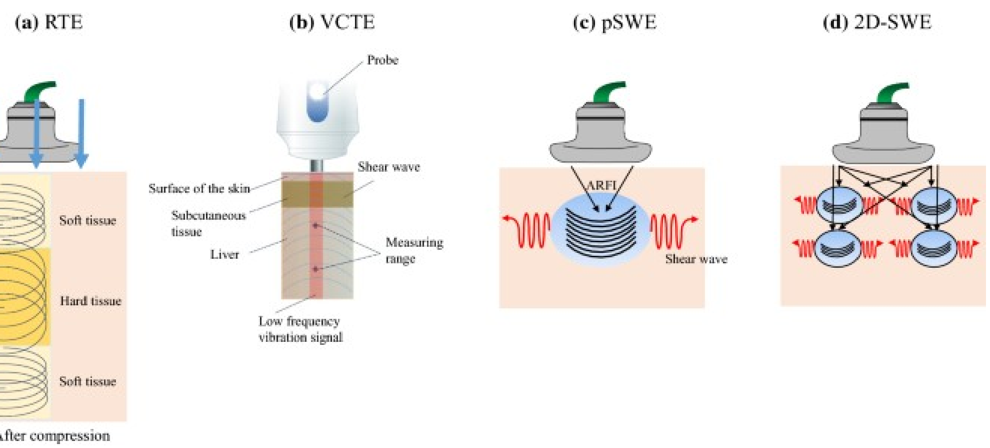

Figure 3: Impact acoustic radiation [19]

3.4. Ultrasonic Shear Wave Elasticity Imaging (SWEI)

In imaging elasticity with shear waves such as ARFI, the method is to apply pressure to the tissue through acoustic radiation. The turbulence created by this pressure is transmitted unilaterally as a shear wave, the schematic of which is shown in Figure 4 [15]. Using imaging techniques such as ultrasound or magnetic resonance imaging (MRI), the wave velocity is assessed at different lateral points, and tissue hardness is extracted at different points.

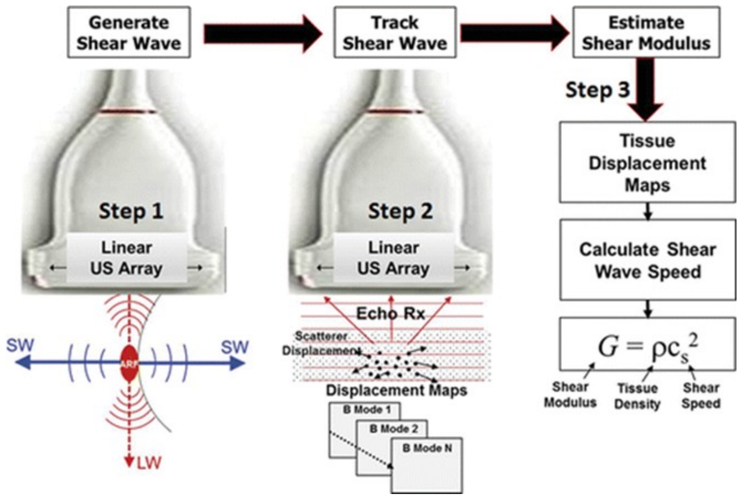

Figure 4: Shear wave imaging [20]

3.5. Supersonic shear imaging (SSI)

In this method, local velocity maps in the tissue are obtained by a conventional method of tracking points and show a complete film of shear wave propagation in the tissue (Figure 5). The two major innovations of SSI are: First, using burst and almost simultaneous pressures, SSI produces a set of shear waves that pass through the target tissue at a speed within the ultrasonic range. Second, these generated shear waves are imaged using very high-speed imaging techniques. Using inverse algorithms, the shear elasticity of the tissue is quantitatively mapped using the wave propagation film. SSI is the first ultrasound imaging technology that can capture more than 10,000 frames per second from organs far from the surface of the skin. A set of mechanical properties of the tissue, including Young's modulus, anisotropy, and viscosity, is quantified and demonstrated by intra-tissue studies. This method has many advantages in clinical applications in imaging of the breast, thyroid, liver, prostate, and skeletal muscle system [15].

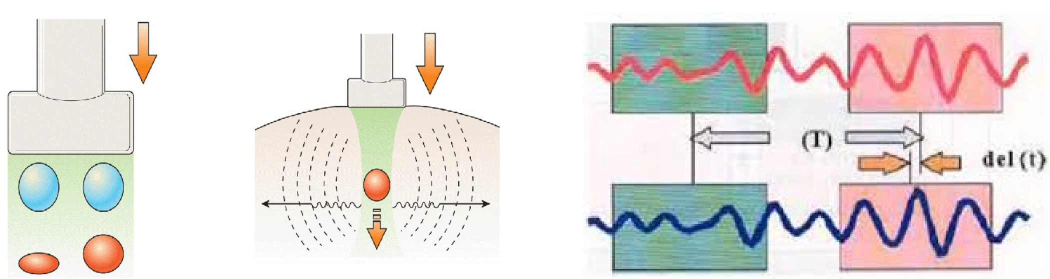

Figure 5: Shear imaging with ultrasound [19]

3.6. Transient elastography imaging

Transient elastography produces a quantitative (numerical) image of the hardness of the tissue. This image is extracted by vibrating the skin using an engine that creates a shear wave in the tissue and capture the movement of this wave along the tissue using a one-dimensional ultrasound beam. Finally, it shows a line of tissue hardness [15]. The performance schematic and the actual image obtained in this method are shown in Figure 6.

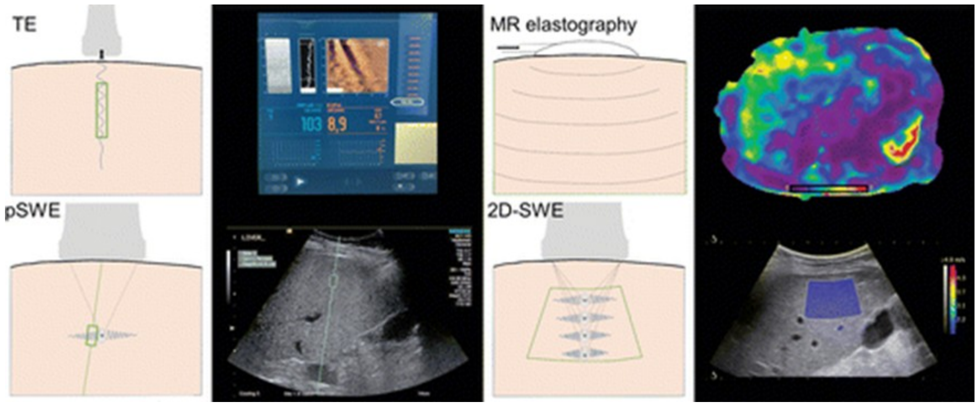

Figure 6: Transient elastography [19]

4. Diagnosis of the disease by elastography

Cancer is a very common disease caused by the abnormal proliferation of cells in one tissue and their migration to other sites (metastasis). If the formation of tumors prone to cancer can be detected in the early stages, the complications of this disease and its widespread mortality can be prevented. Today, there are several methods for detecting and differentiating benign and malignant cells, one of the best of which is the elastography method, which has a good function in identifying and differentiating soft tissue tumors.

4.1. Thyroid elastography

Thyroid nodules are common masses commonly seen on thyroid sonography, so diagnosing cancerous masses from these nodules is one of the priorities for the radiologist to determine which nodule must have a biopsy. The presence of several suspicious features in thyroid masses can lead the radiologist to predict thyroid cancer, including:

- Because cancerous tumors have a stiffer texture than healthy areas, the reflection of sound waves from ultrasound machine is greater. In fact, more shadows can be seen in the image. This process is called hypocogenicity.
-The presence of splicolite margins means that they have irregular margins.
- Microcalcification has small spots of calcium [21].

The irregular margins shown in Figure 7 are microcalcifications. Because hard cancerous tumors can be detected by physical examination, elastography can be used to determine how hard the tissue of these masses is and how advanced the cancerous masses are.

4.2. Breast elastography

One of the most common types of cancer among women is breast cancer and it is one of the leading causes of death among women. A report by the American Cancer Society and the International Agency for Research on Cancer states that breast cancer in women is the most common diagnostic cancer in the world, surpassing the diagnosis of lung cancer. Global cancer statistics show that of the 19.3 million new cases of cancer in 2020, breast cancer in women accounts for about 2.3 million (12 percent), while lung cancer accounts for 11 percent of cases [12].

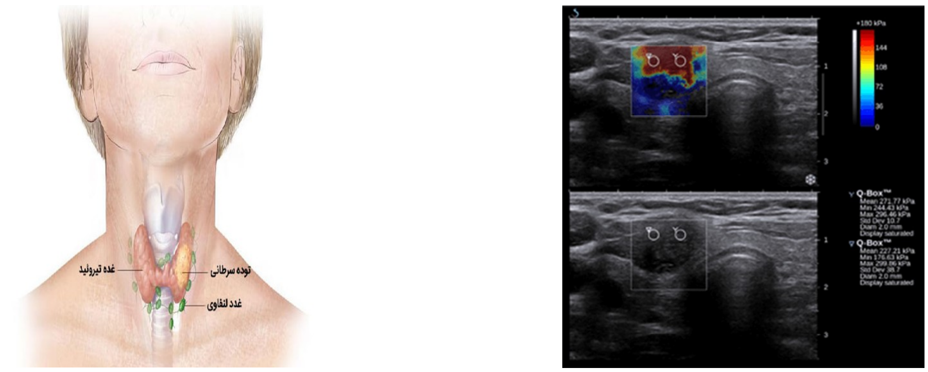

Figure 7: Thyroid elastography [20]

In 1991, the first idea to use elastography in the diagnosis of breast cancer was proposed and in 1997 research showed that ultrasound elastography can help diagnose breast lesions [12]. In 2003 and in this case, the first medical equipment was produced and supplied [12]. This method provides additional information to the radiologist compared to ultrasound. In conventional ultrasound, the texture and appearance of the test area are determined. However, elastography can be used in addition to this information, as mentioned above, to measure the hardness of breast tissue and be a diagnostic supplement in addition to ultrasound. The increase in accuracy that results from the placement of these two imaging methods reduces the percentage of physician error in diagnosing masses [21].
Figure 8 shows an example of the use of elastography for the breast. The figure on the right shows a picture of a disease with 5 cm adenocarcinoma detected by Magnetic Resonance Elastography (MRE). In part “a”, a picture of a breast with a tumor can be seen. In part “b”, the shear wavelength in the tumor area is longer than in normal tissue. In part “c” the elastogram is seen. As can be seen in the image, the tumor area is more rigid than normal tissue.

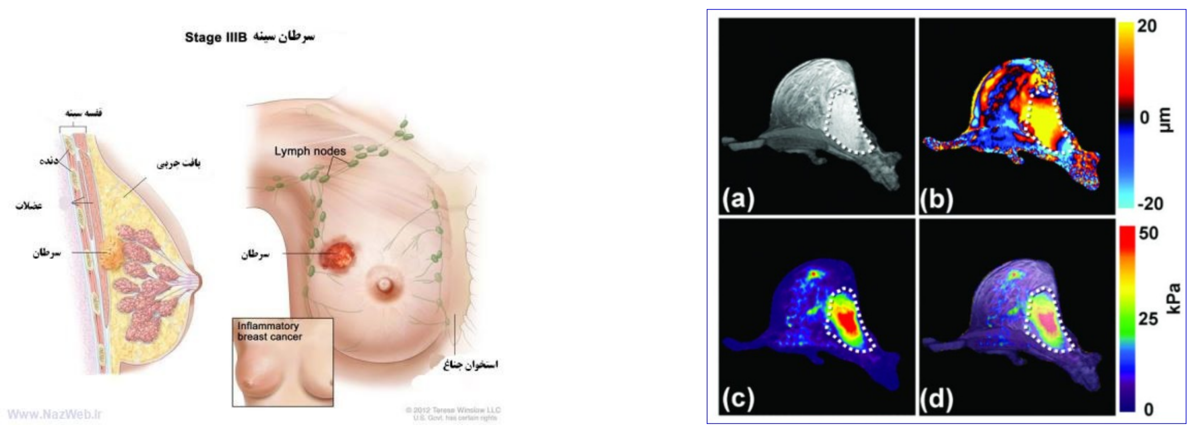

Figure 8: Breast elastography [20]

4.3. Liver elastography

Chronic fatty liver disease is one of the diseases that has become a common disease due to lifestyle changes that have plagued many people these days. Obesity, hyperlipidemia, type 2 diabetes, alcohol use, and certain medications are some of the factors that can cause this condition. Liver elastography helps to diagnose or rule out fatty liver easily and painlessly, instead of using an invasive biopsy or sampling procedure. Liver

elastography is used to examine fibrosis. The elastography method, with its good accuracy in diagnosing tissues, can enable the physician and radiologist to give the correct answer in the diagnosis of fatty liver without the need for biopsy [22].
Figure 9 shows an overview of liver disease and the elastography method used for it. The image on the left is a graph of healthy volunteers and patients with varying degrees of liver fibrosis. The higher the degree of fibrosis, the higher the stiffness of the liver. The threshold for healthy and fibrous liver according to studies is 2.93 kPa. Common imaging modalities such as ultrasound, CT, and MRI usually do not detect liver fibrosis until it has turned into cirrhosis. The image on the right shows two clinical examples of the MRE test. The first is a disease with a healthy liver (upper row) and the second with a liver with cirrhosis (lower row). Images of MRE size of the healthy and diseased liver are shown in sections “a” and “d”, and liver disease is plotted with dashed lines. MRE size images do not provide information on the presence or absence of disease. In sections “b” and “e”, the MRE image taken at 60 Hz is seen for healthy and diseased livers, respectively. As can be seen, shear waves in the liver with cirrhosis are longer than shear waves in a healthy liver. Estimated values of stiffness associated with healthy and diseased liver are also seen in sections “c” and “f”, respectively, indicating that liver stiffness with cirrhosis is greater than that of a healthy liver.

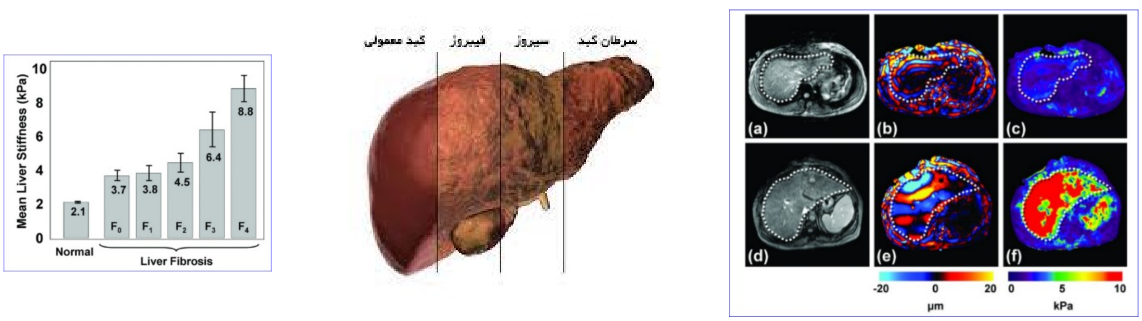

Figure 9: Liver elastography [20]

4.4. Brain elastography

In diseases such as Alzheimer's, hydrocephalus, brain tumors, and MS, studies are underway to evaluate changes in brain tissue stiffness and mechanical properties. While sonography-based elastography is difficult in the brain area, magnetic resonance elastography in this area can be performed well.
Figure 10 shows a view of brain elastography. The image on the right shows the MRE from a healthy person's brain. Section “a” shows the agonial size image of the brain. The vibrations at a frequency of 60 Hz are sent by the driver activated with pressure under the patient's head. In sections “b” and “c”, the corresponding wave image and elastogram are seen, respectively.

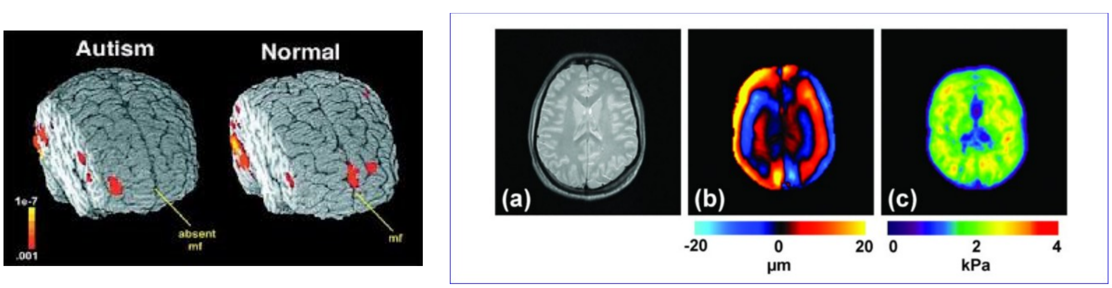

Figure 10: Brain elastography [19]

4.5. Elastography of skeletal muscle

This type of MRE is also widely studied to investigate the stiffness of these muscles because it has been proven that changes in stiffness in muscles are significantly dependent on the contractile state of the muscle. Skeletal muscle MRE can be used to assess the physiological response of a patient's injured muscles.
Figure 11 shows a view of this elastography type. The image on the top shows the MRE of the soleus muscle of a healthy patient. In section “a”, a size MRE image of the muscle can be seen. For this patient, MRE images were taken with an electromechanical driver with 100 Hz shear waves. In the image of sections “b” to “d”, the wave image is taken while the muscle is under the force of 0, 5, and 10 N/m. The shear wavelength in the pressurized muscle area is longer.

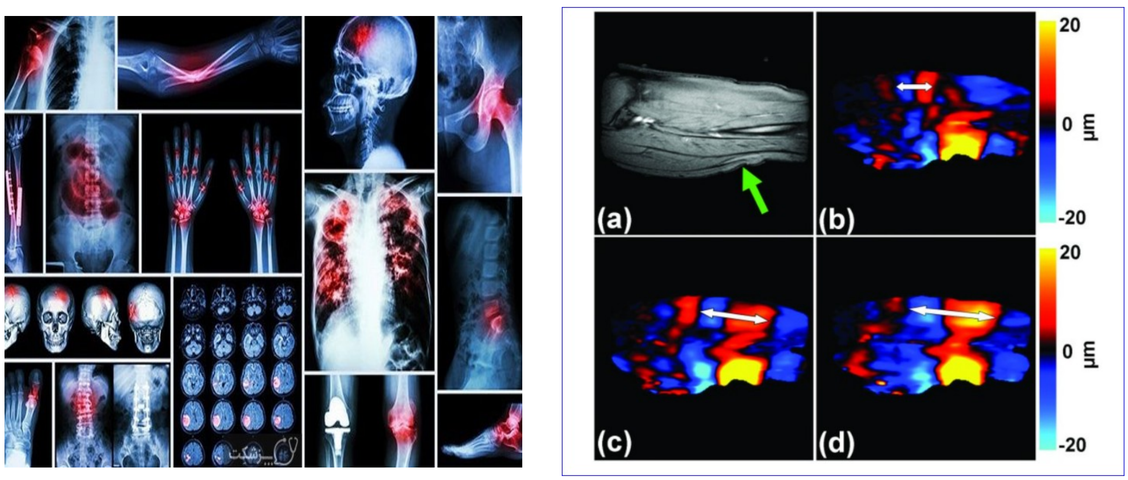

Figure 11: Skeletal muscle elastography [19]

5. Future work

Given the importance of renewable energy in Iran and the world [23-42], in the continuation of the present work, the authors will intend to supply electricity to an elastography device using renewable energy.

6. Conclusion

One of the most accurate methods for identifying cancerous tumors such as breast, liver, prostate, and thyroid cancers is elastography. Using this method, doctors can determine how hard the tissue has become and can identify the masses (using only imaging) without the need for surgery. Therefore, today, the use of elastography imaging has been able to help diagnose cancer more accurately. Today, elastography is used to diagnose cancer more than any other method in the world. Considering these cases that show the importance of the elastography method and also considering that a comprehensive study on different types of elastography methods in the diagnosis of various diseases has not been done so far, the present work has been performed for the first time. Other benefits of the present work include examining a variety of elastography methods and providing images for different applications and different diseases. The authors of the present article hope that the present study can be useful in the development of elastography.

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