Magnetic Resonance Elastography- Techniques & Clinical Applications- An Overview

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ABSTRACT:-

Magnetic resonance Elastography (MRE) is a constantly advancing technique for assessment of stiffness of tissues with newer technology and sequences. It is being increasingly used for the assessment of liver fibrosis. In this article, we discuss the Basic techniques,Principle, advantages and Clinical applications of Magnetic resonance Elastography (MRE) in the assessment of liver fibrosis, Image acquisition and interpretation of liver MRE and different parts like Breast Elastography, Brain Elastography, Muscle Elastography are also discussed.

Key Terms: - Magnetic resonance Elastography (MRE), Liver fibrosis, Active Driver Passive Driver, Phase Contrast sequences

Introduction :-

Elasticity is one of the most important physical properties of the human tissues and can be markedly affected by a variety of diseases. Magnetic resonance Elastography (MRE) is a phase-contrast MRI technique that is used to noninvasively and quantitatively assess tissue stiffness and it is a rapidly developing technology for quantitatively assessing the mechanical properties of tissue and can be performed with USG and MRI both. With this technology used to evaluate of tissue stiffness of different organs like, liver, breast, spleen, muscles, brain and kidneys. The technology can be considered to be an imaging based counterpart to palpation, commonly used by physicians to diagnose and characterized disease. The success of palpation as a diagnostic method is based on the fact that the mechanical properties of tissue are often dramatically affected by the presence of disease processes such as cancer, common inflammation and fibrosis (1-3).

To overcome the limitations of the traditional shear testing of materials, there has been an increasing widespread availability of the latest imaging modalities such as ultrasound, Computed Tomography (CT) and Magnetic Resonance Imaging (MRI), that allowed unprecedented views into the body to distinguish tissue types and diseases states. Nonetheless, the dynamic range available in these modalities is dwarfed by the range of the tissue mechanical property of shear modulus. In Fig. 1 the ranges of measured parameters are illustrated for different imaging techniques. Ultrasound, for instance, provides contrast between tissue types via the bulk modulus (material resistance to a uniform compression) of the underlying tissues. However, while bone has a bulk modulus that is easily distinguished by the bulk modulus of soft tissue all soft tissues have similar bulk modulus, which is a disadvantage of this technique. Using standard MRI there is also a very narrow range of values within the organs. On the other hand, the shear modulus varies over several orders of magnitude and so, it has a vastly range of values for a variety of tissues. Therefore, the appeal of Elastography is to make the most of the two great advantages of this long-standing technique: high level of specificity for mechanical property changes due to disease, and the inherently large underlying range of mechanical properties. For those reasons, over the last decade, the recognition of the potential diagnostic value of characterizing mechanical properties, has led to the development of new and more precise techniques for imaging tissue elasticity using Elastography. Elastography is based on the detection of tissue strain, produced by defined internal or external stresses and it has been used combined with conventional imaging techniques, like ultrasound imaging and MRI (4).

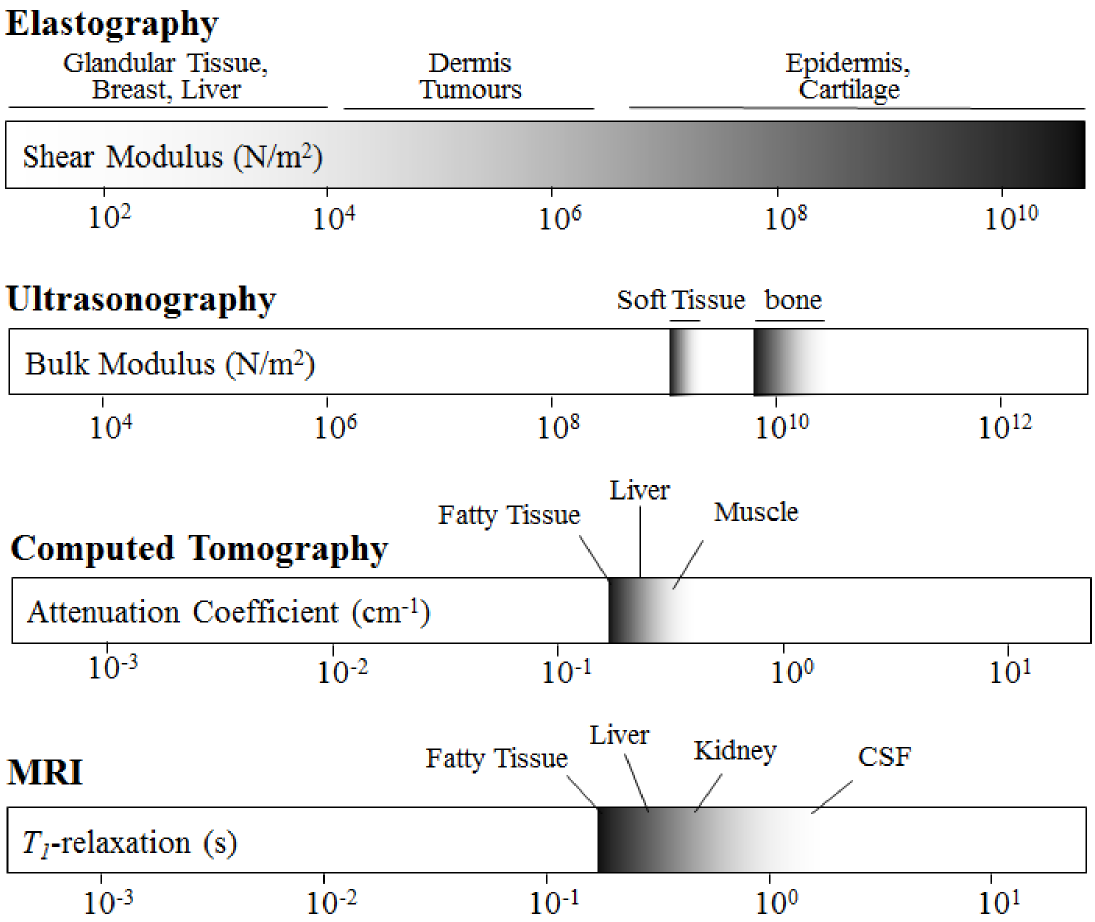

Fig-1 Dynamic Range of shear modulus and Tissue properties in different imaging modalities like ultrasound, CT and MRI.

MRE obtains information about the stiffness of tissue by assessing the propagation mechanical waves through the tissue with a special magnetic resonance(MRI)technique.

The technique essentially involves 3 steps-

1. Generating shear waves in the tissue.

2. Acquiring MR Images depicting the propagation of the induced shear waves and

3. Processing the images of the shear waves to generate quantitative maps of tissue stiffness, called **elastograms.**

Basics Principle of Elastography :-

The elasticity of a material defines its ability to sustain its original size and shape when the material is subjected to deforming force or stress. The change in size or shape known as "strain" is the force exerted on a unit area. Elastography is an imaging technique that monitors and measures the mechanical properties of biological tissues. Measuring the response of a particular mechanical stimulus is the basic principle of Elastography. The stimuli can be static, quasistatic, or dynamic. The examinations with static/quasistatic stimuli provide "strain" images while dynamic mechanical tissue stimulation enables "shear-wave" imaging. Dynamic stimulation can be "transient" or "continuous". Dynamic stimulus-based techniques use vibrations between 20 Hz and 500 Hz and examine the characteristics of the waves produced by vibrations propagating throughout the tissue. Shear-wave based US Elastography and MRE are dynamic stimulation techniques.

Fig 2- Disc-shaped passive driver. flat surface touching the patient is made of drum-like elastic membrane. Plastic connecting tube transports the acoustic wave originating from the generator, known as the active driver which is located outside the MRI examination room, to the passive driver. Passive driver is placed over the liver and held in place by an elastic binder. Continuous low frequency (60 Hz) vibrations are delivered into the liver from the surface of lower rib cage.

Magnetic Resonance Elastography Techniques:-

Harmonic MRE is a non-invasive technique that can directly visualize and measure propagating acoustic strain waves in tissue-like materials subjected to harmonic mechanical excitation [8]. Fig. 3 illustrates a schematic representation of the main steps of an MRE exam necessary to obtain the elastograms of the tissue of interest.

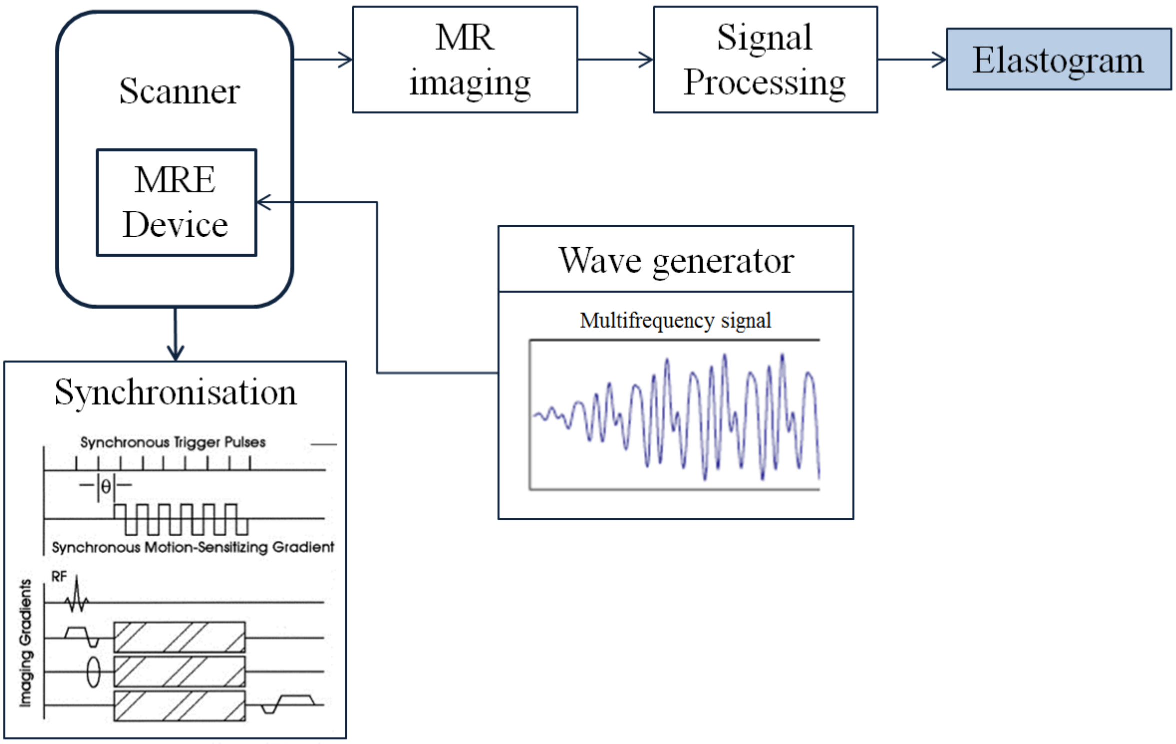

Fig-3 Schematic Diagram of the main steps to acquire an elastogram in MRE.

A conventional MRI system is used with an additional Motion Encoding Gradient (MEG), and a vibration device is used to mechanically excite the tissue. A vibration actuator creates shear or compression waves in the object at the same frequency as the MEG. Synchronisation is achieved by triggering the actuation device from the image sequence (5,6). Any cyclic motion in the presence of the MEG generates a phase shift in the signal from which it is possible to calculate the displacement at each Voxel and directly image the acoustic waves within the tissue of interest. The phase MEG measures the mechanical vibration and the magnetic resonance image data is post-processed so that the phase and the amplitude of vibration can be acquired. Finally, an inversion algorithm based on measured displacements is applied to calculate the shear modulus distribution of the tissue.

The tissue displacement at the nanometer or micrometer level is measured by the MRE sequence. Two groups of raw images, magnitude and phase images are obtained which give information about the progression of the "shear waves" in the liver. Magnitude and phase images are automatically processed using an inversion algorithm to generate a two-dimensional (2D) displacement map called "wave image" and a 2D gray or colour code map called "elastogram" in which the liver stiffness is measured (7, 8) Fig4,5

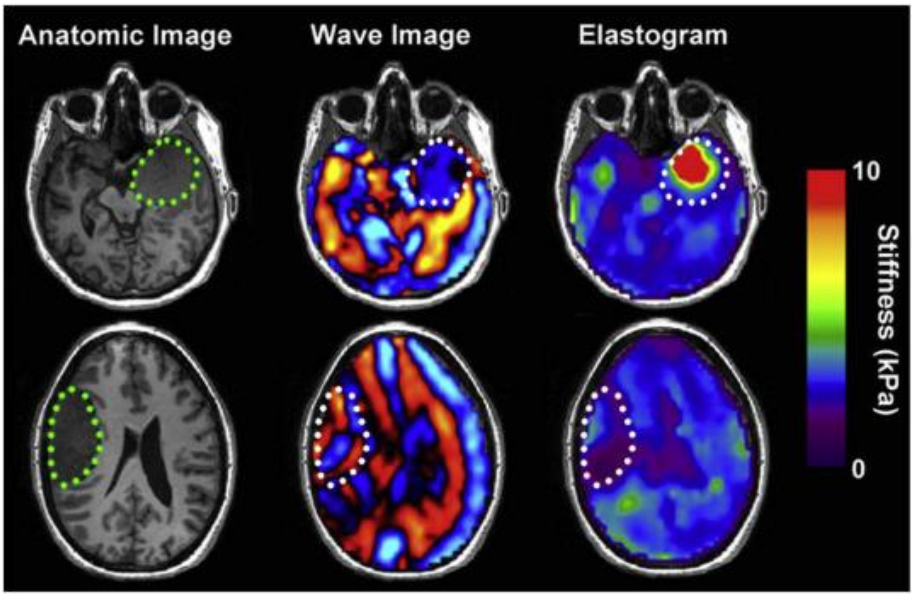

Fig-4 MR Elastogram of Brain

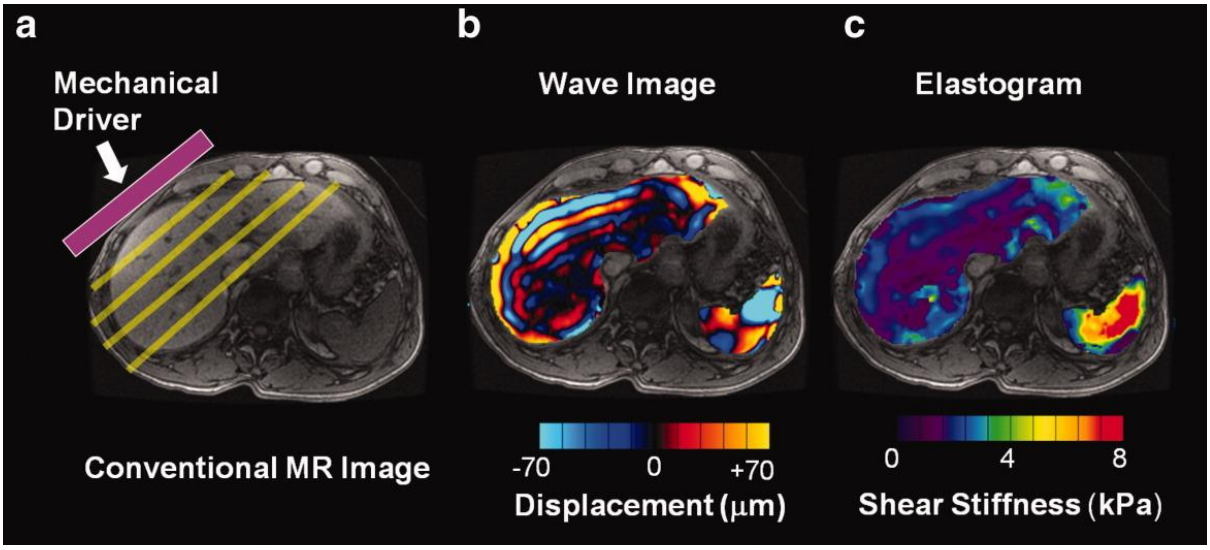

Fig-5- Representation of MR Elastogram of Liver

Clinical applications of MR Elastography:-

MRE is already being used clinically for the assessment of patients with chronic liver diseases and is emerging as a safe, reliable and non-invasive alternative to liver biopsy for staging hepatic fibrosis. MRE is also being investigated for application to pathologies of other organs including the brain, breast, blood vessels, heart, kidneys, lungs and skeletal muscles.

The following current application of MR Elastography that is Listed below:-

Liver MR Elastography - Magnetic Resonance Elastography has been widely investigated for the diagnosis of hepatic diseases and is currently used in clinical practice for fibrosis and cirrhosis assessment where the stiffness of the diseased liver is significantly higher than normal liver tissue stiffness. stiffness In liver MR Elastography suite, an active pneumatic mechanical wave driver is located outside the MR Elastography room and is connected, by way of a flexible 25-ft (7.62-m) polyvinyl chloride tube, to a passive driver that is fastened onto the abdominal wall over the liver (Fig 5) (9,10). The passive driver generates a continuous acoustic vibration that is transmitted through the entire abdomen, including the liver, at a fixed frequency, which is typically 60 Hz. A phase-contrast pulse sequence with motion encoding gradients is synchronized to the frequency of mechanical waves created by the passive driver. This sequence is then used to image the micron-level cyclic displacements caused by the propagating shear waves to create a magnitude image, which provides anatomic information and a phase image, which provides wave motion information (11,12). Clinical hepatic MRE is performed at a frequency of 60 hertz using pneumatic -based pressure- activated drivers. Wave data are acquired with 4 phase offsets and a modified direct inversion algorithm with multiscale capabilities is used for the estimation of the liver.

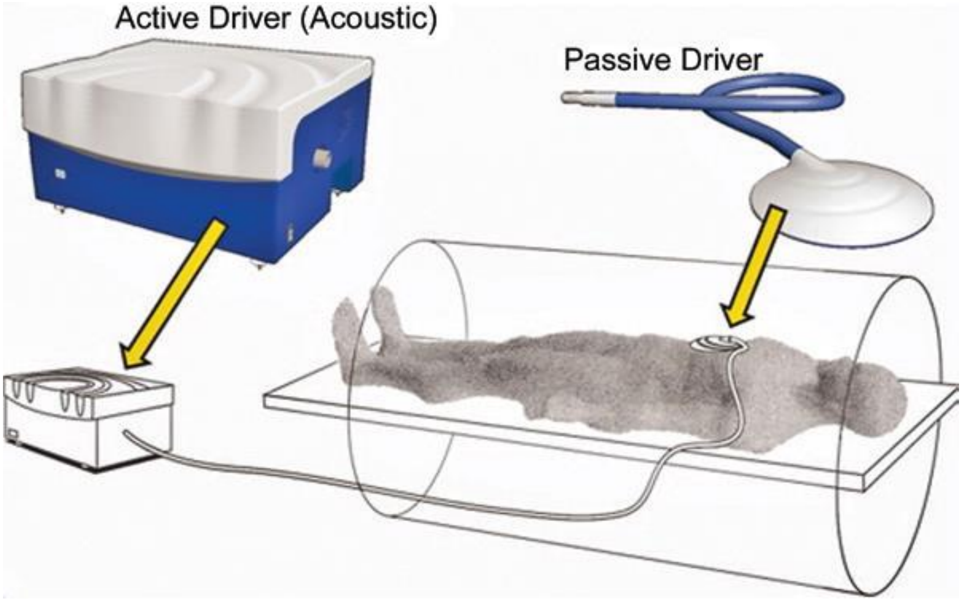

Figure 5. A typical liver MR Elastography suite. The patient is positioned supine in the MRI unit, and a passive driver is secured onto the abdominal wall over the liver. A plastic connecting tube connects the passive driver to the active driver, which is located behind a wall outside the imaging room.

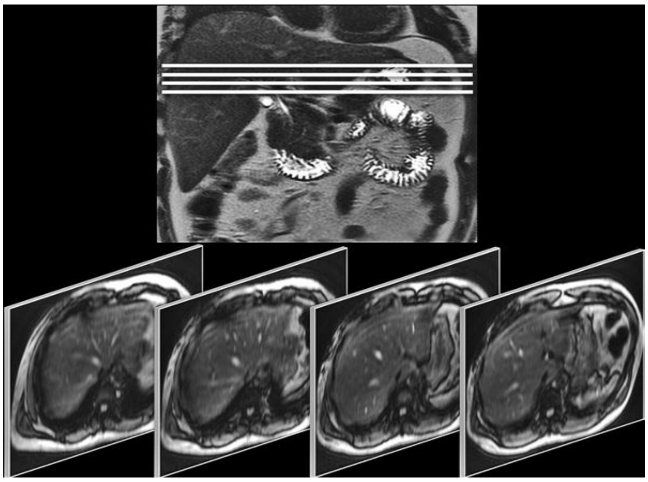

Fig-6 MR Elastography section positioning. Top: Coronal T2-weighted MR image shows the sites (four lines) where the four MR Elastography magnitude image sections at the bottom were obtained. Bottom: Magnitude image sections include the largest portion of the liver, with the liver dome and inferior aspect of the liver excluded.

Breast MR Elastography-Another application of MRE that is being investigated with great interest is for the assessment of breast cancer. Breast tumors are known to be typically stiffer than benign lesions and normal breast tissue. Manual palpation is a recommended part of routine screening of breast cancer and helps in the detection of these hard masses. Contrast

-enhanced MR imaging (CE-MRI) has proven to have a very high sensitivity for the detection of tumor nodules, but the specificity of the technique can be a problem leading to numerous false positives and unnecessary biopsies. MRE is being investigated as a complementary technique to CE-MRI to provide additional information about these suspicious regions and the combined technique has shown promise to increase diagnostic specificity.

Skeletal Muscle MR Elastography-MRE has also been extensively investigated for studying the stiffness of skeletal muscle since it is well known that the stiffness changes significantly depending upon the contractile state of the muscle. Skeletal muscle MRE can be used for studying the physiological response of diseased and damaged muscle .For instance, it has been found that there is a difference in the stiffness of muscle with and without neuromuscular disease.

Brain MR Elastography-Assessment of the mechanical properties of brain tissue with MRE is another area of significant research and clinical interest due to the diagnostic potential of brain tissue stiffness information as it may be related to diseases like Alzheimer's disease **,** hydrocephalus **,**brain cancer and multiple sclerosis .While it would be difficult to use ultrasound-based approaches to non-invasively assess brain mechanical properties, MRE is well suited for this application.

Challenges of MR Elastography:-

There are many challenges and opportunities for further technical development of MRE .The effective spatial resolution of the technique increases as the frequency of the applied waves is increased. Unfortunately, high- frequency shear waves are attenuated more rapidly than low- frequency waves, so there can be a tradeoff between spatial resolution and distance from the vibrations source in some applications.

- Improved driver technology of MRE, such as the use of arrays of multiple vibration sources, is also under investigation. Very stiff tissues such as bone, tendon and cartilage require much higher vibration frequencies than soft tissues for evaluation with MRE.

- Current MRI scanners don't have gradient hardware that is capable of encoding wave motion at such high frequencies. These limitations may be addressed in the future with specialized hardware solutions.

Future of MR Elastography:-

1. Improving image quality and reducing acquisition time (Ex: - Use of echo-planar imaging, parallel imaging, reduced k-space acquisitions, imaging at >=3T, adoption of sophisticated inversion algorithms, 3D-and multi-frequency techniques, etc.)
2. Expanding research into topics beyond fibrosis (Ex- Inflammation, necrosis, edema, perfusion, tumor characterization, evaluation of treatment response, etc.)
3. Better defining the pit falls of MRE and developing novel solutions for overcoming these limitations, and better defining the clinical indications for MRE beyond the research setting. Unquestionably, MRE is an emerging technology with genuine promise but the technique has yet to be fully mapped out and new frontiers exists for exploration.

Conclusions:-

Magnetic Resonance Elastography is an MRI-based technique which is capable of non-invasively assessing tissue stiffness and it has already been shown to be beneficial as a clinical tool for the diagnosis of hepatic fibrosis. A number of other applications of MRE for determining tissue properties, structures, and function, such as the once discussed here, are being investigated which could offer valuable information to clinicians and researchers in the future and interest in the field continues to grow rapidly. Magnetic Resonance Elastography (MRE) can be used as a non-invasive alternative to liver biopsy in detecting the presence and extent of fibrosis as well as in monitoring its response to therapy.

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